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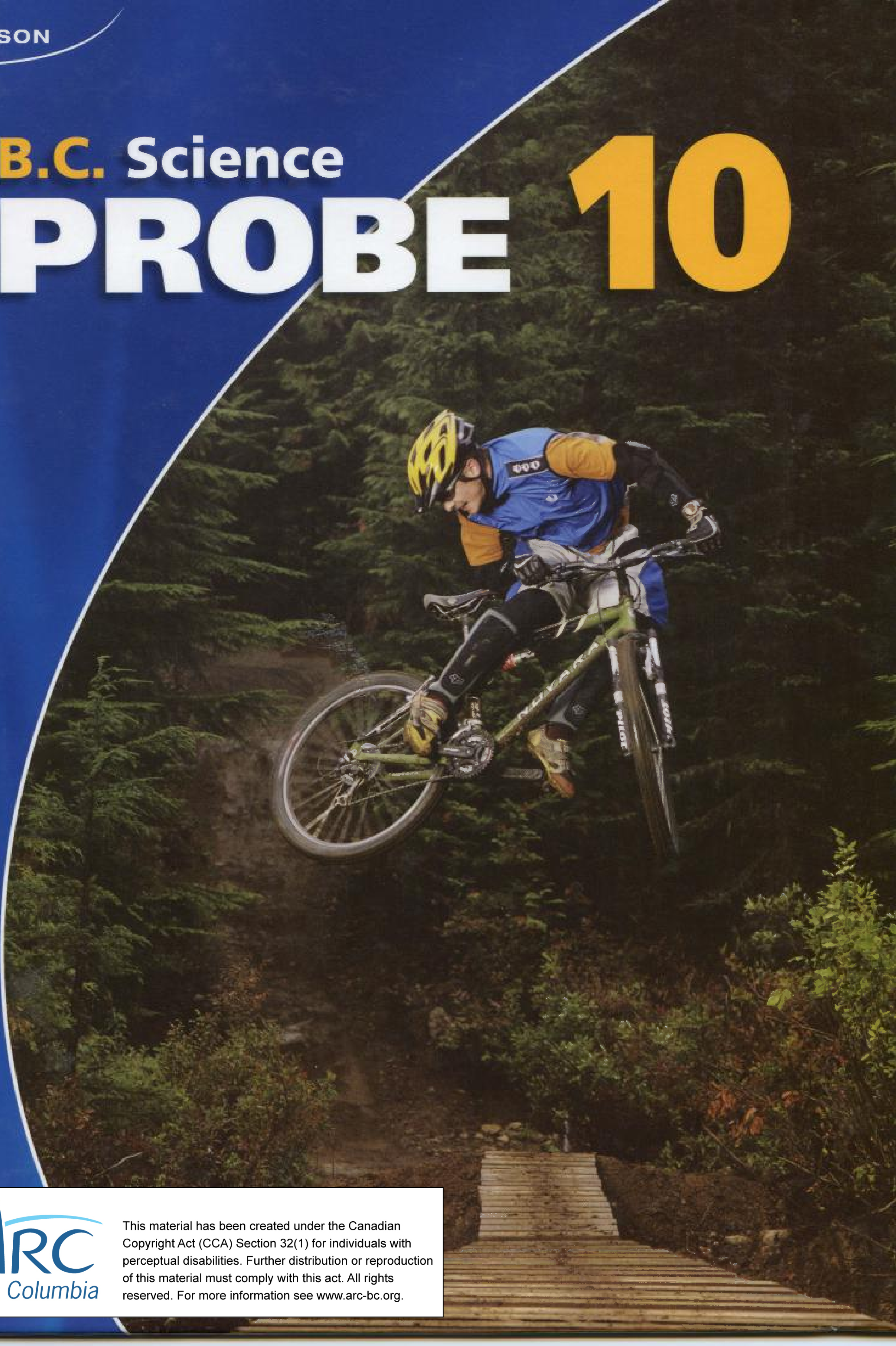
B.C. Science PROBE 10



B.C. Science PROBE 10

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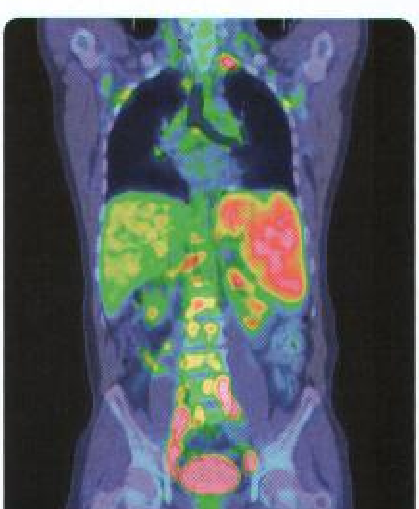

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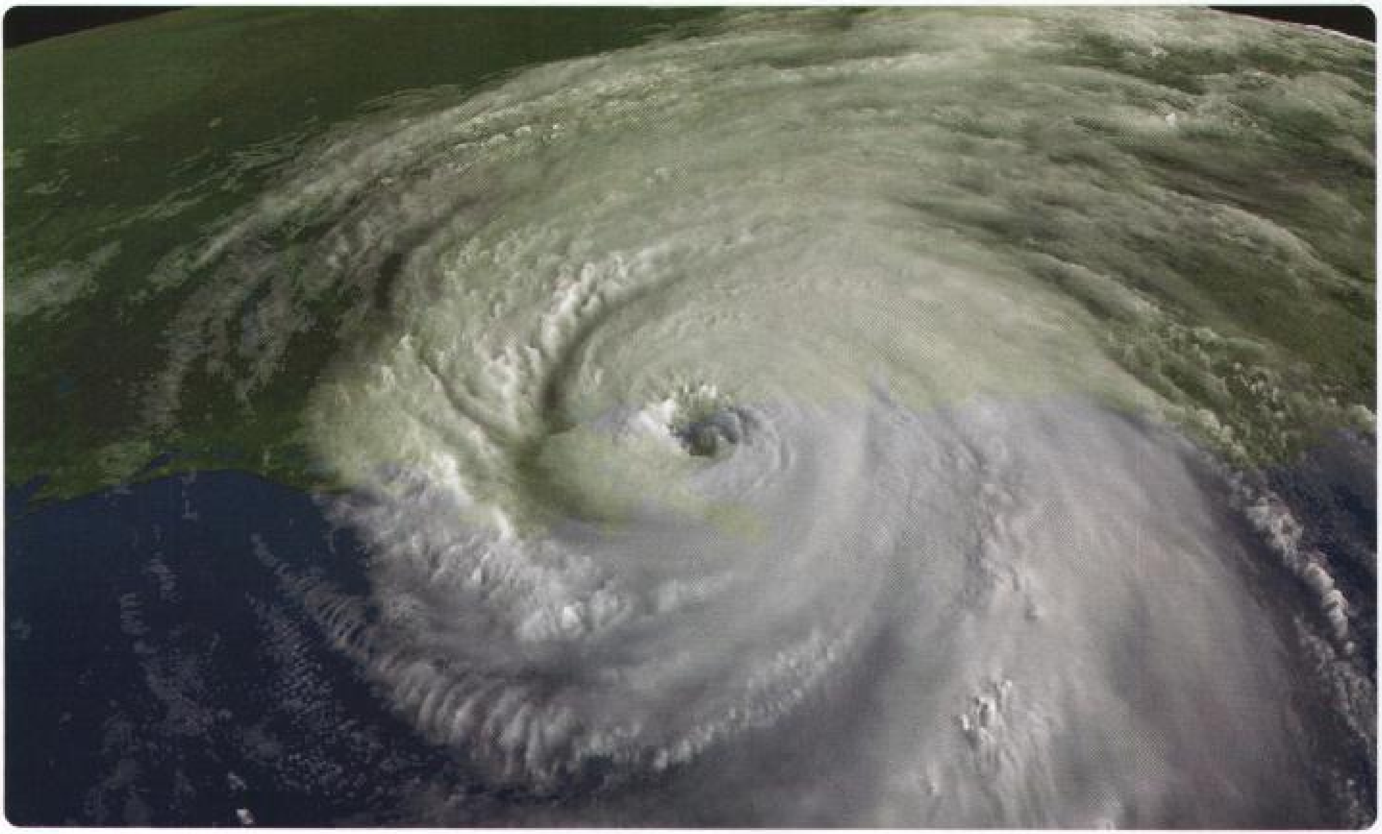

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CHAPTER 1

Science, Technology, Society, and the Environment

Chapter Preview

Science influences our daily lives far more than most of us realize. Do you use scientific knowledge every day? How many technological devices do you use in an average day? Our everyday lives are filled with examples of science and technology. In fact, many aspects of our lives are determined or controlled by technology.

Science and technology can be found everywhere—in a satellite orbiting Earth, in a beam of sunlight, in your cell phone, in the equipment you use in the science laboratory, in your resemblance to your parents, and even in today's weather!

The topics studied in this text will help you recognize examples of science and technology, and understand how they influence your everyday life.

KEY IDEAS

- **Science and technology are different, but related, fields and are often interdependent.**
- **Scientific discoveries and technological developments affect society, and society influences the direction of scientific and technological research.**
- **Science and technology have both positive and negative effects on the natural environment.**

TRY THIS: *What in the World Isn't Science?*

Skills Focus: analyzing, communicating

Think about all of the objects, events, and phenomena that you have encountered since you woke up this morning.

1. In a small group discussion, identify an everyday object, event, or phenomenon that you believe is not connected to science. As ideas are presented by your group members, challenge yourself to identify a science connection. If a science connection cannot be made, a point is awarded to your group. Follow the time limit set by your teacher.

A. List the objects, events, or phenomena that your group agreed did not have a science connection.

B. Did most objects, events, or phenomena suggested by your group have a science connection? Explain.

C. Write a short paragraph describing the influence of science on your everyday life.

1.1 Science and Technology

What Is Science?

Science is a way of learning about the natural world by making observations, asking questions, proposing answers, and then testing those answers. Scientists describe nature by using the knowledge they gain through experience. This knowledge, known as **empirical knowledge**, can be thought of as knowledge gained by the five senses (touch, smell, taste, vision, and hearing), and by tools and devices that extend the senses (e.g., microscopes, telescopes, sensors). Empirical knowledge (Figure 1) includes the knowledge gained by scientists in the process of scientific inquiry, as well as the knowledge gained by Aboriginal peoples, often referred to as Traditional Ecological Knowledge and Wisdom. **Traditional Ecological Knowledge and Wisdom (TEKW)** is the knowledge, experiences, and wisdom gained over many generations of close interaction with the living and non-living components of the environment.

Empirical knowledge is generally incomplete. It could be argued that complete knowledge is not achievable. We seldom know everything there is to know about a natural phenomenon, but we continue to learn as scientific inquiry progresses. Sometimes what we think we know is incorrect, so empirical knowledge is continuously being updated as new information becomes available.

STUDY TIP

Study smarter, not harder. As you read each section, look for the study tips in the margins of your student book. They will offer you practical tips on effective study and exam techniques.

(a)

(b)

Figure 1 Empirical knowledge that helps us understand the natural world comes from different sources. (a) A botanist uses scientific inquiry to learn more about plant life. (b) A Lillooet tribe member lands a sockeye salmon from the Fraser River using traditional Lillooet fishing techniques.

STUDY TIP

You'll notice that Chapter 1 includes many new terms. To get a head start on your studying, make vocabulary cards. On one side of the card, write the word (e.g., discovery). On the other side, write a brief definition (e.g., an observation no one has made before).

Science is often thought of as facts, laws, and theories. While this is partially true, science is much more than that. The main goal of science is to understand the natural world, and the result of this understanding 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 observation and analysis of the Sun and the night sky. Science also refers to 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 lead to this understanding.

An observation of nature that no one has made before, or that no one has made in the same way before, is called a **discovery**. Scientists make discoveries by looking for patterns and regularities in nature (natural phenomena). These regularities are sometimes called laws of nature and, in some cases, laws are described mathematically. For example, Isaac Newton discovered a mathematical relationship between the force, F, and the acceleration, a, of an object whose mass is m. In general, if the force used to push (or pull) an object increases, its acceleration increases as well. This law is commonly known as Newton's Second Law of Motion, and it can be expressed mathematically as $F = ma$. The scientific community accepts Newton's Second Law of Motion because it is simple, understandable, and supported by empirical evidence.

Unlike a scientific law (which is determined by careful observation), a scientific theory, or scientific explanation, is the product of creativity and inventiveness. Scientists use scientific theories to try and explain natural phenomena whose root causes are not easily identifiable. To develop a theory, a scientist may first suggest an untested explanation, or hypothesis. For example, many years ago people noticed that certain diseases are contagious, but there was no satisfactory explanation for this observation. With the invention of the compound microscope in the seventeenth century, scientists discovered micro-organisms and hypothesized that some of these micro-organisms (called germs) might be the cause of infectious diseases. After conducting many experiments and gathering evidence to support this hypothesis, the transfer of germs was accepted as an explanation for the spread of infections, and the germ theory was developed.

LEARNING TIP

Set a purpose for your reading. As you read this section, read to answer the question posed in the heading. Share your answer with a partner.

Scientific theories, such as the germ theory, are tentative explanations. This means that they are subject to change when new scientific evidence indicates that a change is required. For example, the germ theory was changed once viruses were discovered. Viruses are non-living entities that are much smaller than bacteria and other micro-organisms, so that they cannot be seen under a typical light microscope. When viruses were discovered, many scientists hypothesized that they too could cause infectious diseases. After obtaining experimental evidence to support this hypothesis, the germ theory was revised to include viruses as potential causes of infections.

Classification of Science

There are many ways of classifying the activities that we refer to as science. Science tries to understand nature, which really means the whole universe. Science is usually divided into three main branches—life science, physical science, and Earth and space science (Figure 2).

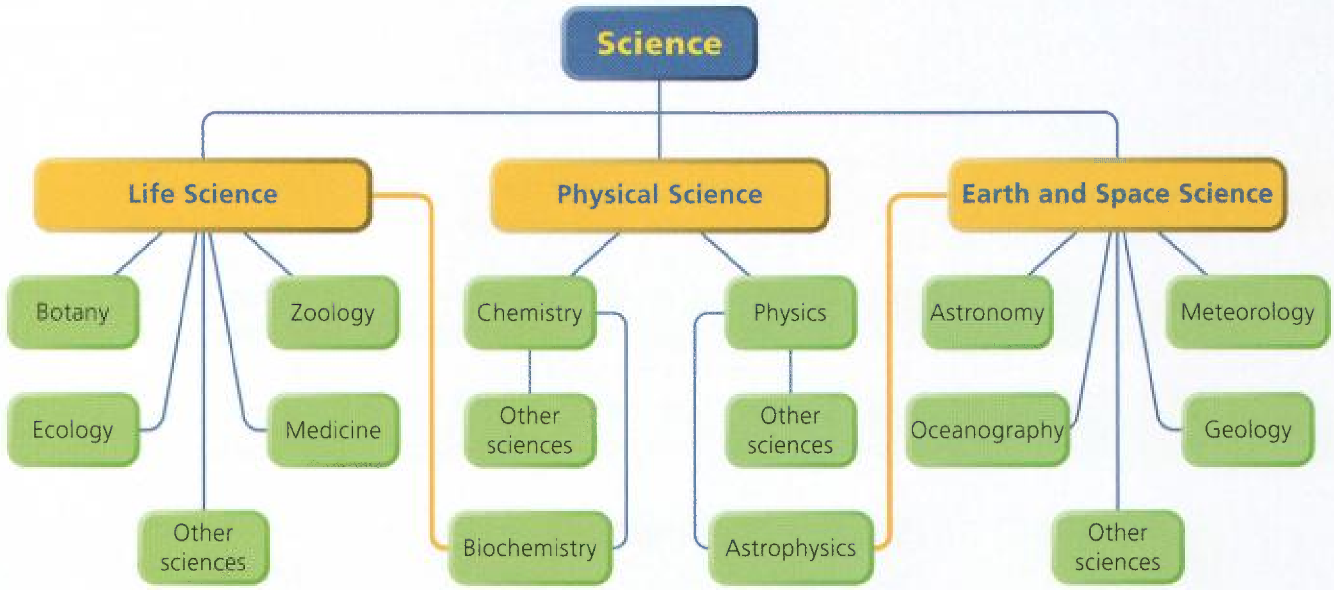


Figure 2 There are many separate branches of science, but there are also many interactions among the various branches.

Life science is the study of living things and is often referred to as biology. It has many branches, including botany, the study of plants; zoology, the study of animals; and ecology, the study of the natural environment. Medicine and agricultural science are also branches of life science because they deal with the study of living things.

Physical science has two main branches—chemistry and physics. Chemistry is the study of matter and its changes, and physics is the study of forces and energy.

The branches of Earth and space science include geology, the study of the physical nature and history of Earth; meteorology, the study of the atmosphere and weather; astronomy, the study of celestial objects (galaxies, stars, planets, comets, etc.); and oceanography, the study of oceans and ocean life.

This classification of the branches of science appears very simple and neat, like the drawers in which nuts and bolts are arranged in a hardware store. In reality, science is not quite so simple. As science progresses over time, the branches of science expand and collaborate so that they no longer fit into the neat categories. For example, chemists began to study chemicals (such as DNA) that make up living things. This resulted in the science of biochemistry, the study of the matter of living things. It is both a life science and a physical science. In the same way, geophysics, the study of forces that affect Earth, is both an Earth science and a physical science.

LEARNING TIP

Check in with your learning. Discuss with a partner how "what science is" has evolved dramatically over the last hundred years.

TRY THIS: Identifying Sciences

Skills Focus: analyzing, classifying, inferring, communicating

The branches of science and their interactions are too numerous to identify in this text. However, you can get an idea of the nature of a branch of science from its name.

1. Examine the following list of science branches and classify them as either a life, physical, and/or Earth and space science. (Some branches can fit into more than one category.)

A. For each of the sciences, analyze the name and write a one-sentence description that you think matches the science.

B. Compare your definitions with those of your classmates, and then, using a dictionary or the Internet, find a formal definition for each of the sciences. Compare your definitions with the formal definition.

aerobiology	genetics
analytical chemistry	geochemistry
astrobiology	marine biology
astrochemistry	materials science
biophysics	microbiology
electrostatics	mineralogy
environmental science	optics
fluid dynamics	sedimentology

What Is Technology?

Technology is the process by which humans develop ways to satisfy some of their needs and wants. People use skills and resources to develop processes and equipment that help them solve problems in everyday life. Professionals such as technologists, technicians, and engineers develop technologies through invention and innovation.

The term **invention** describes the creative development of a new device or process that helps people meet their needs or satisfy their wants. For example, people have invented beds to satisfy their need for comfortable rest. They have invented microwave ovens, refrigerators, freezers, and the canning process to meet their needs for cooking and preserving food. They have invented radios, televisions, telephones, computers, and the Internet to help them satisfy their desire for efficient communication. In general, inventions can be described as newly found solutions to problems in everyday life.

Some technological devices combine existing inventions in new ways to solve new problems. The modification of an existing technology to serve a new purpose is known as **innovation**. For example, the use of circular devices to facilitate movement originated in prehistoric times, and over many years has developed into the wheel. The invention of the wheel has led to its use in many innovative ways. It is now used in gears and pulleys; on trains, bicycles, carts, and automobiles; and as the rotating base of dials on a radio. You have probably innovated many times in your everyday life. If you have ever used a piece of chewing gum to stick a note on a wall, you've innovated!

Did You KNOW?

Technology at Home

Liquid Paper was invented by Bette Nesmith-Graham in 1951, while working as a typist. Using her kitchen and garage as a laboratory, she developed a paint-turpentine mixture she called "Mistakes Out" to hide her typing mistakes at the office. She later changed the name of her product to Liquid Paper and sold it out of her home for 17 years. In 1979, the Gillette Company purchased Liquid Paper for US$47.5 million.

TRY THIS: New Uses for Old Technology

Skills Focus: observing, analyzing, communicating

Many everyday devices are used for purposes other than those they were designed for. For example, a butter knife can be used as a screwdriver, a plaster knife, a scraper, or as an artist's knife.

1. In a small group, select one of the items from the following list and think "outside the box" to come up with at least 15 alternative uses for the object. Follow the brainstorming guidelines provided by your teacher.

cardboard box	bath towel	nail
spoon	sheet of paper	spoon
candle	craft stick	toothpick
fan	marble	old newspaper
pencil	drinking straw	2 L pop bottle
paper clip	rubber band	roll of cash register paper

2. After 10 min of brainstorming, refine your list of possible uses by eliminating duplication or combining ideas.
3. As a group, share the list of alternative uses for your object with the class.

A. Explain what "thinking outside the box" means to you.

B. Did you learn new ideas from other groups? What does this tell you about the nature of invention and innovation?

C. Suggest things you can do to improve your skill of looking at old ideas in new ways.

In 1959, Canadian inventor Joseph-Armand Bombardier combined a number of existing technologies to produce the world's first recreational snowmobile, called the Ski-Doo (Figure 3). While unique in its overall design, the snowmobile used a number of existing technologies in innovative ways. A pair of modified skies allowed the front end of the machine to slide over the snow, while handlebars (like those on a motorcycle) were used for steering. A rubber track, like that used for farm and military equipment, gripped the snow and allowed the vehicle to move forward. These features have been modified and improved over the years; notice the features of modern snowmobiles, shown in Figure 4.

Figure 3 Early models of the Ski-Doo snowmobile incorporated several innovations to produce a unique vehicle.

Science and Technology Work Together

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. Scientists rely on technologies to further their research and gain an understanding of natural phenomena. Technologists and engineers look for ways to use this knowledge for practical applications. For example, scientists want to know how certain kinds of materials, called superconductors, conduct electricity with almost no loss in energy. Technologists and engineers focus on how that knowledge can be applied in the design and construction of high-speed computers.

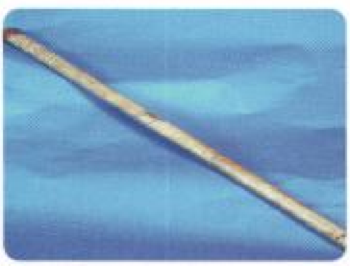
Figure 4 While the basic design is the same as the original vehicle, new features and materials have vastly improved the modern snowmobile.

In some cases, technological inventions and innovations occur before the scientific principles are known. Alessandro Volta invented the battery in 1800, well before theories about current electricity were developed. Sometimes scientific discoveries are made because of technological inventions. For example, the invention of glass lenses led to the development

Did You KNOW?

The First Telescope

Contrary to popular belief, the first telescope was not invented by Galileo. A spectacle maker, Hans Lipperhey, invented the telescope when he put a convex and a concave lens together to produce threefold (3×) magnification. In 1609, Galileo learned of the invention and immediately saw its potential. He began experimenting with different lens curvatures and arrangements, and achieved a magnification of 9×—an invaluable asset to scientific and military endeavours.



To learn more about the early development of the telescope, visit

www.science.nelson.com GO

of telescopes, which allowed astronomers to observe and learn more about our solar system and the universe. The telescope, in turn, led to more accurate astronomical observations and measurements. This contributed to the change from an Earth-centred scientific model of the universe to a Sun-centred model. You can see how science and technology often support each other.

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 (Table 1).

Table 1 Examples of the Science–Technology Relationship

Science	Technology	Example
Physicists explain how forces act on an object under a load.	Structural engineers and technologists design buildings, bridges, roads, and tunnels that can support specific loads.	suspension bridge 
Physiologists discover the biochemical reactions that keep organisms alive and healthy.	Technologists design life-support systems for astronauts and space stations.	astronaut suit 
Plant biologists learn how roots absorb nutrients from water and soil.	Engineers and technologists design hydroponic systems for efficient crop production in areas with poor soil.	hydroponic system 

In most cases, scientists do not foresee or predict how their discoveries will be used in the development of technologies. For example, in 1831, Michael Faraday found that if you push a magnet toward a wire, a current is generated (or induced) in the wire. When Faraday demonstrated this phenomenon to his peers, someone asked, "All this is very well, but of what use is this discovery?" He replied, "It is a newborn child. Of what use is a newborn child?" He had discovered electromagnetic induction. This discovery led to the development of electric motors and generators, and made possible all of the devices that use or produce electricity. But that was not the reason Faraday discovered electromagnetic induction; he was simply trying to better understand nature. He could never have imagined how dependent on electricity society would eventually become.

The development of plastics is a good example showing the relationship between science and technology. In 1928, X-ray technology enabled confirmation of the theory that polymers are long chains of chemical units (molecules). This theory had been proposed by German chemist Herman Staudinger in 1920, but was not accepted until the technology to observe and confirm his idea was available. With this new understanding of polymers and their molecular structure, technologists began producing a new class of polymers called "plastics." This included materials such as nylon, Teflon, polystyrene (e.g., Styrofoam), and acrylic—all of which are widely used in science and society today.

Medical researchers use biodegradable polymers to deliver drugs in situations where the drugs cannot be administered orally or by injection. To achieve this, the drugs are embedded within a polymer structure, and are gradually released as the polymer breaks down (Figure 5).

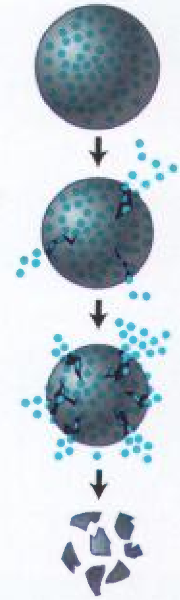
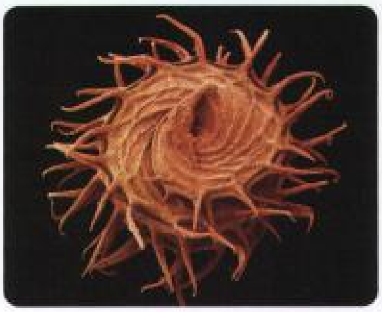


Figure 5 Drugs are embedded in biodegradable polymer particles (step 1). As the particles biodegrade, or break down, the drugs are released (step 2).

Many scientific discoveries and technological inventions occur by chance, or serendipity. **Serendipity** is the act of discovering or inventing something useful by accident. One famous example of serendipity in science is the discovery of background radiation. While tuning a powerful antenna used for astronomy experiments, American physicists Arno Penzias and Robert Wilson noticed a constant, low-level noise coming from the antenna. The noise was being formed by an invisible type of light energy (radiation), which was detected regardless of what direction the antenna was facing. Soon Penzias and Wilson realized that the radiation was present everywhere. They also discovered that they had stumbled on the best evidence to date supporting the Big Bang theory—a theory that explains how the entire universe was created in a huge explosion of matter and energy.

Serendipity can also occur in technology, as shown by the invention of Velcro (Figure 6). In 1948, George de Mestral, a Swiss engineer, returned from a walk in the woods and noticed that some burs were stuck to his cloth jacket and pants. He examined a bur under his microscope and noticed that it contained little green hooks that clung to fabric and fur. De Mestral immediately recognized the potential for a practical new fastener. After eight years of experimentation and development, he created Velcro, the first synthetic hook-and-loop fastener.



(a)

(b)

Figure 6 Technologies are often modelled after structures in nature. (a) The hooks on a bur were the model for the design of Velcro. (b) The magnified view of Velcro shows how the hooks get caught in the loops when the two strips are pressed together.

1.2 Science and Technology in Society

Science and technology have both had an immense impact on society. The houses we live in, the food we eat, the vehicles we drive, and the electronic gadgets we use to communicate and to educate and entertain ourselves, are all products of scientific and technological achievement (Figure 1).

Many important discoveries and inventions have occurred within the last century—vaccinations against diseases, antibiotics, tranquilizers, organ transplants, reproductive technologies, genetic engineering, microwave heating, computers, lasers, plastics, television, and the Internet. You don't have to look far to find an example of the impact of science and technology on society.

(a) (b) (c)

Figure 1 Examples of science and technology in our daily lives: (a) the smart car, (b) the Apple iPhone, and (c) portable DVD players

TRY THIS: *The Greatest Discovery or Invention of All Time*

Skills Focus: observing, analyzing, communicating

Of the numerous achievements in science and technology, most do not have a profound effect on society. Some achievements, however, stand out because they fundamentally change our culture.

1. In a small group, brainstorm a list of discoveries or inventions that have significantly changed our culture. Consider discoveries or inventions such as the heliocentric model of the solar system, the printing press, the telephone, antibiotics, and the internal combustion engine. Follow the brainstorming rules provided by your teacher.
2. After the brainstorming period, discuss each of the discoveries and inventions you came up with and identify the ten most important.
3. Rank the top ten from most important (1) to least important (10).

A. Explain why the number one ranked discovery or invention was considered by your group to be the most important.

B. Did your group unanimously agree on which discovery or invention was ranked number one? What arguments were made for or against ranking it number one?

One area in which the combination of science and technology has had a large impact is in the medical field. Medical knowledge and technologies have increased life expectancy, particularly in developed countries. On average, we are living longer and healthier lives because science and/or technology have found cures for diseases and treatments for illnesses. Similarly, as the field of molecular biology develops, this knowledge is used to develop new technologies and applications. Genetic engineering was possible only after the structure of DNA was understood.

Recent developments in tissue culture have made it possible to "grow" replacements for organs that have been damaged by injury or disease. In 2006, it was announced that an American research team had successfully grown bladders from patients' cells in the laboratory, and successfully transplanted the organs back into the patients (Figure 2). Researchers are continuing work on growing different tissues and organs, including blood vessels and hearts, in the laboratory. Research is also being conducted on new protein-based drugs that encourage damaged organs to repair themselves. In animal trials, new drugs that stimulate the re-growth of muscle tissue that has died after a heart attack have been tested successfully.

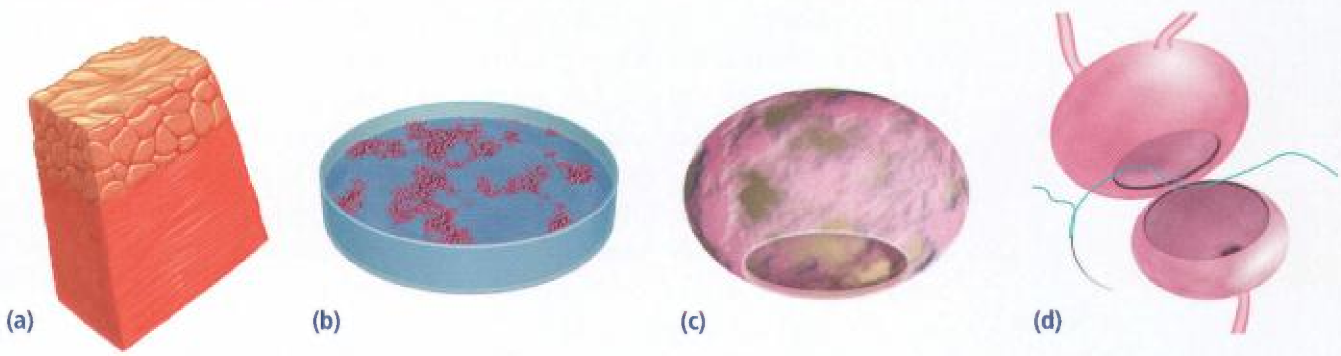


Figure 2 (a) Muscle and bladder cells are extracted from a small piece of the patient's own bladder. (b) They are grown in a Petri dish and (c) then layered onto a mould shaped like a bladder. (d) In a few weeks, the cells reproduce to grow a new bladder, which is then transplanted into the patient. The new bladder continues to grow to a normal size and starts functioning.

The development of communication technologies, including television, telephones, and satellites, has "shrunk the world." While the physical Earth has not changed in size, achievements in transportation and communication technologies have made us more aware of what is going on around the world. In less than a day, we can travel to the other side of the world. In an instant, we can see what is happening on the other side of the world. We can see and talk to friends and family in distant countries as if they were in the next room.

The invention of the telephone and all of the related innovations that followed have significantly changed our culture. With cellular and satellite telephones, communication is possible from any location on Earth. The influence of the telephone has been largely positive, and has led to the development of technologies such as handheld and vehicle GPS devices.

Figure 3 Handheld and vehicle GPS devices are convenient and accurate enough for everyday use.

These devices are accurate enough to pinpoint locations to within 10 m (Figure 3). This is more than adequate for establishing your location in the wilderness and finding your way back home or navigating in a busy unfamiliar city. The cost of these devices has decreased so that they are affordable for many people. Some would argue, however, that the telephone and related technologies have also had a negative influence on society. We have technology that enables us to work anywhere and anytime, so that our work lives and our personal lives are no longer separated.

Science and technology have been described as a double-edged sword. This expression is used to describe anything that can both help and hinder, or anything that has both risks and benefits. There are both risks and benefits associated with many scientific discoveries and technological inventions. While most technologies are developed with the intention of solving problems, there are often unintended consequences associated with their use. For example, the chemical DDT is an effective pesticide that controls the populations of disease-carrying insects, but it has been more recently found to have a devastating effect on the eggs of peregrine falcons and bald eagles. Another example of a technology with unintended consequences can be seen in chlorofluorocarbons (CFCs), a common, non-toxic chemical that was commonly used as a refrigerant. After many years, it was discovered that CFCs were contributing to the reduction of Earth's ozone layer, a layer in the atmosphere that protects us from harmful radiation. Similarly, the radioactive wastes produced in nuclear generating stations also create a serious environmental concern and potential health risks because we do not have a satisfactory disposal method. However, the benefits of the radiation-related medical technologies that enable diagnosis and treatment are immeasurable.

It is difficult, if not impossible, to foresee all of the consequences that might arise from using specific technologies. Furthermore, new applications of scientific knowledge and technological inventions are often developed long after the discovery or the invention occurred. In many cases, it is not science or technology itself that is to blame; it is the human use of the knowledge or technology that has negative impacts on society and the environment.

Society Affects Science and Technology

LEARNING TIP
Approach text with a critical eye. As you read the section Society Affects Science and Technology, ask yourself, "Does this information reinforce, contradict, or add new information?"

That science and technology influence society is obvious. But do you know that the values and priorities of society at a particular time can also influence the direction and progress of developments in both science and technology?

Scientific and technological research is very expensive. Research facilities employ highly paid and highly skilled professionals. They consume large amounts of energy and require expensive and sophisticated tools and equipment. Funding for research comes from both private and public sources.

Basic research is research that helps people learn more about how the natural world works (Figure 4). Basic research in areas such as medicine, alternative energy sources, food supplies, and natural resources, usually receives funding from government agencies, such as the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Social Sciences and Humanities Research Council of Canada (SSHRC). Basic research often produces knowledge that is used by engineers and technologists to develop practical solutions to everyday problems. The priorities of government, representing the priorities of the public, determine which areas of research are funded. For example, if a cure for AIDS is deemed to be a social priority, funding for research in this area will become a priority. If protection of the environment is a public priority, then research into alternative energy sources will likely be promoted and funded.

Applied research is research that is primarily focused on developing new and better solutions to practical problems. Research into the development of consumer products—such as new cosmetics, telephones, automobiles, computer software and hardware, and sports equipment—is usually carried out in privately owned and funded facilities. The marketplace, or the public demand for new products, will obviously influence which areas of research private companies fund. If market analysis shows that there is a demand for new electronic gadgets such as cell phones or video games (Figure 5), research and development in these areas will be supported.

LEARNING TIP

Check your understanding of the terms "basic research" and "applied research" by explaining the differences to a partner.

Figure 4 A meteorologist studies weather patterns only to learn more about weather and climate trends. This knowledge may then be used to develop solutions to weather-related problems.

Figure 5 The demand for electronic gadgetry to entertain us ensures that funding will be available for further research.

1.3 Science and Technology and the Environment

The impact of human activity on the natural environment was first seen in the late 1700s with the start of the Industrial Revolution. The industrial age had an immense impact on the environment, with dramatic changes to the land, the oceans, the forests, and the atmosphere. The development of iron-making techniques, the manufacture of machinery, the introduction of steam power, and the extensive use of coal as a fuel marked the beginning of a period of increased industrial production. Technology became a tool by which humans could dominate and exploit Earth's resources. Many of the industries that arose from this period rely on natural resources such as minerals, wood, fish, and farm products. The harvesting of these resources and their use in industry has had direct impacts on the environment.

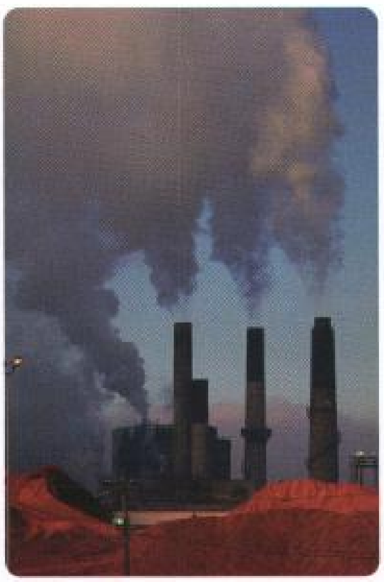


Figure 1 The burning of fossil fuels and the use of natural resources creates environmental pollutants.

Since the Industrial Revolution, the industrialized world has continued to use resources at an alarming rate. The growing population and society's demand for more goods and services has resulted in industrial and household wastes that pollute the land and water. With the use of resources, the development of technology, and the human population all increasing, wastes are being produced faster than they can be recycled or reduced to harmless substances. Many of the by-products of human industry and technology become pollutants. For example, dioxins, released in the pulp and paper industry, are known to cause cancer and birth defects in laboratory animals. The burning of coal and other fossil fuels produces air pollution and, as you will learn in Chapter 16, contributes to the increasing level of greenhouse gases in the atmosphere—an accepted cause of climate change due to global warming (Figure 1).

Industrialized society did not use the traditional ecological knowledge of Aboriginal societies who understood that, to ensure survival, people have to live as part of the environment and manage it properly. The hunter who kills all of the game within the area has to relocate to survive, as does the farmer who does not properly maintain the soil. Today, we see the impact that decades of industrial development has had on the environment, and in recent decades we have realized that we cannot survive on an abused and polluted planet.

Modern technology enables, and sometimes requires, increased use of Earth's renewable resources, often at a rate faster than they can be replenished. For example, in many locations around the world, a renewable resource—fish—is being used up faster than it can replenish itself. Improvements in fishing technology (vessels, fishing gear, navigation, sonar) have increased the ability to find and catch fish, and the world's fish stocks are being depleted. Because technology has provided the capability, we have been overfishing with little regard for the future. Overfishing simply means

LEARNING TIP
Visuals such as the photographs in this section help you to make more accurate predictions. Survey the visuals. What issues do you predict will be addressed?

that we are catching so many adult fish that not enough remain to breed and replenish the population (Figure 2). Overfishing is not only disastrous for the environment, but also for the people and communities that rely on the fishing industry for food and income.

The collapse of the cod fishery off Newfoundland and Labrador is an example of what can result from overfishing. This led to a decision by the government of Canada in 1992 to close the commercial fishery on the Grand Banks (Figure 3). The stocks have improved somewhat since the closure, but a fishery is still not permitted. Despite the fragile condition of the stocks, vessels from other countries are still fishing the nose and tail of the Grand Banks and the Flemish Cap, which lies just outside Canada's jurisdiction.

Figure 2 Technology has allowed us to catch fish at a rate greater than the stocks are able to reproduce.

Figure 3 About a third of the fishing area of the Grand Banks lies outside the area managed by Canada.

The impact of science and technology on the environment is not always negative. New knowledge improves our understanding of the natural world, and new technologies that allow us to use the environment in a more sustainable way are being developed. For example, new energy technologies are available that can harness the energy of the Sun, the wind, or the tides. These technologies are much more environmentally friendly than the use of fossil fuels as a source of electrical energy. Alternative sources of energy are also being researched in the development of vehicles that have less of an impact on the environment and that are more fuel efficient.

Innovations are being devised to help us cope with environmental problems associated with growing populations and global warming. The world's wetlands—home to thousands of bird and animal species—are being lost to development and to rising sea levels. Bruce Kania of Montana, USA has developed a new method for constructing artificial floating islands out of recycled plastic and foam.

The construction starts with layers of polymer mesh held together by adhesive foam. Sod and vegetation are then added. Finally, plants are selected to attract insects, frogs, birds, beavers, and other wildlife (Figure 4). Once established, these artificial islands function like natural wetlands, providing a home for many organisms and filtering harmful substances from the water. As with most new technologies, artificial wetlands are expensive—approximately US$500 million per square kilometre of floating island.

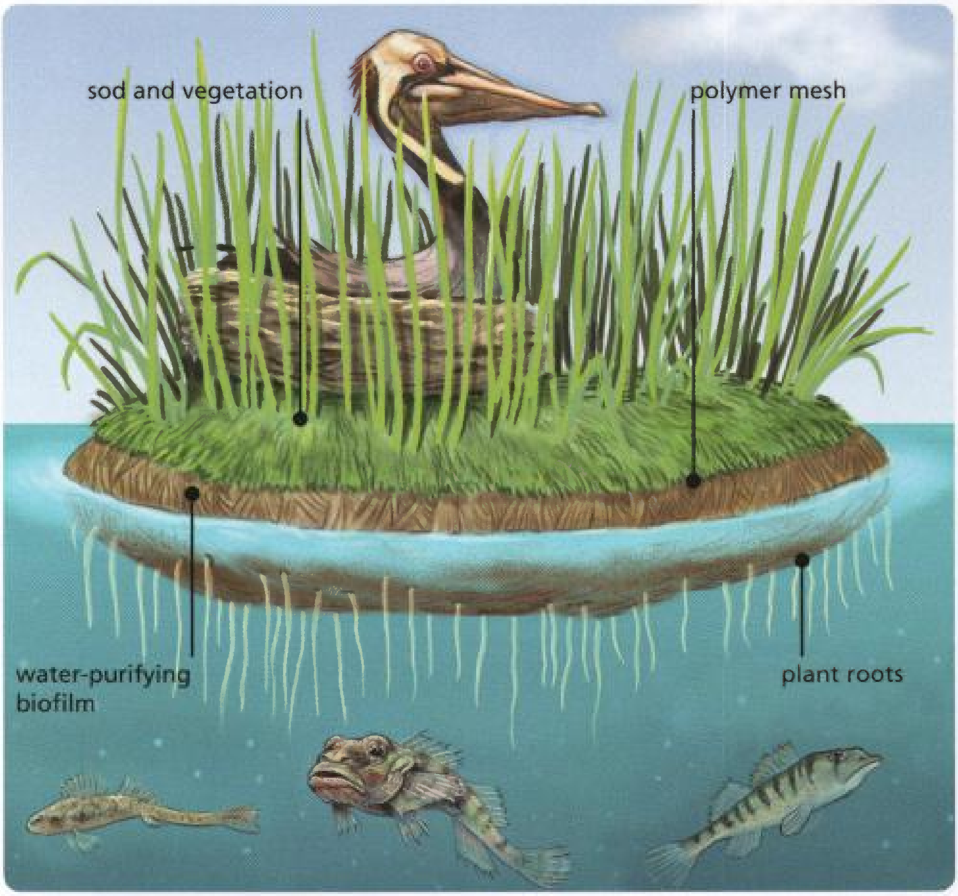


Figure 4 Synthetic wetlands serve the same purposes as natural wetlands, and are now being used in areas where natural wetlands no longer exist.

Figure 5 The protection of glaciers during the summer is an innovative use of thermal blankets.

Another innovation that has been applied to solve an environmental problem is the use of special blankets to prevent the melting of glaciers. The top of the Gurschen glacier on Gemsstock Mountain in the Swiss Alps has receded by about 20 m in the last 15 years. A ski resort in Switzerland that relies on the glacier has attempted to prevent further melting by covering the glacier in blankets (Figure 5). The blankets are composed of polyester and propylene layers, and are pure white in colour. The blankets are used during the summer months to protect the snow cover from heat and UV radiation, which helps to minimize melting. However, this is not a practical solution to the global problem of melting glaciers. The blankets are expensive (approximately US$5 million per square kilometre), and it would be practically impossible to install blankets over all glaciers during the summer months and remove them again during the winter.

The Importance of Scientific and Technological Literacy

We live in a time when growing scientific knowledge and rapid technological innovations are playing an increasingly significant role in everyday life. Science and technology have become so common and prevalent in our society that often we do not see them, or we take them for granted. Most people do not attempt to understand new technologies because they are designed so that the average person can use them without having to understand how they work. Science is often perceived as too complex to be understood by the average person.

Carl Sagan, a renowned astronomer and author, recognized the role of science and technology and the importance of being scientifically and technologically literate when he said in his book *The Demon-Haunted World*

> "We've arranged a global civilization in which the most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power will blow up in our faces."

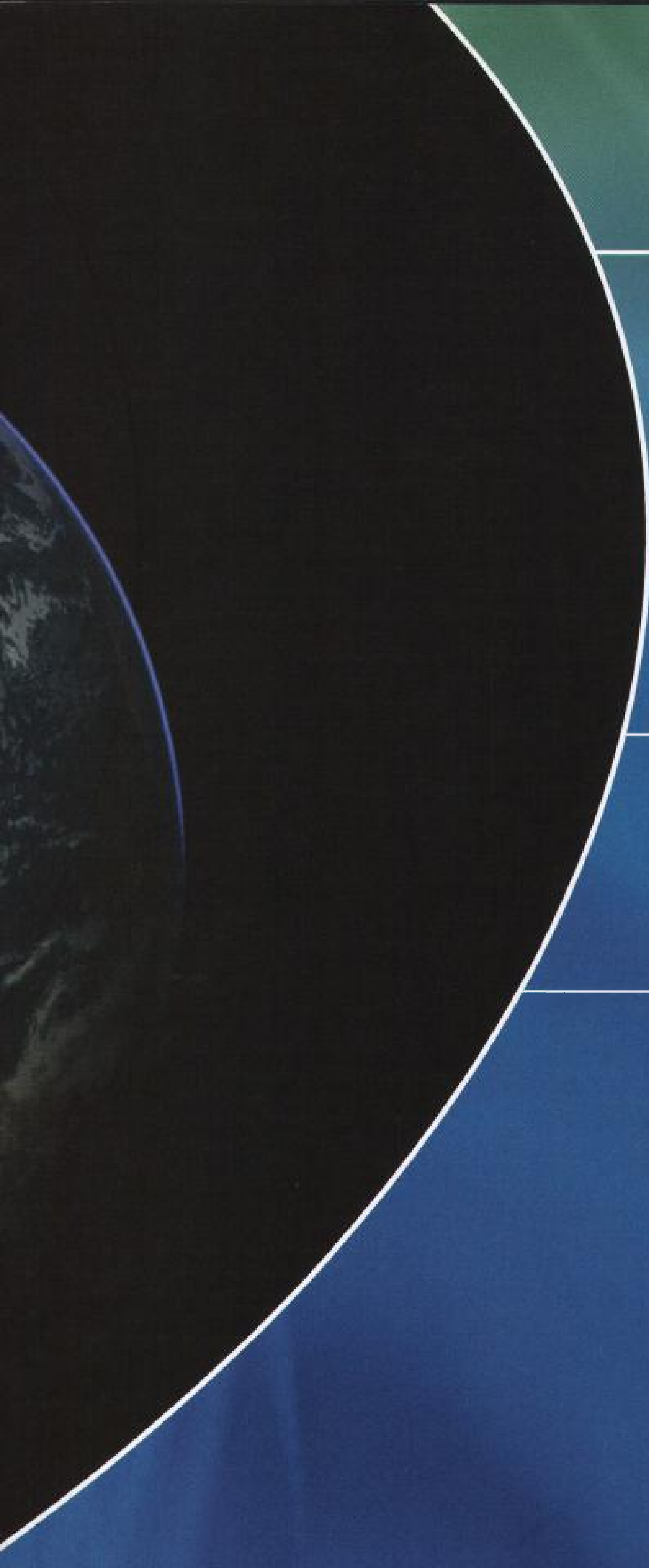
To make wise personal decisions and to act as a responsible citizen, it is necessary to be scientifically and technologically literate. **Scientific and technological literacy** can be thought of as a combination of the science-related attitudes, skills, and knowledge needed to develop inquiry, problem-solving, and decision-making abilities.

A scientifically and technologically literate person understands first of all that the future will be very different from the present because there are always new developments in science and technology. Such a person also understands that society influences science and technology as much as science and technology influence society. We each have a responsibility to ourselves, to society, and to future generations to aim for scientific and technological literacy.

Because science and technology influence our lives so profoundly, it is important that we recognize and understand this influence so that we can make rational decisions about which scientific and technological research we support. We, as a part of society, need to consider both the positive and negative impacts of developing and using scientific knowledge and new technologies. Although we cannot foresee all of the possible consequences of new scientific and technological achievements, a society that does not consider both the positive and the negative implications of proposed new technologies may understand the consequences of that decision only after the technology has been adopted.

STUDY TIP

Having notes, study cards, and past exams organized and handy will help you prepare for a chapter exam. An effective organization system is to put all your notes, cards, and past exams for each chapter in a three-ring binder.



UNIT A

SUSTAINABILITY OF ECOSYSTEMS

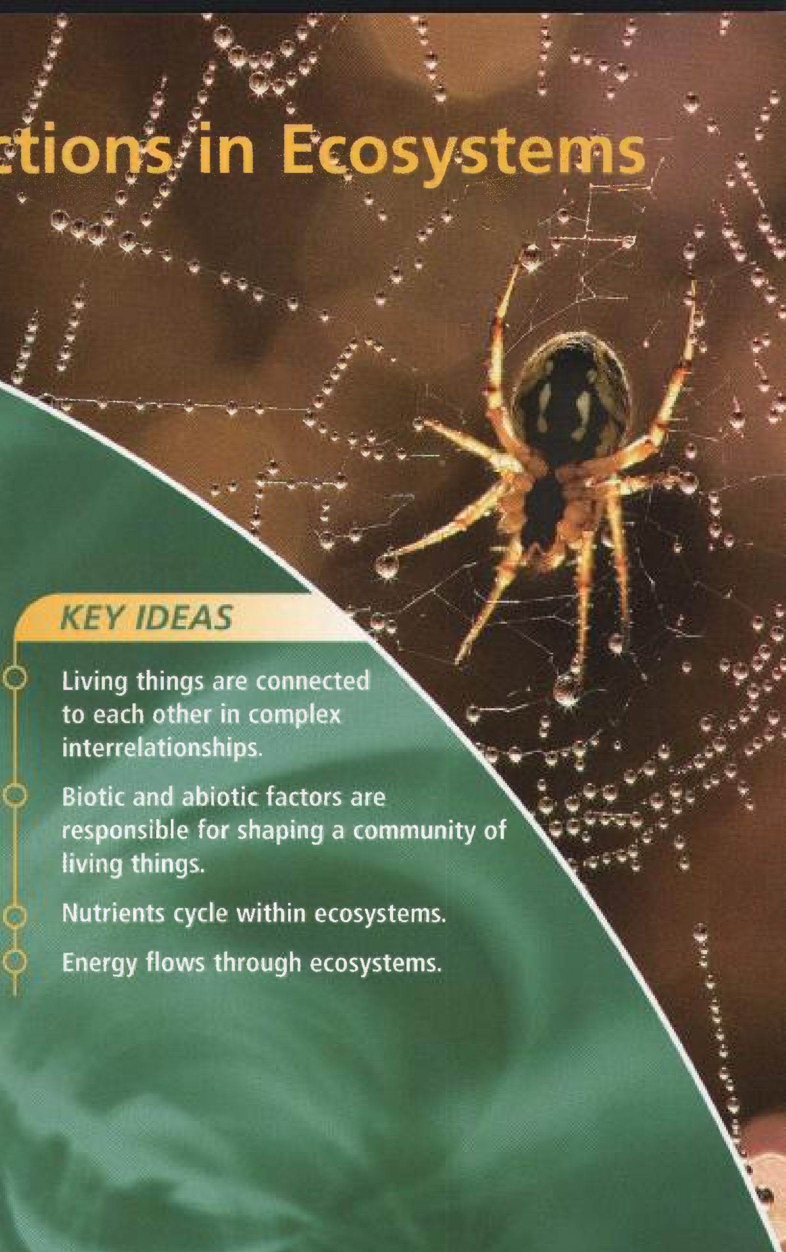
Unit Preview

What causes the varied shades of green, brown, and blue seen on Earth from space? What is the white shading, and why does it move around the planet's surface? What factors control the types of organisms present in any area on Earth? How are these organisms related and how do they interact? Where do humans fit into the complexity of life on Earth?

In this unit, you will learn about the intricate relationships that exist among organisms and how they interact with the non-living components on Earth. You will learn how various conditions on Earth shape the types and numbers of organisms that exist in each area. You will also learn about the movement and cycling of energy and matter within ecosystems. Finally, you will learn about the impact of natural phenomena and human activities on the fragile balance that makes Earth so unique.

CHAPTER 2

Interactions in Ecosystems



Chapter Preview

What do you need to live? How are your needs different than those of other living things on Earth? Where do the things that you need come from? What would happen if something you needed was not available?

Life exists almost everywhere on Earth. All life, and everything needed to maintain it, exists within a thin layer of land, sea, and air. While the estimates vary, some scientists believe that as many as 40 million different species may populate the planet. But only about 3 million of them have been identified and given a name. Only a few thousand of them have been studied in detail. Scientists attempt to learn more about each living thing. But they do not stop there.

To fully understand the world of living things, scientists look at how organisms interact with each other and with their environment. No living thing can exist in isolation. Every organism is linked to other organisms on the planet. Trying to understand all of the relationships that exist among different living things, as well as with their surroundings, is the goal of ecology.

KEY IDEAS

- **Living things are connected to each other in complex interrelationships.**
- **Biotic and abiotic factors are responsible for shaping a community of living things.**
- **Nutrients cycle within ecosystems.**
- **Energy flows through ecosystems.**

TRY THIS: *Modelling Interactions*

Skills Focus: communicating, recording

In this activity, you will explore the interactions that one organism has with the other organisms around it, and with the environment in which it lives.

Materials: notebook or graphic organizer

1. Create a graphic organizer to represent interactions between a spider and its environment.
2. Consider what the spider eats. What other organisms might compete with it for the same food? What eats spiders? Consider other relationships as well.
3. Consider the non-living factors that affect the spider.
4. Add these organisms, relationships, and factors in your graphic organizer. Connect the interactions by drawing lines between them and the spider.

A. In what way is this model of representing interrelationships useful?

B. What are the weaknesses of this type of model for showing interrelationships?

C. Why are models like this one useful for understanding interrelationships among organisms and their environments?

D. The spider is just one organism. What can you predict about modelling interactions that occur between all of the living things on planet Earth?

2.1 Biotic and Abiotic Factors in Ecosystems

Ecology is the study of how organisms interact with each other and with their physical environment. Ecologists collect information about living things, and then look for patterns to explain the observations. This is an enormous challenge because there is a tremendous variety of organisms and so many different relationships among them. It is for this reason that ecologists organize their study into several levels (Figure 1).

The first and simplest level of organization that ecologists study is a single living thing or **organism**. They study the behaviors, the functions, and the body structures that an organism has in order to survive in its **habitat**, or region in which it lives. For example, they might study how a sea otter captures food or how its body is specialized for the marine habitat. But most organisms do not live as isolated individuals. Usually organisms live as a **population** (the second level of organization), which is all of the organisms of the same species that share a habitat. Ecologists might study how the number of sea otters in the waters of coastal British Columbia changes over time. But populations interact with other populations of organisms.

Did You KNOW?

Sounds like Greek to Me!

The word "Ecology" comes from two Greek words: *oikos*, which means "house," and *logos* or "word," referring to study. So, Ecology is literally the science of studying the place where something lives.

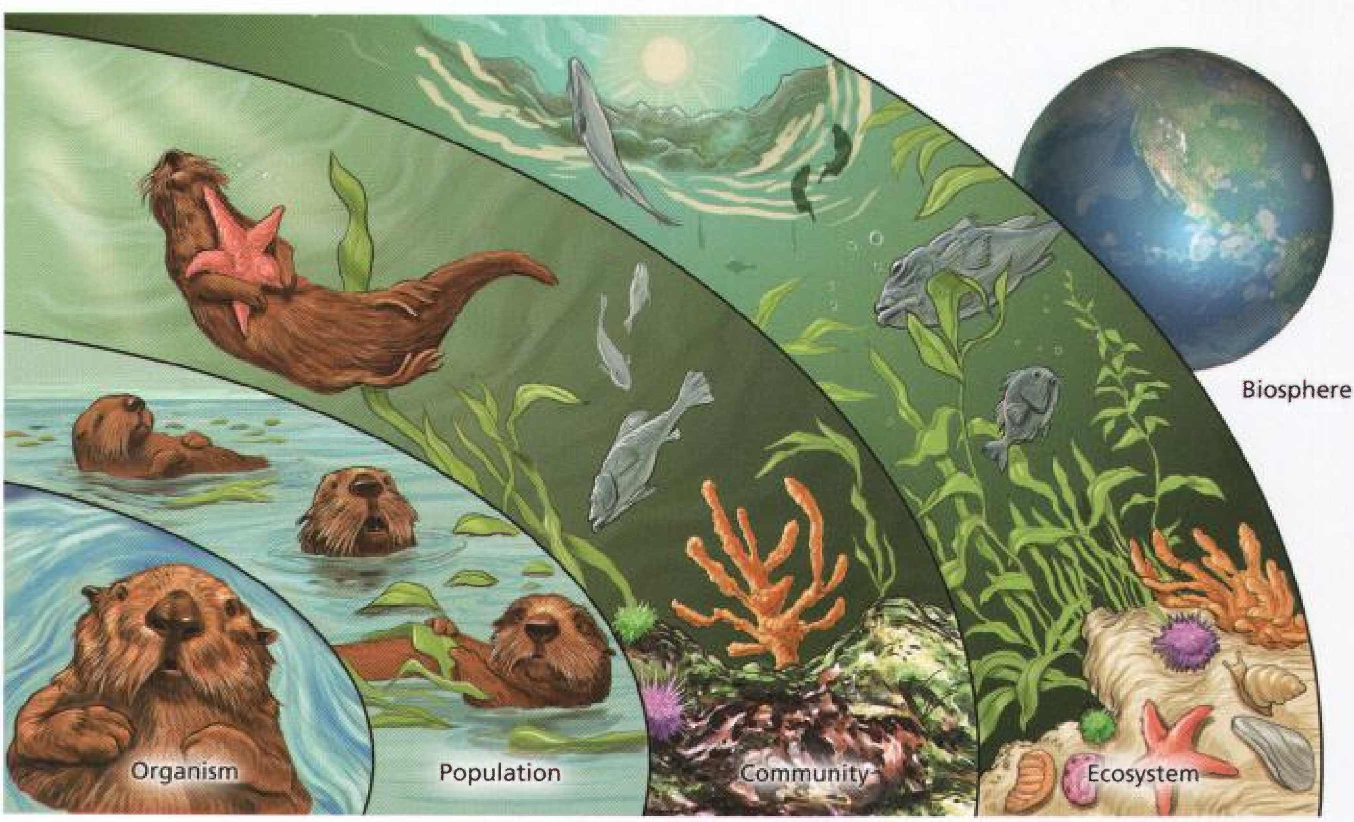


Figure 1 The study of ecology involves organisms, populations, communities, and ecosystems. The biosphere includes all of the ecosystems on Earth.

STUDY TIP

Check your understanding. Are you able to recall the levels within the biosphere? If not, reread the main ideas and words in bold, and re-examine Figure 1, on page 21.

To learn more about the ecosystems found in British Columbia, go to **www.science.nelson.com** GO

All of the different populations in a particular area interact, forming a **community**, which is the third level of organization. The community that lives within the kelp beds off the coast of British Columbia includes many populations of plants, fish, and invertebrates like sea urchins, sea stars, and sponges. At the community level, an ecologist might study how the number of sea urchins affects the number of sea otters in the kelp bed community. They are interested in ways that internal and external factors affect the size of the populations in a community.

An **ecosystem**, which is the fourth and most complex level of organization, includes the living community as well as the physical environment in which the organisms live. GO

Factors such as the introduction of a new species or a temperature change would have a huge impact on the kelp bed community. An ecosystem is simply a convenient way to look at interactions between the living and the non-living things in an area. It is not defined by size or complexity. It could be as small as the spaces in a rotting log, or as big as the ocean. You could even think of Earth as one big ecosystem, but because of its complexity it is usually considered on a different level called the **biosphere**. The biosphere is the total area of Earth where living things are found, including the soil, atmosphere, and ocean.

TRY THIS: Make a Model Ecosystem

Skills Focus: conducting, recording, communicating, questioning, evaluating

In this activity, you will combine living and non-living factors to create your own ecosystem.

Materials: 3–4 L jar with lid, 250 g of sand or gravel, 4–5 aquatic snails, 2 small guppies, 4–5 aquatic plants

Handle glass products with care. Assemble the equipment where it will stand so that it does not need to be moved after being filled.

1. Place 2–3 cm of sand or gravel into a large jar.
2. Fill the jar with tap water to within 5 cm of the top. Let it stand without the lid on for 48 h.
3. Add the aquatic plants, snails, and guppies.
4. Place the lid on the jar and seal tightly.
5. Place the jar in an area where it can receive indirect sunlight for 1 week.

A. What was the purpose of sealing your model ecosystem?

B. What is the source of carbon dioxide that the algae and plants require?

C. What is the source of oxygen that the fish and snails require?

D. How do the plants and animals get the necessary nutrients?

E. What would happen to the ecosystem if one of the fish died?

There are two types of environmental factors in an ecosystem, the living community and the physical environment. The living components of the ecosystem are called **biotic factors**. For example, in the kelp beds off the coast of British Columbia the biotic factors include the plants, fish, and invertebrates, as well as the complex interactions occurring between them. The non-living components, or **abiotic factors**, include the physical and chemical components in the environment. Some of the more significant abiotic factors are temperature, wind, water, sunlight and oxygen. The abiotic factors in the kelp beds would include (among others) the water temperature, the currents, and factors such as an oil spill.

Abiotic and biotic factors are connected to each other (Figure 2). As organisms live, they alter the environment around them, which in turn affects the organisms. This type of balance, where there is continuous change but the overall system remains stable, is called **dynamic equilibrium**. Ecosystems are normally able to adjust to small changes from within. The importance of abiotic factors cannot be emphasized enough. The difference in abiotic factors like climatic conditions and soil quality determine the distribution of life and contribute to diversity within the biosphere. 2A *Investigation*

Sometimes one factor, known as a **limiting factor**, is the most critical factor in determining the types of organisms that can exist in an ecosystem. For example, the large Douglas fir trees in our Pacific coastal forests grow only in regions with high annual rainfall. In aquatic environments, important limiting factors are sunlight, temperature, and the amount of dissolved oxygen in the water.

Did You KNOW?

Abiotic Technology

Many of the technologies you use everyday were invented in response to an existing abiotic factor. Furnaces, air conditioners, solar panels, and many other technologies, are just a few of the adaptations humans have made in response to abiotic factors.

2A *Investigation*

The Effect of Abiotic Factors on a Yeast Population

To perform this investigation, turn to page 42.

In this investigation, you will investigate the effects of abiotic factors on populations.

(a) (b) (c)

Figure 2 Abiotic factors such as (a) frost, and biotic factors such as (b) pests, and (c) other organisms affect the growth of the biotic factors like crops.

TRY THIS: A Day at the Beach

Skills Focus: recording, communicating

Abiotic factors have a large impact on living things. In this activity, you will explore the biotic and abiotic factors that can influence a day of outdoor fun.

Materials: notebook or graphic organizer

1. Plan a great day at the beach. Make a list of all of the things you should consider in your planning.

A. What abiotic factors should you consider?

B. Identify biotic factors that might be a part of your day at the beach.

C. How would these abiotic and biotic factors differ if you were planning a great day of skiing or snowboarding?

2.1 CHECK YOUR Understanding

1. Compare the following terms. Give both similarities and differences.
   (a) ecosystem and habitat
   (b) organism and population
   (c) biosphere and community
   (d) ecosystem and community
2. What level of organization within the biosphere is represented by each of the following?
   (a) a herd of water buffalo
   (b) the plants and animals on the Serengeti plain of Africa
   (c) a lake and all of the organisms that live within it
   (d) a grizzly bear
   (e) sunflowers growing in a garden
3. Which level of organization is being considered in each of the following ecological studies?
   (a) observing how the talons of a bald eagle are used to capture food
   (b) observing the migratory pattern of a flock of snow geese
   (c) observing the impact of a hazardous chemical spill on living things in a nearby stream
   (d) observing the nest-building behaviour of hummingbirds
   (e) observing the effect of fleas on the health of house pets
   (f) measuring the changes in oxygen levels of a small lake during periods of rapid plant growth
4. Why is the science of ecology important?
5. List at least three characteristics of ecosystems that make them challenging to understand in detail.
6. Provide two other situations besides ecology in which it is helpful to use a classification system like the one developed by ecologists.
7. The mouth of a dog or Earth itself could each be defined as entire ecosystems. What characteristics do they have in common that makes this similar classification appropriate?
8. Use Figure 3 to answer the following questions:

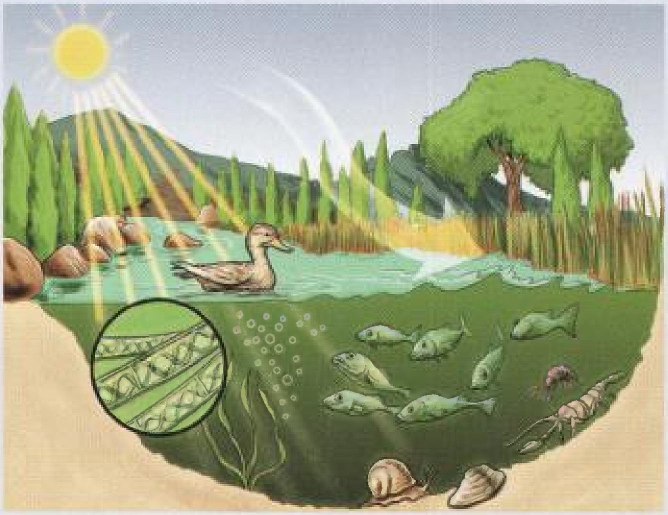


Figure 3

   (a) Identify each of the following from the illustration. Explain your reasoning.
      i) two biotic factors
      ii) two abiotic factors
      iii) a limiting factor
   (b) Describe the relationship between the abiotic and biotic factors that you selected.
   (c) Which abiotic factor could be altered to have the greatest effect on the ecosystem? Explain your reasoning.

2.2 Ecological Roles and Relationships

We can look at an ecosystem as a complex network of interactions. Within an ecosystem, all organisms need to carry out basic essential life functions such as growth, movement, repair, and reproduction. In order to perform these functions, organisms must take in food, water, and other nutrients. **Nutrients** are the elements and compounds that organisms must have in order to live and grow. Nutrients include water, oxygen, vitamins, and minerals, as well as the foods we eat that provide fats, proteins, and carbohydrates. Some organisms, like plants, can make their own food, while other organisms need to consume food in order to live.

LEARNING TIP

Active readers interact with the text. As you read Section 2.2 go back and forth between the words in bold and the photographs. Ask yourself, "How can I figure out the meanings of unfamiliar terms from cues in the text and illustrations?"

Producers

The **producers** or **autotrophs** (Figure 1) are organisms that make their own food, usually using energy from the Sun in a process called photosynthesis. You will learn more about this process in Chapter 4. Producers are also an important food source for other organisms.

Almost all plants can photosynthesize, and on land they are the most important type of producer. In aquatic environments, producer organisms called algae photosynthesize as well. Algae include some plant-like protists (single-celled, eukaryotic organisms), single and multicellular plants, and some photosynthetic bacteria. Microscopic algae are called **phytoplankton**.

Some producers are not photosynthetic and can live on the ocean floor or deep within caves, in the total absence of light. Instead of using the energy of the Sun, they use the thermal and chemical energy of Earth's interior in a process called chemosynthesis.

(a) (b) (c)

Figure 1 Producers come in all shapes and sizes, including (a) *spirogyra* algae, (b) purple lupins, and (c) deciduous trees. What they share in common is the ability to make food from inorganic materials and a source of energy, such as the Sun.

To learn more about the role of organisms in an ecosystem, watch the animation found at www.science.nelson.com

Consumers

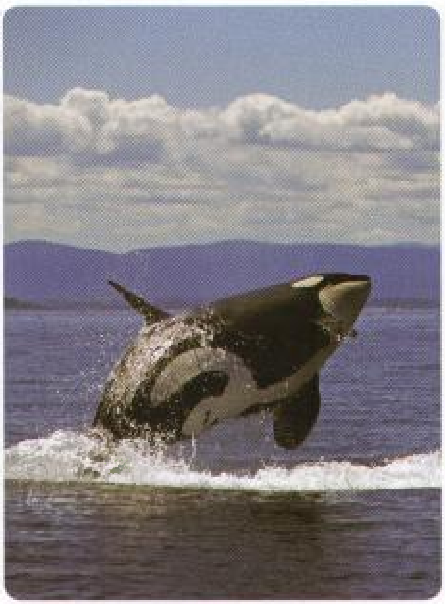
Organisms that consume other organisms or biotic waste in order to survive are called **consumers** or **heterotrophs.** Consumers ingest other organisms and break down the chemical bonds within those organisms to obtain energy and carbon. You will learn more about this process in Chapter 4.

Consumers that eat producers are called **herbivores** or **primary consumers.** Herbivores include insects and animals, such as caterpillars and elk, that eat plants (Figure 2). In aquatic environments, herbivores include microscopic **zooplankton** that eat phytoplankton. Consumers that eat other consumers are called **carnivores,** such as those shown in Figure 3. Some organisms called **omnivores** eat both producers and other consumers (Figure 4). Humans are omnivores, as are grizzly bears that eat a variety of foods including salmon and insects as well as fruits and berries.

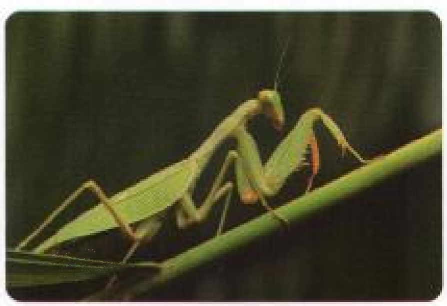
(a)

(b)

Figure 2 (a) The elk and (b) caterpillar are both herbivores. Both rely on producers as food.



(a)



(b)

Figure 3 (a) The killer whale and (b) praying mantis are both carnivores. They eat other consumers in order to gain the energy they need to survive.

(a)

(b)

Figure 4 (a) Grizzly bears and (b) humans are both omnivores. They eat producers as well as other consumers.

Detrivores are consumer organisms that feed on the waste material in an ecosystem, including the bodies of other organisms that have recently died, plant debris, and animal feces (Figure 5). **Decomposers** are a special type of consumer that breaks down the complex molecules found in dead organisms and waste matter into simpler molecules. Decomposers like bacteria and fungi cause the decay of material. Decomposer organisms like bacteria are nature's recyclers. They make the nutrients contained in waste and dead matter available to producers once again through a process called **biodegradation** (Figure 6). In areas where decomposers are abundant, rich fertile soil exists. Ecosystems with few decomposers have very little decay, and as a result the soil tends to be thin and low in nutrients.

(a)

(b)

Figure 5 Organisms such as (a) earthworms and (b) hagfish that feed on the waste and remains of other organisms are called detrivores.

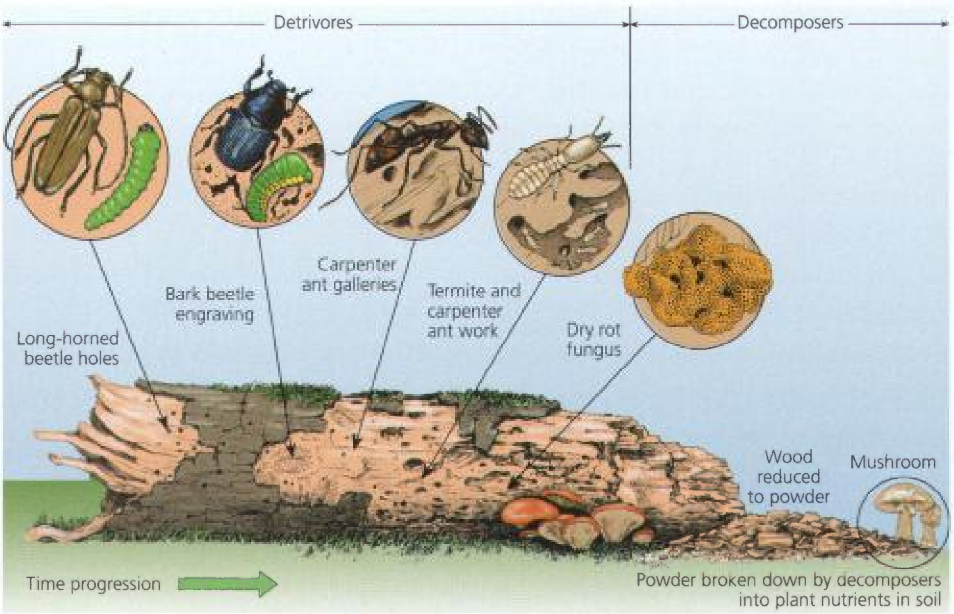


Figure 6 Decomposers such as fungi and bacteria, as well as detrivores like insects and other scavengers, form a complex community within a log. Eventually they break the log down, releasing the nutrients into the soil.

TRY THIS: *Leaf Debris*

Skills Focus: conducting, recording, communicating, questioning, observing, predicting

In this activity, you will explore leaf litter for signs of decomposers and the work that they do.

Materials: fallen rotting leaves; hand lens or dissecting microscope

Some people have reactions to airborne microbes in decomposing material. Use caution if you have allergies or asthma.

1. Collect some fallen leaves that have been on the ground for some time.
2. Observe the leaves under a hand lens or dissecting microscope. Look for any signs of decomposers.

A. What characteristics help you to identify a decomposer?

B. What kind of organism is mould? What role do moulds play in a forest ecosystem?

C. What other organisms can you find in your sample? What roles do they play in a forest ecosystem?

D. What do you think will eventually happen to the material contained in the leaves?

E. Select two abiotic factors and predict how they will affect the process occurring in the rotting leaves.

Figure 7 Not all predators are fast, with sharp claws and teeth. This sea star is a predator.

Predators

Predation occurs when a consumer captures and eats another organism, such as when a **predator** like a mountain lion, captures, kills, and eats a **prey** animal such as a deer. It is common to think of predators as fast-moving carnivores, but the term more broadly refers to any consumer in an ecosystem. Organisms as varied as sea stars, centipedes, rabbits, and tigers are all predators (Figure 7).

At first glance it might seem that a predator simply reduces the population of prey in a community. However, there tends to be a cyclic rise and fall in both populations called the **predator–prey cycle** (Figure 8). The cycle begins when the prey population decreases as the predators eat the prey. Then, the predator population decreases as available prey run out. The cycle continues as the decreased number of predators allows more prey to survive, and the prey population rebounds. The predator population then increases because it now has an abundant food supply. The predators reduce the prey population and the cycle begins again. A distinct characteristic of this cycle is the time lag of the predator population. This refers to the delay as the predator population responds to the changes in the prey population.

The cycle in actual populations, such as the Canadian lynx and the snowshoe hare (Figure 9) is much more complex than the simple predator–prey cycle predicts, and only slightly resembles the simplified model shown in Figure 8. However, the model remains useful to understand the cycling of the two interrelated populations. 2B Investigation

In natural populations there are several other environmental factors at work, and effectively two predator–prey cycles. Remember! Herbivores are predators as well, and have a predator–prey relationship with the plants they eat. Both populations are interacting with the prey they consume.

2B *Investigation*

Predator–Prey Simulation

To perform this investigation, turn to page 44.

In this investigation, you will simulate the interactions between a predator and a prey species.

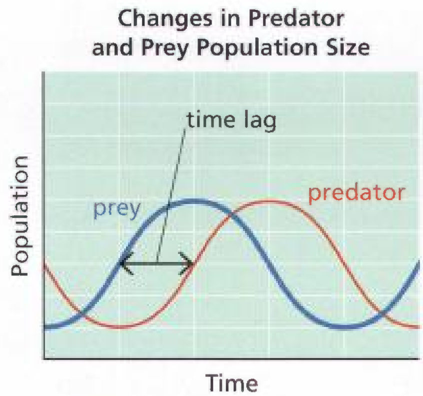


Figure 8 The predator–prey model describes the cycling of the predator and prey populations.

Figure 9 The interaction between the snowshoe hare and the Canadian lynx is one of the best known illustrations of the predator–prey cycle.

2.2 CHECK YOUR Understanding

1. Compare the following terms. Give both similarities and differences.
   (a) producer and consumer
   (b) omnivore and carnivore
   (c) carnivore and herbivore
2. The word "autotroph" literally means "self-feeder." Why is this term appropriate in reference to producers?
3. The word "heterotroph" literally means "other-feeder." Why is this term appropriate in reference to consumers?
4. How does a consumer differ from a decomposer?
5. What role do decomposers fill in an ecosystem?
6. List five producers and five consumers that live near your home.
7. Compare a herbivore, a carnivore, and a detrivore. Indicate both similarities and differences.
8. In your own words, define "nutrient."
9. Which of the following classifications is most appropriate for bread mould and mushrooms?
   A. producers
   B. herbivores
   C. carnivores
   D. decomposers
10. Often farmers will plough the remains of their crops into the soil. Explain why this is a better option than taking them away to burn.
11. Which of the following terms refers to organisms that are able to cause biodegradation?
    A. herbivores
    B. omnivores
    C. carnivores
    D. decomposers
12. The word "omnivore" is from two Latin words: *omne* meaning "all" or "everything," and *vorare* meaning "to devour." What characteristic of omnivores makes this an appropriate name for them? In what ways is the name misleading?
13. The interaction between the snowshoe hare and the Canadian lynx has been documented for over 100 years.
    (a) In what ways is the predator–prey cycle shown in Figure 10 similar to the idealized model shown in Figure 8?
    (b) In what ways is it different?
    (c) Suggest factors that may be responsible for any difference you see.

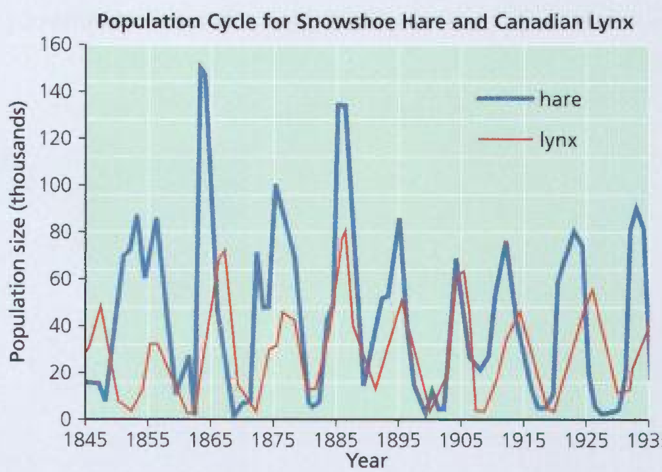


Figure 10

14. Create a six-column table with the following headings: producer, herbivore, carnivore, omnivore, decomposer, detrivore. Insert examples of each type of organism in the proper column.
15. Draw the predator–prey cycle shown in Figure 8 into your notebook. Describe what happens to cause each direction change on the graph. Clearly label the time-lag.

2.3 Symbiosis

Figure 1 A fungus and a green algae form a composite organism (a lichen) through symbiosis.

Symbiosis refers to any close relationship between two different species. Symbiotic relationships are the most specialized form of species interaction and each species often develops very specialized behaviours, life cycles, or structures. There are three types of symbiotic relationships: mutualism, commensalism, and parasitism.

Mutualism is a relationship in which both species obtain some benefit from the interaction. For example, lichens are made up of a fungus and a photosynthetic organism, usually a green algae. The fungus grows around the algae, protecting the algae which then makes food for the fungus through the process of photosynthesis (Figure 1).

Commensalism is an interaction in which one organism benefits while the other is unaffected. Relationships of this type often are difficult to detect and the term is usually applied to situations where there is no obvious cost or benefit to one of the organisms. For example, the relationship between barnacles and grey whales is usually classified as commensalism. The barnacles live on the hide of the whale and feed passively from the water passing by, while there is no apparent benefit or harm to the grey whale (Figure 2).

LEARNING TIP

Periodically stop reading to recall what you have read. Ask yourself, "What are some examples of mutualism, commensalism, and parasitism?"

Figure 2 The whale barnacle has a commensal relationship with the grey whale.

Parasitism occurs when one organism lives and feeds on, or in, the body of another organism called the **host**. The **parasite** benefits from the relationship by getting its nutrients from the host. The host is harmed by the relationship, but the death of the host means the loss of a habitat for the parasite, so the host's death usually comes slowly, if at all. From the perspective of any host, the parasite is harmful. The host is often starved for nutrients, and may be unable to reproduce or carry out some basic life functions. However, parasites can have a positive role, because they control species' population growth and prevent them from becoming too abundant. In this way, parasites ensure the survival of the strongest and healthiest members of a population. Nevertheless, parasites are responsible for many serious diseases.

Biologists estimate that as many as 25 % of all animal species may be parasites. Parasites often have hooks or suckers for attaching to the host. In some parasitic species, only the reproductive system is well developed. Tapeworms that live in the intestine of their host can absorb nutrients directly through their skin. Tapeworms, ticks, and fleas, as well as many bacteria and protozoa, are among the parasites that are responsible for widespread disease among animals and humans (Figure 3).

Many plant parasites gain nutrients from a host plant instead of producing their own food through photosynthesis. Some plant parasites cannot photosynthesize at all, and must gain nutrients from a host plant instead. Mistletoe is a common parasite of lodgepole pine and Douglas fir trees in British Columbia (Figure 4). GO

STUDY TIP

A summary answers the question, "What is the writer really saying?" Create a summary card for the three types of symbiosis. Ask yourself, "What are the main ideas in each paragraph? How would I explain them in my own words?"

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

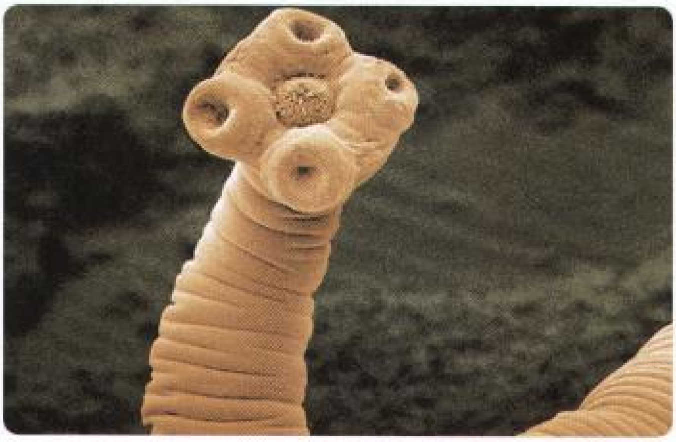


Figure 3 The tapeworm is highly specialized for survival in the mammalian digestive system.

Figure 4 Parasites like mistletoe can cause damage to trees in British Columbia's forests.

TRY THIS: Host Sweet Host

Skills Focus: recording, communicating, researching

Parasites are not usually the primary cause of the death of the host organism. Instead, the host organism dies from a secondary cause due to its weakened condition. Parasites often have very complex life cycles that help them to move to a new host body on a regular basis.

Materials: research materials

1. Choose an internal parasite to study, such as a fluke, a tapeworm, a roundworm, or a species of *Plasmodium* or *Trypanosome*.
2. Research the methods by which it gets from one host body to the next.

www.science.nelson.com GO

A. Draw the life cycle of your chosen parasite, indicating how it moves between hosts.

B. How does the parasite get its nutrients?

C. Describe the effect of the parasite on the host's body.

2.3 CHECK YOUR Understanding

1. What characteristics of parasitism would lead some scientists to classify it as a form of predation? What characteristics of parasitism suggest that it is not a form of predation?
2. Why is it often difficult to distinguish between mutualism and commensalism?
3. Give an example of a situation in which humans are involved in symbiotic relationships, including commensalism, parasitism, and mutualism.
4. Suggest several reasons why it is beneficial for a parasite to be small.
5. Create a graphic organizer to compare the different types of symbiosis.
6. Which type of relationship is illustrated by each of the following situations?
   (a) a small tick that slowly sucks the blood from a black tail deer
   (b) a grizzly bear that leaves the bodies of salmon as food for birds and small mammals
   (c) a bat that pollinates a plant as it feeds on nectar from a flower
7. In which of the following situations do both organisms benefit?
   A. predation
   B. parasitism
   C. mutualism
   D. commensalism
8. *Streptococcus* bacteria in the human mouth digest sugars and produce lactic acid that dissolves tooth enamel, causing cavities. Which of the following types of interactions is represented by this example?
   A. predation
   B. parasitism
   C. mutualism
   D. commensalism
9. *Corynebacterium* are microscopic bacteria that live on the surface of the human eye. They feed off the secretions and discarded cells and do not seem to affect the human they are living on. Which of the following types of interactions is represented by this example?
   A. predation
   B. parasitism
   C. mutualism
   D. commensalism
10. *Helicobacter pylori* is a bacteria that can thrive in stomach acid, where they are known to cause stomach ulcers. Which of the following types of interactions is represented by this example?
   A. predation
   B. parasitism
   C. mutualism
   D. commensalism
11. Biologists estimate that as many as 25 % of all living things are parasites. Suggest several characteristics that may allow them to be so successful.
11. Many parasites have complex life cycles involving two or more host species. How does this fact ensure the survival of the parasite?
12. Explain how parasites may actually improve the survival of many animal populations.
13. Some plant species have a mutualistic relationship with a single species of pollinator. Explain how this might be an advantage to the plant. Explain how this might lead to the extinction of the plant species.

2.4 Trophic Levels and Energy Flow

As one organism eats another, nutrients and energy move through the ecosystem, passing from producers to consumers. The nutrients are recycled through the process of biodegradation but the energy only moves in one direction through the community (Figure 1). This means that ecosystems require a continuous source of energy, such as the Sun.

To learn more about energy flowing and materials cycling, watch the animation at **www.science.nelson.com**

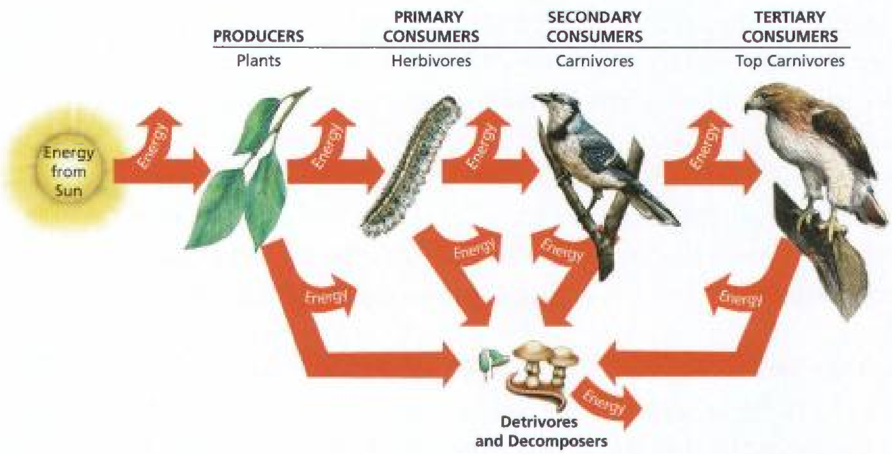


Figure 1 Nutrients cycle through ecosystems, but energy flows and eventually leaves. Energy must be continually supplied to the ecosystem by the Sun.

A **trophic level** describes the position of the organism in relation to the order of nutrient and energy transfers in an ecosystem (Figure 2). All producers belong to the first trophic level. The herbivores that consume the producers belong to the second trophic level, while carnivores occupy the upper trophic levels. Decomposers play a unique role and consume material from all of the trophic levels, so they can be shown in all consumer trophic levels.

To test your knowledge about trophic levels, go to **www.science.nelson.com**

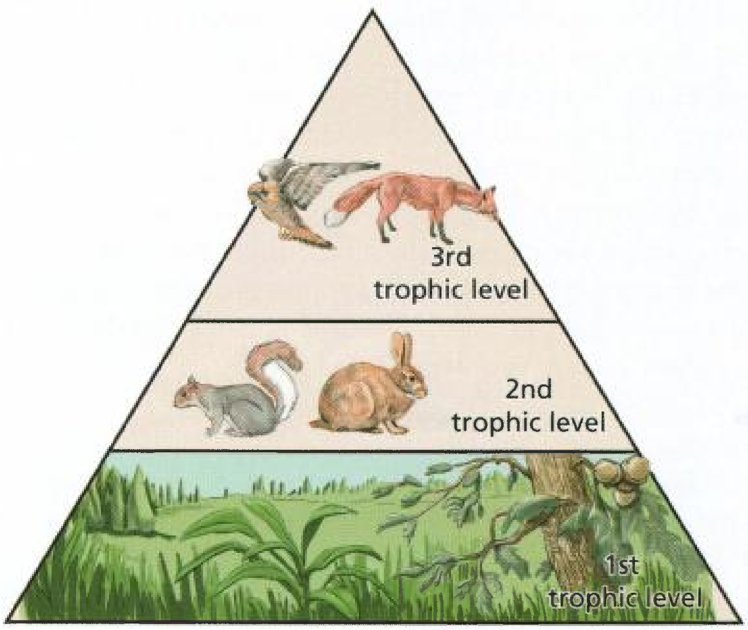


Figure 2 In an ecosystem, all of the organisms that consume the same type of food belong to the same trophic level. Decomposers could be shown at each consumer trophic level because they consume material from all trophic levels.

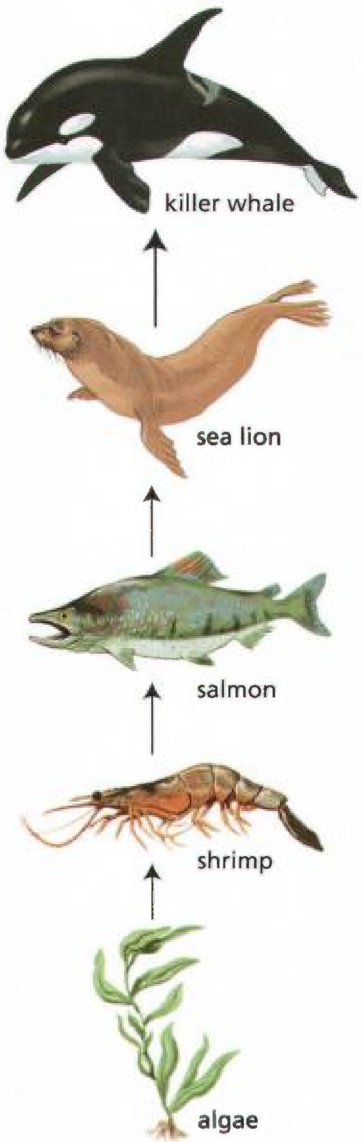


Figure 3 This food chain shows one way that nutrients and energy might flow in an ecosystem found in the waters of the Pacific Ocean off the coast of B.C.

Food Chains

A pathway taken by nutrients and energy through the trophic levels of an ecosystem is called a **food chain.** A diagram for a food chain shows arrows directed from one species to the next. The arrows indicate that the first organism is food for the next. Within an ecosystem, many food chains will exist and interact. Grazing food chains involve the typical producer–herbivore–carnivore pathway. Herbivores are primary consumers and they eat the producers from the first trophic level. Carnivores that eat herbivores are called secondary consumers. These include organisms like foxes, praying mantises, and salmon. Tertiary (or third level) consumers eat these secondary consumers. Tertiary consumers, such as eagles or harbour seals, might become food for quaternary (fourth level) consumers. Organisms like killer whales or lions might be included in this group. The top carnivore is at the highest trophic level, and has no natural predators. Its body, along with others in the community, decomposes after death and provides nutrients to the producers in the community.

Figure 3 shows an example of a simple grazing food chain for the waters off the coast of British Columbia. In this ecosystem, algae are the producers. They may be eaten by shrimp, which are in turn eaten by salmon. A sea lion may feed upon the salmon, and a killer whale might be the top carnivore. Food chains highlight predator-prey cycles that exist within a community. It is clear that the size of one population could affect others. If the number of killer whales increases, it is likely that there will be a decrease in the number of seals, which in turn leads to an increase in the number of salmon. A change in one population sends a ripple of change through the food chain. The simplified feeding model represented by the food chain becomes useful in monitoring population changes within an ecosystem. There are many examples of grazing food chains, but they all start with a producer and end with a carnivore.

Ecologists have traditionally placed decomposers as the final step in a grazing food chain, but now consider them separately. A detritus food chain begins with dead material and waste. Bacteria and fungi, along with the materials they decompose, become food for scavengers such as worms, millipedes, or larger decomposers, and in turn, these organisms are eaten by small carnivores (Figure 4). When an organism is eaten, there are always some parts that are not able to be digested by the consumer. A wolf that eats an elk cannot digest the antlers, hooves, teeth, hair, and bones. As a result, most of the energy contained in these components does not move through the grazing food chain. Instead, the nutrients contained in these materials become available to decomposers, or are slowly broken down by sunlight and weathering. In this way, the nutrients contained in waste material are recycled for use by other organisms. In ecosystems with deep rich soil, over 90 % of the nutrients and energy contained in plants decompose and move through the detritus food chain. Ecosystems with few decomposers have very

LEARNING TIP

As you examine Figure 3, make connections to what you already know. How is a food chain connected to what you have already learned about producers, consumers, and trophic levels?

little decay. As a result, the soil tends to be thin and low in nutrients. The condition of the soil is important in determining the types of producers that can grow, and therefore also affects the types of communities that can develop.

The detritus food chain is important in another way as well. Scavengers, such as vultures, prevent the spread of disease as they feed on the decaying bodies of recently killed animals. In this way, they help to maintain the health of plant and animal populations within the ecosystem. The grazing and detritus food chains are closely linked because small carnivores like shrews and raccoons are often part of both energy pathways.

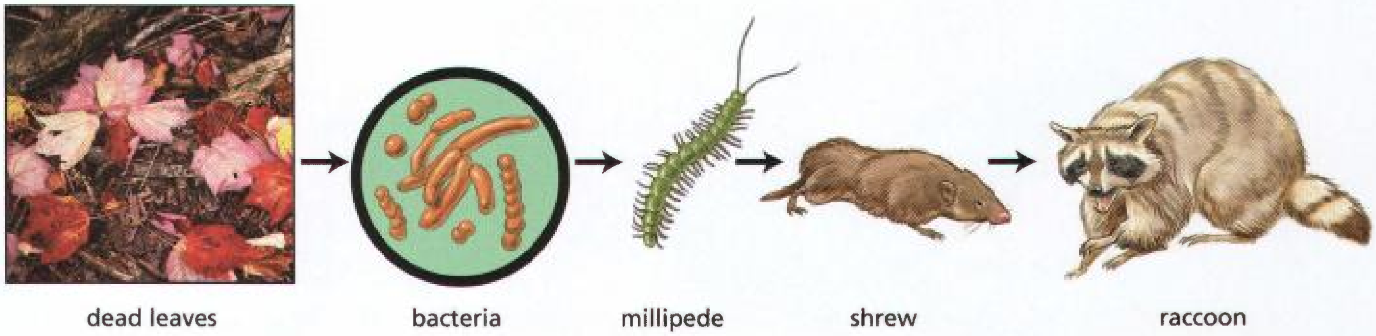


Figure 4 The detritus food chain makes the nutrients in dead organisms and waste available to other organisms.

TRY THIS: *Exploring a Detrivore Microhabitat*

Skills Focus: questioning, observing, identifying, concluding, recording, communicating

Explore the decomposers and detrivores in a rotting log.

Materials: gloves, safety goggles, tools (such as screwdriver, pliers, hammer), newspaper or large garbage bag, large plastic basin, newly collected rotting log, several small dishes or jars, magnifying glass or hand lens, field guides

Be careful of centipedes; they are capable of inflicting a painful bite. Wear gloves when collecting the log.

1. Collect a section of rotting log with as much moss, fungus, and decay as possible.
2. Put on gloves and safety goggles. Place your log section in a large plastic basin on newspaper or a large garbage bag.
3. Use your tools to carefully pry open the log.
4. Place any organisms you find in several small dishes or jars for closer observation.

A. Use a magnifying glass or hand lens and field guide to identify your organisms. If you cannot identify them, carefully describe them.

B. Which components that you observed are parts of the log ecosystem and which components are parts of the log community?

C. Describe one organism–organism interaction you observed.

D. Describe one organism–environment interaction you observed.

E. Draw one food chain that occurs within the community that lives inside the rotting log.

Food Webs

Energy relationships in a real ecosystem are too complex to be illustrated by a single food chain. Most consumers eat a variety of foods, and more than one consumer species will eat the same species of organism. A more accurate picture of the nutrient and energy pathways in an ecosystem can be seen in a **food web**, which represents many cross-linked food chains (Figure 5). The organisms in a food web are arranged by trophic level, with the producers and the consumers in successive levels. Figure 5 shows that a killer whale occupies the third, fourth, or fifth (top) trophic level, depending on the prey it is eating. Often top carnivores will occupy more than one trophic level because of the limited availability of prey at the top level.

LEARNING TIP

Pause, think, and evaluate what you have learned. Ask yourself, "What do I now know about a food chain and food web that I didn't know before? Have any of my ideas changed as a result of what I have read? What questions do I still have?"

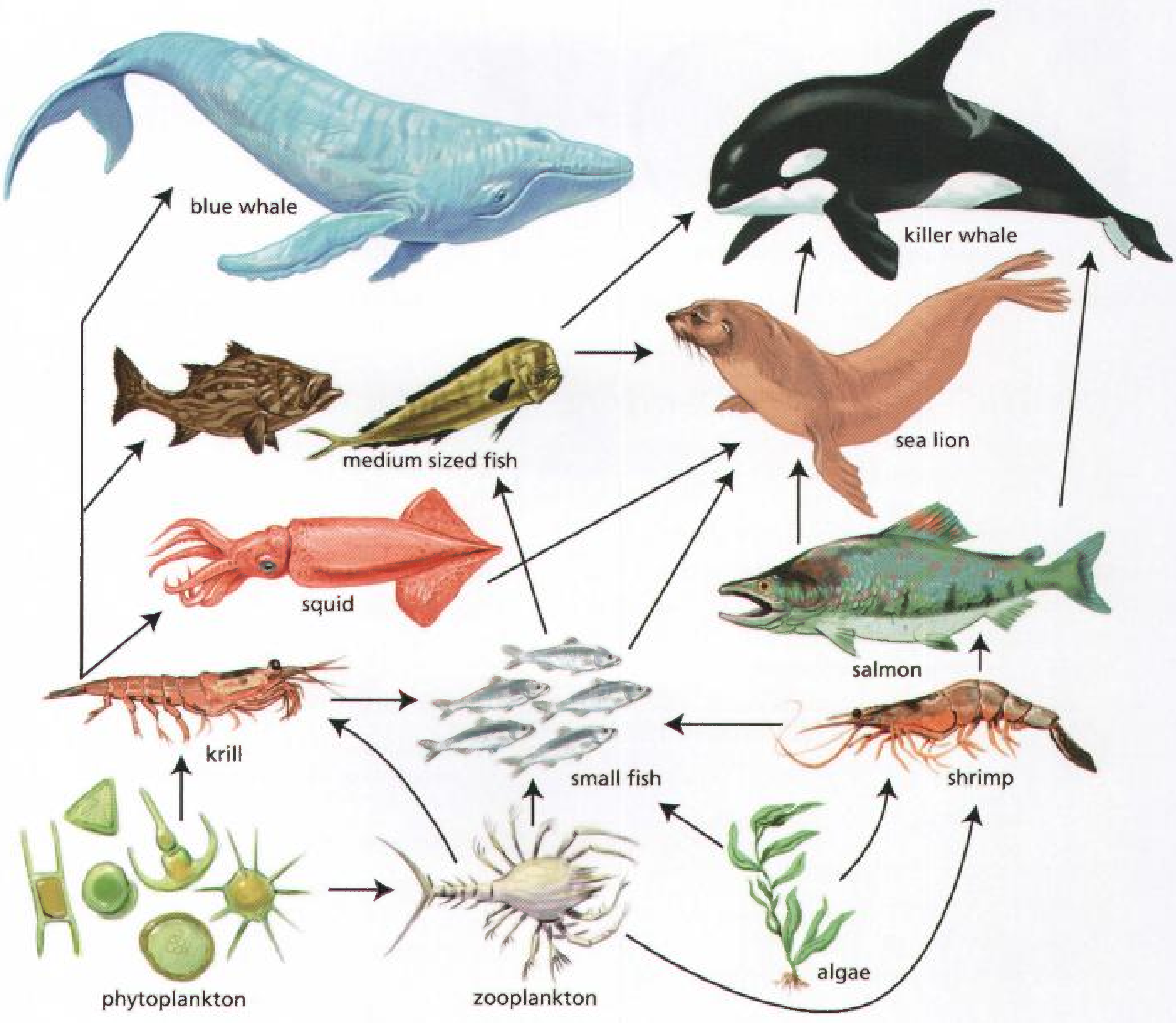


Figure 5 A food web, like this one for the Pacific Ocean, gives us a more complete picture of all of the different feeding relationships in an ecosystem.

2.4 CHECK YOUR Understanding

1. Why is sunlight essential to most food chains and food webs?
2. Explain the term "trophic level" in your own words.
3. Define and give three examples of a top carnivore.
4. Contrast food webs and food chains.
5. Energy flows through two different food chains in an ecosystem: grazing and detritus food chains. Describe each food chain. How does energy enter and leave each food chain?
6. Consider the food chain shown in Figure 6.

grass → insect → frog → snake

Figure 6

    (a) How would a decline in the number of frogs affect each of the other organisms in this food chain?
    (b) Redraw this food chain with the addition of bacteria, in order to show the role of decomposers in this community.
7. Why is energy flow in an ecosystem considered a one-way process?
8. (a) What type of food is eaten by a consumer in the second trophic level?
    (b) What type of food is eaten by a consumer in the third trophic level?
9. Is it possible for an organism to belong to more than one trophic level? Explain, using an example and description.
10. In your notebook, sketch a food web containing at least six organisms. Write labels to represent the organisms. Complete the food web by connecting the organisms with arrows.
11. What is meant by the statement "nutrients cycle, but energy flows"?
12. Use the food web shown in Figure 7 to answer the following questions:
    (a) Which organisms are the top carnivores in this food web?
    (b) Which organisms are the producers in this food web?
    (c) If the population of grasshoppers was eliminated from the area, what organisms would lose one of their food sources?
    (d) Which organisms in the food web could be classified as primary consumers? Which organisms in the food web could be classified as secondary consumers?

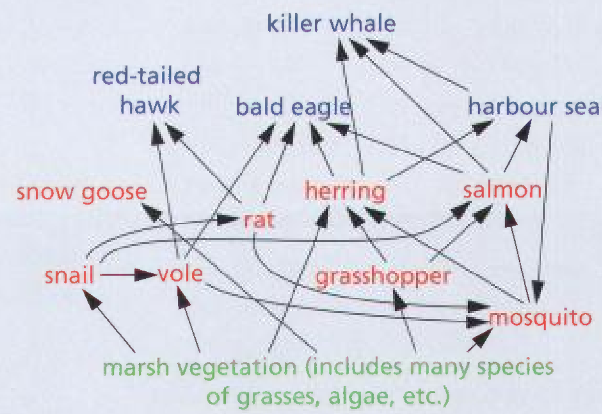


Figure 7

KELP-MART: THE BOUNTY OF A KELP FOREST

The biodiversity found in kelp forests is part of one of the most dynamic and productive ecosystems found anywhere in the biosphere.

The diversity of organisms that make kelp forests their home is impressive (Figure 1). These plant-like giants of the sea can grow as much as 30 cm each day. They prefer cold, nutrient-rich waters that form the base of one the most biologically productive and dynamic ecosystems on Earth and extend into both the Arctic and Antarctic circles. Foraging sea otters, frolicking in the tangles of long stipes of B.C. coastal kelp forests, are offered a diverse buffet of sea urchins, clams, and crabs. Found in shallow, open coastal waters worldwide, kelp forests not only provide a plentiful bounty for the ocean but also a staggering array of products useful to humans.

Brown seaweeds, such as those of kelp forests, produce substances called alginates. Alginates are classified as complex carbohydrates and possess a unique molecular structure that forms heat-stable, non-melting compounds. These compounds are ideal as food stabilizers and thickening agents to prolong the shelf life and increase the mass and volume of food products. Imagine runny ice cream or watery Ranch salad dressing. Without alginates, you would probably not experience mealtimes in the same way. In fact, you probably consume alginates daily because their use is so widespread in our food products.

Often labelled as sodium alginates, these food additives can be found in ice cream, soups, creamy liquids such as salad dressings, yogurt, relishes and sauces, and both frozen and dehydrated foods. Products of algae can also be found in cosmetics, antacid preparations, and paper and textile products.

So, the next time you make a trip to the grocery store, remember the extensive contribution of the kelp forests. Not only are they the producers in intricate ocean food webs, but they are also the source of key ingredients that give many of our manufactured food products the texture and appearance we expect and demand as discerning consumers.

Figure 1 Otters are not the only creatures that take advantage of the kelp forests!

2.5 Ecological Pyramids

Often, the pathway of energy through an ecosystem is illustrated by an **ecological pyramid**, also called a **food pyramid**. Ecologists use three basic types of pyramids: a pyramid of energy, a pyramid of numbers, and a pyramid of biomass.

Pyramid of Energy

A **pyramid of energy** is an ecological pyramid that uses blocks of different lengths to represent how much energy is available in each trophic level. The blocks are stacked one on top of the other, with producers on the bottom and carnivores on the top. The size of each layer represents the amount of energy present in that trophic level. Since the amount of energy available at each trophic level is less than the one below it, the diagram always has a pyramid shape (Figure 1), however, the size of the layers is not always proportional.

On average, only about 10 % of the energy present in one trophic level is passed on to the level above, as shown in Figure 1. Most of the energy at any level is used for basic life processes of the organisms at that level, such as movement, reproduction, and maintaining body temperature. Energy is also lost as heat at each trophic level, reducing the energy available to the next level even more. The low rate of energy transfer limits the number of trophic levels. Ecosystems rarely contain more than four levels because there is simply not enough energy in all the organisms at the top trophic level to support any more levels above them.

Did You KNOW?

Where Does the Energy Go?

The First Law of Thermodynamics states that energy cannot be created or destroyed but can only change from one form to another. The Second Law of Thermodynamics states that an energy transformation between two different forms is never 100 %. Some energy is always lost as heat in the process.

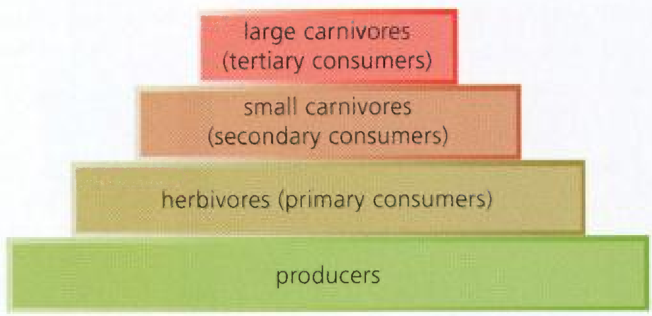


Figure 1 In a pyramid of energy, the amount of energy passing from one trophic level to the next is not always constant. The basic shape of the energy pyramid is constant however, and each level is always smaller than the one below it.

TRY THIS: *The Energy You Eat*

Skills Focus: recording, evaluating, analyzing, communicating

You can determine how much land was needed to produce the foods you eat.

Materials: notebook or graphic organizer

1. Record amounts of everything you eat in a 24-hour period. Determine how many kilojoules you ate from plant and from animal products, using an energy counter or by recording values from packaging.
2. To determine your annual energy intake, multiply your values by 365 days.
3. Determine how much land was needed by dividing the energy intake from plants by 8350 kJ/m^2, and dividing the energy intake from animals by 835 kJ/m^2.

A. Is it a more efficient use of land to eat plant or animal products? Explain.

B. What changes could people make to their diets in order to reduce the amount of land needed to make their food?

C. How might your average energy intake compare with people living in less developed regions of the world?

Pyramid of Numbers

A **pyramid of numbers** represents the actual number of organisms present in each trophic level. The shape of a pyramid of numbers varies widely depending on the physical size of the producers. For example, grasslands have very large numbers of small producers, while a forest of similar size might contain only a few large trees. A single tree might support thousands of small herbivores like insects. For a grassland community, a pyramid of numbers would have the typical shape (Figure 2). For a forest community, the producer level would likely be smaller than the herbivore layer above it (Figure 3). This distorted shape can be expected whenever a few large producers support large populations of small herbivores.

LEARNING TIP
Reinforce your understanding of pyramid of numbers and pyramid of biomass by examining Figures 2 to 4.

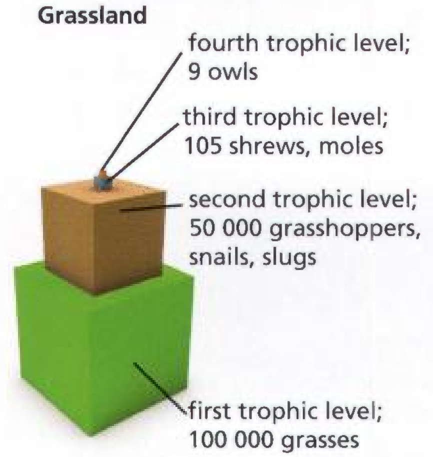


Figure 2 In a grassland community, there are fewer carnivores than herbivores and many more producers than herbivores.

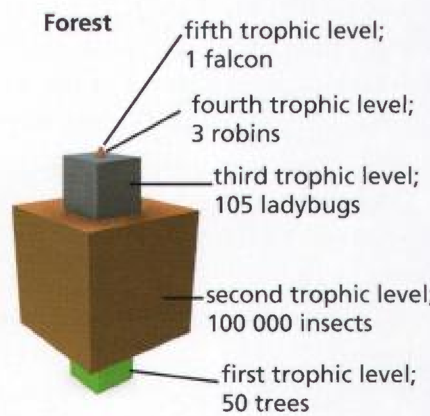


Figure 3 Pyramids of numbers are poor indicators of available energy. In a forest community, a single large organism such as a tree could be food for many small herbivores.

Pyramid of Biomass

Ecologists attempt to represent the total mass of the living things in each trophic level using a **pyramid of biomass.** These pyramids provide a snapshot in time of the mass at each trophic level in a community. In most communities, the pyramid of biomass has the standard pyramid shape (Figure 4), but sometimes the shape is inverted. This usually occurs in aquatic systems when a small biomass of producers, such as algae, supports a larger biomass of herbivores, such as fish. This is possible because the algae reproduce very quickly and are able to replace the biomass that is being consumed.

Figure 4 A typical pyramid of biomass

2.5 CHECK YOUR Understanding

1. Why are producers essential to a stable ecosystem?
2. List two factors that are responsible for the small percent of energy that passes from one trophic level to the next.
3. Why can more herbivores than carnivores live in equal-sized ecosystems?
4. On average, how much energy is available to organisms in the third trophic level if 5000 kJ were available at the first trophic level?
   A. 5 kJ
   B. 50 kJ
   C. 500 kJ
   D. 5000 kJ
5. Describe the effects of removing all of the herbivores from an ecosystem. Which organisms would be affected and how?
6. Explain why ecosystems usually contain only a few trophic levels.
7. Why do energy pyramids have the specific shape that they do?
8. Explain the similarities and differences between an ecological pyramid of energy, a pyramid of biomass, and a pyramid of numbers for a coniferous forest.
9. You have the option of choosing between a beef steak or a plate of beans and rice. Both meals provide you with 1000 kJ of energy. How will your choice affect the amount of energy required from the ecosystem?
10. Create a concept map that shows the path of energy in an ecosystem. Include the following terms in your diagram: herbivore, producer, carnivore, detrivore, trophic level, food web, food chain, and any additional terms you require.
11. Why does energy only flow in one general direction (from producer to consumer) in an ecosystem?
12. Which biome is most likely to have a pyramid of numbers that looks like Figure 5? Justify your answer.

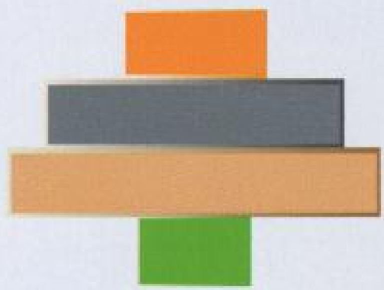


Figure 5

13. Draw two different energy pyramids for the food web in Figure 5 on page 36.
14. How might the shape of an energy pyramid differ throughout the year in a region that has a cold winter and a warm summer?
15. What types of organisms are able to make use of the energy that is not present in the top level of an energy pyramid?

2A Investigation

The Effect of Abiotic Factors on a Yeast Population

In this investigation, you will observe the effect of changes in abiotic factors on the growth of a yeast population. Yeast is a type of fungus and is often used in the production of bread.

INQUIRY SKILLS

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

Question

What are the optimal conditions for the growth of yeast?

Prediction

Predict what conditions of temperature, pH, and nutrient availability will be best for the growth of yeast.

Experimental Design

In this investigation, you will observe evidence of yeast growth under different experimental conditions. The population's cellular activity will be measured under different abiotic conditions.

Materials

- 8 large clean test tubes labelled #1–#8
- 25 mL graduated cylinder
- 3 600 mL beakers
- thermometer
- measuring spoons
- active dry yeast
- sugar
- vinegar (acid)
- ammonia solution (base)
- pH paper
- ice
- safety goggles

Acids and bases, even weak ones, can cause irritation to skin. If any acid or base solution is spilled, clean it up immediately. If any solution falls on skin, flush it well with running water. Report any instances to your teacher.

Procedure

Part 1: The Effect of Temperature on Yeast Respiration

1. Read through the Procedure and copy the tables to record your observations in each part. Remember to give your tables a title.
2. Put on your safety goggles. Prepare three separate water baths in the 600 mL beakers: one bath at 0 °C (containing ice water), one bath at 50 °C, and one bath near 100 °C.
3. Measure 2.5 mL of yeast and 2.5 mL of sugar into three separate test tubes labelled #1, #2, and #3. Add 10 mL of room-temperature water to each of the test tubes. Place one test tube into each of the three water baths.
4. Leave the test tubes in the water baths for 15 min. Record your observations in Table 1. While you are waiting, set up Part 2 of the Investigation.

Table 1

Test tube	Temperature	Observation
#1	0 °C	
#2	50 °C	
#3	100 °C	

Part 2: The Effect of pH on Yeast Respiration

5. Measure 2.5 mL of yeast and 2.5 mL of sugar into another set of test tubes labelled #4, #5, and #6. Add 10 mL of water to test tube #4. Add 10 mL of acid solution to test tube #5. Add 10 mL of base solution to test tube #6.
6. Use the pH paper to determine the approximate pH of each solution. Place all three test tubes in the 50 °C water bath.
7. Leave the test tubes in the water baths for 15 min. Record your observations in Table 2. While you are waiting, set up Part 3 of the Investigation.

Table 2

Test tube	pH	Observation
#4		
#5		
#6		

Part 3: The Effect of Nutrient Availability on Yeast Respiration

8. Measure 2.5 mL of yeast into two test tubes labelled #7 and #8. Add 2.5 mL sugar to test tube #7. Do not add any sugar to test tube #8. Add 10 mL of room-temperature water to each test tube. Place both test tubes in the 50 °C water bath.
9. Leave the test tubes in the water baths for 15 min. Record your observations in Table 3.

Table 3

Test tube	Nutrient	Observation
#7	Sugar present	
#8	Sugar absent	

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) What temperature was most suitable for the growth of yeast? Suggest a reason for this conclusion.

(b) What pH was the most suitable for the growth of yeast? Suggest a reason for this conclusion.

(c) What effect did the presence of sugar have on the rate of yeast growth?

Evaluation

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

(e) Why was it important that all of the materials added to each test tube were accurately measured?

(f) Three test tubes containing water and sugar were placed in the 50 °C water bath. Did they all produce the exact same result? Explain any differences.

(g) For each of the three parts of this experiment, list the independent variable.

(h) Describe what measures were taken to ensure that each part of this experiment was controlled.

Synthesis

(i) How does this investigation show that biotic and abiotic factors are interacting?

(j) List three additional abiotic factors that you think might affect the growth rate of yeast.

(k) How can an understanding of abiotic factors assist farmers in finding the best farming techniques?

(l) Use the term "limiting factor" to summarize the observed effects of temperature, pH, and nutrient availability in this investigation.

2B Investigation

Predator–Prey Simulation

Ecologists often use models and simulations to help understand natural processes. In this investigation, you will simulate a predator–prey relationship between two species: the great horned owl and the white-footed deer mouse (Figure 1).

Figure 1

Question

Can a predator–prey relationship effectively regulate the size of both species' populations?

Prediction

Predict what pattern will describe the changes in size of the predator and prey populations.

Experimental Design

In this investigation, you will use models of predators and prey to simulate the predator–prey cycle responsible for population regulation.

INQUIRY SKILLS

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

Materials

- metre stick
- 20 10 cm × 10 cm cardboard squares (predator)
- 200 3 cm × 3 cm paper squares (prey)
- masking tape
- graph paper
- 2 coloured pencils

Procedure

1. Use masking tape to mark out a 1 m × 1 m boundary on a flat tabletop or floor. You may also use a flat desktop.
2. Scatter five prey cards throughout the area. Hold a predator card at least 10 cm above the surface and drop it in the marked area, trying to capture as many prey as possible.
3. If the predator card touches at least three prey cards, remove those prey cards. They have been eaten.
4. If the predator card does not touch at least three prey cards, remove the predator card and leave the prey cards. The predator has starved.
5. If at any time the number of prey or predators drops to zero, replace them with five prey or one predator card as needed.
6. Copy Table 1 in your notebook. Leave room for additional rows, and give it a title. Record the number of surviving prey and surviving predators. This represents one generation. You will need to record 20 generations.
7. Double the population of surviving predators and surviving prey. They have reproduced.
8. Scatter enough prey cards to represent the new population of the area.

Table 1

Generation	Initial prey	Prey caught	Surviving prey	Initial predators	Surviving predators
1	5			1	
2					
3					
4					

9. Continue to repeat Steps 3 through 8 for a total of 20 generations.
10. Graph the number of prey and predators present at the beginning of each generation. Use a scale of 0–200 for prey and 0–20 for predators. Include this as part of your results.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Which population showed the first increase in size?

(b) Which population showed the first decrease in size?

(c) What maximum predator population was reached in your simulation?

(d) What maximum prey population was reached in your simulation?

Evaluation

(e) What factors limit the size of the owl (predator) population?

(f) What factors limit the size of the mouse (prey) population?

(g) Use the results of your simulation to describe the principle of time lag.

Synthesis

(h) Explain how your results might change if the area were larger or smaller.

(i) Copy the idealized predator–prey cycle shown in Figure 7 in your notebook. What aspects of your simulation would cause your predator–prey cycle to differ from the idealized model?

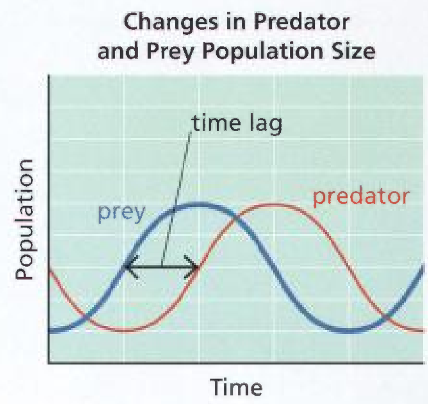


Figure 7

(j) What factors cause predator–prey cycles among actual populations to differ from the idealized predator–prey cycle?

(k) Explain how the owl population could be replenished even when all of the owls present have starved to death.

CHAPTER 2

Review

Interactions in Ecosystems

Key Ideas

Living things are connected to each other in complex interrelationships.

- Living things interact on several levels of organization: organism, population, community, ecosystem, and biosphere.
- A community of organisms and the non-living environment make up an ecosystem.
- Organisms can be producers, consumers, herbivores, carnivores, or decomposers in ecosystems.
- Predators and prey control each other's population size as they go through cycles in their relationship.
- Symbiosis describes complex relationships occurring between two species. The types of symbiotic relationships are mutualism, commensalism, and parasitism.

Biotic and abiotic factors are responsible for shaping a community of living things.

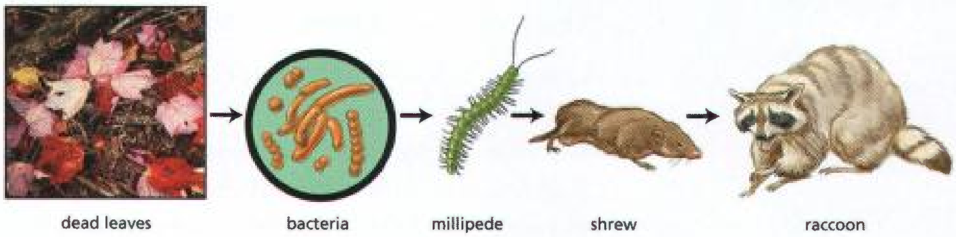
- Relationships between organisms and their environment include both living (biotic) and non-living (abiotic) components.
- Abiotic factors determine the types of organisms that can exist in a community and the characteristics of the environment.
- Biotic factors change continually in response to each other.

Vocabulary

ecology, p. 21
organism, p. 21
habitat, p. 21
population, p. 21
community, p. 22
ecosystem, p. 22
biosphere, p. 22
biotic factors, p. 22
abiotic factors, p. 22
dynamic equilibrium, p. 23
limiting factor, p. 23
nutrients, p. 25
producer, p. 25
autotroph, p. 25
consumer, p. 26
heterotroph, p. 26
herbivore, p. 26
primary consumer, p. 26
zooplankton, p. 26
carnivore, p. 26
omnivore, p. 26
detrivore, p. 27
decomposer, p. 27
biodegradation, p. 27
predation, p. 28
predator, p. 28
prey, p. 28
predator–prey cycle, p. 28
symbiosis, p. 30
mutualism, p. 30

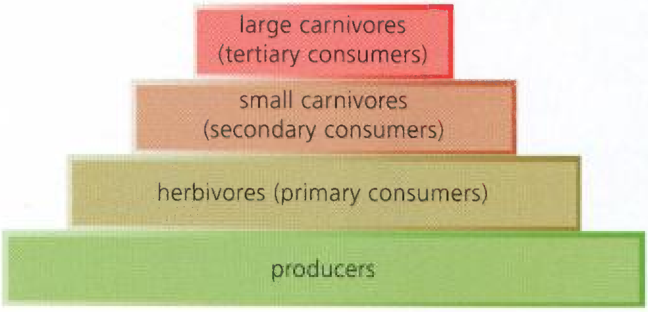
Nutrients cycle within ecosystems.

- Food chains and food webs show how nutrients cycle through ecosystems.
- Each type of organism is found at a trophic level in a food chain or web.
- Decomposers play an important role in recycling nutrients.



Energy flows through ecosystems.

- The primary source of energy for living things is the Sun.
- Producers are able to convert solar energy into a form that living things can use.
- Energy passes from producers to herbivores to carnivores.
- Most terrestrial ecosystems have only three or four trophic levels because energy transfer is inefficient.
- Only about 10 % of the energy at one trophic level is transferred to the next trophic level.



commensalism, p. 30
parasitism, p. 30
host, p. 30
parasite, p. 30
trophic level, p. 33
food chain, p. 34
food web, p. 36
ecological pyramid, p. 39
food pyramid, p. 39
pyramid of energy, p. 39
pyramid of numbers, p. 40
pyramid of biomass, p. 40

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

1. Match the term on the left with the correct definition on the right.

Term	Definition
(a) biosphere	I. A community as well as the physical environment
(b) community	II. All of the ecosystems on Earth
(c) ecology	III. All of the individual populations in a particular area
(d) ecosystem	IV. All of the organisms of one type that inhabit a particular area
(e) habitat	V. An individual life form of one specific type
(f) organism	VI. The place where an organism or population lives
(g) population	VII. The study of the interactions between organisms and between their environment

2. Explain the term "interconnectedness" as it applies to ecology.
3. Identify each of the following as a population, community, or ecosystem:
   (a) a pod of killer whales
   (b) a pack of wolves in a forest
   (c) all of the living and non-living things in a pond
   (d) all of the organisms living in a decomposing log
4. List five abiotic factors that affect life in terrestrial ecosystems.
5. Describe five ecosystems of differing size.
6. What is the relationship between the first trophic level and a primary consumer?

K 7. Which of the following terms does *not* represent a level within the biosphere that is studied by ecologists?
   A. cell
   B. ecosystem
   C. population
   D. community

K 8. Which of the following processes could produce the energy necessary to support a community of organisms in a deep cave in the total absence of sunlight?
   A. photosynthesis
   B. biodegradation
   C. decomposition
   D. chemosynthesis

Use What You've Learned

9. A student conducts an experiment to measure the effects of pH on the growth of bread mould (*Rhizopus nigricans*). The student moistened slices of bread with solutions of three different pH levels. The bread slices were incubated at a constant temperature and observed for a period of three days as recorded in Table 1.

Table 1

Day	Number of mould colonies		
	pH = 4.0	pH = 6.0	pH = 8.0
Start	0	0	0
1	0	7	1
2	1	15	3
3	2	27	3

   (a) Graph the results of the experiment using three line graphs on the same set of axes.
   (b) To which pH is the bread mould best adapted?
   (c) What was the purpose of keeping the temperature constant throughout the experiment?
   (d) List three other factors that must be kept constant in order to ensure that the experimental results are valid.
   (e) List three other abiotic factors that might affect the growth of bread mould.
   (f) What would be an appropriate control for this experiment?

10. Which of the following lists includes only abiotic factors?
    A. pH, height of trees, water temperature
    B. temperature, annual precipitation, rock type
    C. solar radiation, nutrient availability, number of decomposers
    D. salt concentration, stream flow rate, migration pattern of reindeer
11. Which of the following characteristics distinguishes decomposers from other consumers?
    A. the ability to produce food
    B. their position within a grazing food chain
    C. the tendency to gain nutrition from dead organisms
    D. the ability to chemically break down organic compounds
12. Name and define four different categories of consumers. Give two examples of each.

Think Critically

13. A scientist is interested in creating a conservation strategy at the ecosystem level. Which of the following would she have to consider for her strategy to be at the correct level?
    A. all regions of Earth where life exists
    B. all members of all of the species in an area
    C. all members of a single species in an area
    D. all living and non-living things in an area
14. What type of food do organisms in the second trophic level eat? What type of food do organisms in the third trophic level eat?
15. Explain how changes in abiotic factors can influence the types of communities that develop in an area.
16. List three different abiotic factors and describe a way in which each of them has had a direct impact on your day so far.
17. Use the food chain shown in Figure 1 to answer the questions.

tree → beetle → spider → mouse → hawk

Figure 1

    (a) What level of the biosphere is represented by the food chain?
    (b) Which of the organisms in the food chain is an autotroph?
    (c) Which of the organisms would belong to a population with the least biomass?
    (d) Which level contains the least energy?
18. Use your knowledge of ecological pyramids to construct an energy pyramid, biomass pyramid, and numbers pyramid for the food chain shown in Figure 1.
19. A wolf that eats an elk cannot digest the antlers, hooves, teeth, hair, and bones. What do these materials represent?
    A. matter available to omnivores
    B. energy available to herbivores
    C. energy not available to carnivores
    D. matter not available to decomposers
20. What effect would spraying insecticides to kill beetles have on the size of a hawk population in the food chain shown in Figure 1? Explain your reasoning.

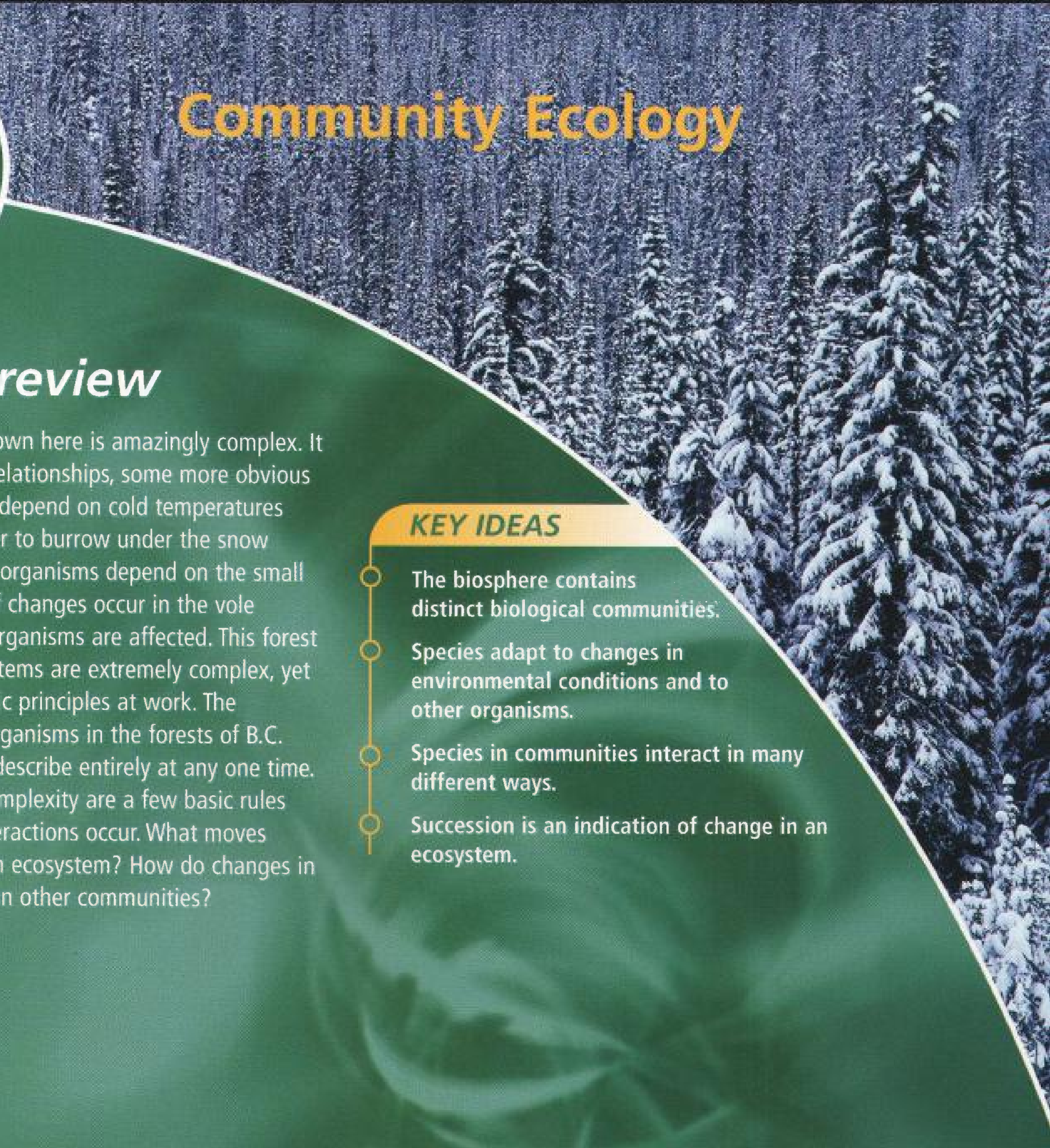
Reflect on Your Learning

21. Scientists study many different ecosystems. Some are small and some are large. Explain how a puddle and a mountain range are both valid ecosystems. What are the similarities and what are the differences between these ecosystems?

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

CHAPTER 3

Community Ecology



Chapter Preview

The forest ecosystem shown here is amazingly complex. It is a vast community of relationships, some more obvious than others. Small voles depend on cold temperatures and precipitation in order to burrow under the snow during the winter. Other organisms depend on the small voles as a food source. If changes occur in the vole populations, the larger organisms are affected. This forest system and other ecosystems are extremely complex, yet there are only a few basic principles at work. The relationships between organisms in the forests of B.C. would be impossible to describe entirely at any one time. Yet at the root of this complexity are a few basic rules that govern how the interactions occur. What moves between organisms in an ecosystem? How do changes in one community impact on other communities?

KEY IDEAS

- The biosphere contains distinct biological communities.
- Species adapt to changes in environmental conditions and to other organisms.
- Species in communities interact in many different ways.
- Succession is an indication of change in an ecosystem.

TRY THIS: *Modelling Interactions in an Ecosystem*

Skills Focus: predicting, analyzing, communicating

In this activity, you will try to model the relationships that exist within an ecosystem. You will then be able to appreciate how a single change can impact the entire system.

Materials: Ball of string or yarn, index cards from your teacher (1 for each member of your group)

1. Your teacher will provide your group with cards representing organisms. As a group, suggest relationships that may exist among the organisms.
2. Model these relationships by passing the ball of yarn between students holding the cards representing related organisms until each organism is connected.
3. Model an organism leaving the area or dying by letting go of the connecting string.

A. In what ways was a single disturbance able to impact the entire community?

B. Consider an organism that is connected to a large number of organisms. How would a disturbance of this population compare to a disturbance in a population with fewer connections?

3.1 The Distribution of Organisms in the Biosphere

Organisms are specialized for different living conditions in the biosphere. At its most basic level, the distribution of life in the biosphere is largely determined by two factors: average temperature and average precipitation (Figure 1). The long-term pattern of temperature and precipitation is called **climate.** These long-term weather patterns are largely affected by location on Earth. Particularly important are **latitude** (the distance from the equator), and **elevation** (height above sea level) as shown in Figure 2, and distance from a body of water. The abiotic factors that tend to differ by location and influence global climate patterns are amount of solar energy, wind patterns, and ocean currents. You will learn more about these factors in Unit E.

LEARNING TIP

You will notice that Chapter 3 includes many new terms. These are words that you need to know. To get a head start on your studying, make vocabulary cards. On one side of the card, write the word, and on the other side, write a brief definition.

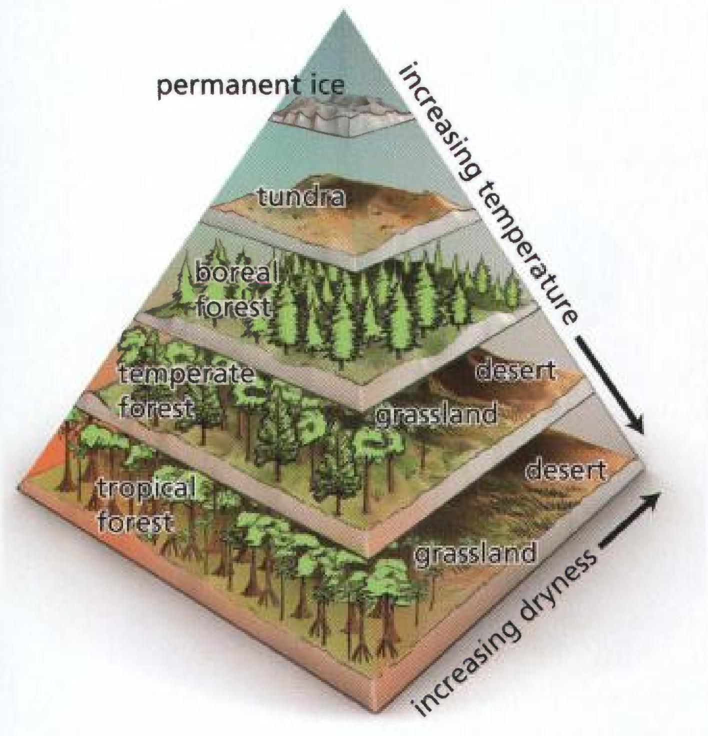


Figure 1 Variations in temperature and precipitation create different plant communities with distinct characteristics.

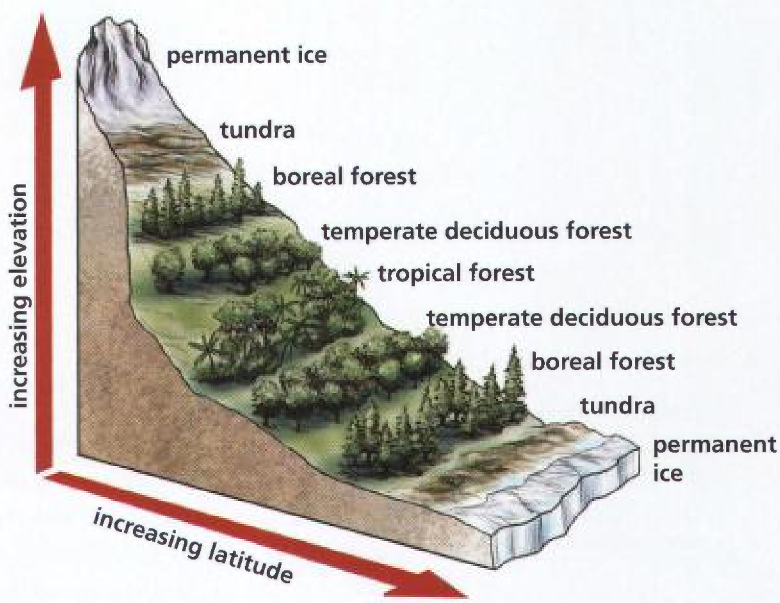


Figure 2 Changes in both latitude and elevation are responsible for establishing ecosystems with distinct vegetation.

Factors Affecting Abiotic Conditions

Solar energy

Solar energy is responsible for determining average temperature at various locations on Earth. In the region near the equator, the Sun's rays hit Earth directly, creating a climate with a higher average temperature than at Earth's poles. The solar energy is less intense at the Earth's poles because it is

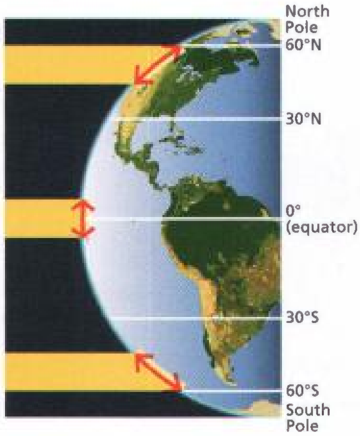


Figure 3 Earth is a sphere, so solar energy striking Earth near the polar regions is spread over a greater area than a similar amount of energy striking Earth near the equator.

striking a greater amount of surface area (Figure 3). Similar changes in temperature are seen with changing elevation, where there is a marked decrease in the temperature with increased elevation. As a result, the same climate changes that occur with increasing latitude can occur with increasing elevation.

Earth is tilted on its axis, which affects the seasonal temperatures in many regions. On Earth's annual journey around the Sun, the northern and southern regions of the globe spend part of the year tilted toward and part of the year tilted away from the Sun. For example, during the northern hemisphere's winter period, Earth is tilted away from the Sun. This creates noticeable variation in temperature and precipitation throughout the year. In tropical regions, there are no noticeable seasonal changes since the region is continually exposed to the direct solar rays of the Sun (Figure 4).

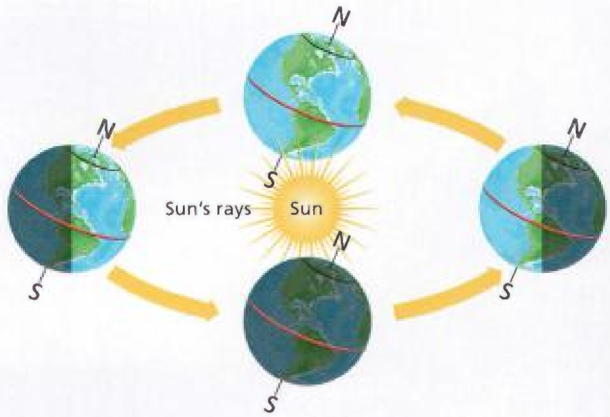


Figure 4 The tilt of Earth creates warm and cold seasons in most regions on Earth.

Learn more about the world's major climate zones and ocean currents, and test your knowledge, at **www.science.nelson.com**

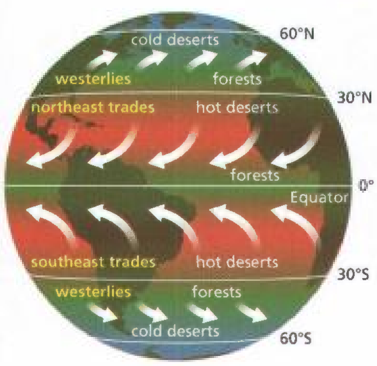


Figure 5 The location of warm and cold air masses cause global wind systems that are responsible for climate condition.

Winds and Currents

The movements of warm and cold air masses create winds (Figure 5). As air masses move from warm regions near the equator to cold regions near the poles, they cause wind patterns that affect the climate.

Wind patterns drive the movement of ocean currents, which in turn are involved in circulating heat. The ocean has a greater heat capacity than land, so it absorbs solar energy and releases it at a slower rate than land does. The movement of large bodies of water in currents and the release of energy from them affects the climate of nearby regions. Airflow is disrupted where oceans meet continents (Figure 6). Warm, moist air from over the ocean rises over coastal mountains and cools, releasing large amounts of precipitation. On the far side of the mountain range, a rain shadow exists where dry mountain air warms as it descends and releases very little moisture.

You will learn more about global patterns of wind and water in Chapter 15.

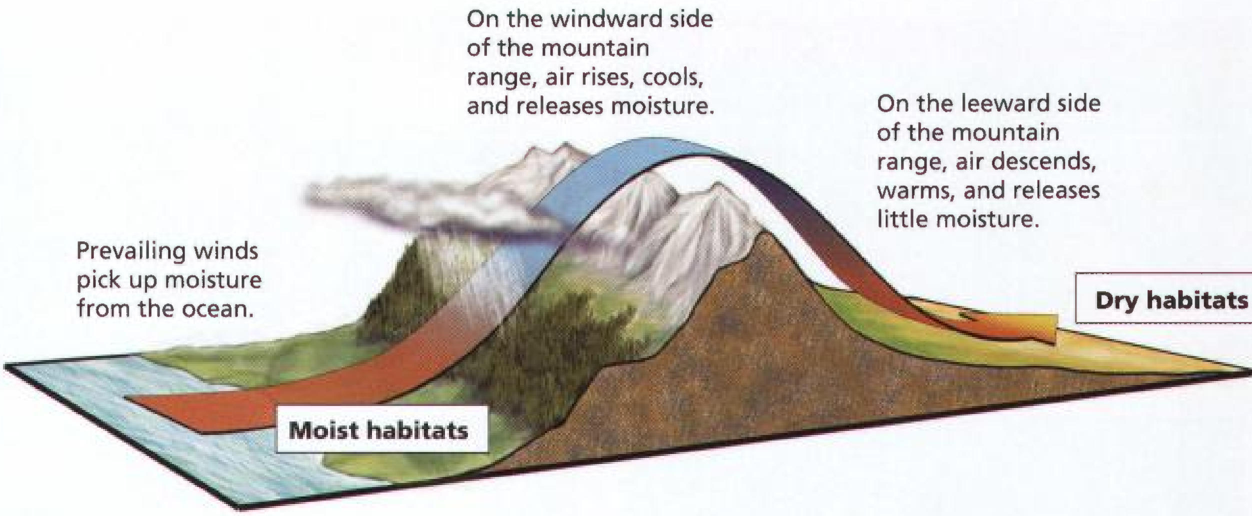


Figure 6 Warm, moist air rises and cools near mountain ranges. Most precipitation falls before the air passes over the mountain.

Precipitation and temperature are the abiotic factors that seem to be the most influential in determining the characteristics of the plant and animal communities within an ecosystem. The long-term climatic trends in precipitation and temperature are described using climatographs. A **climatograph** is a graphical way to show the monthly changes in temperature and precipitation throughout a year (Figure 7). You will explore climatographs further in Investigation 3A. 3A *Investigation*

3A *Investigation*

Working with Climatographs

To perform this investigation, turn to page 74.

In this investigation, you will analyze climatographs and determine the characteristic conditions that they represent.

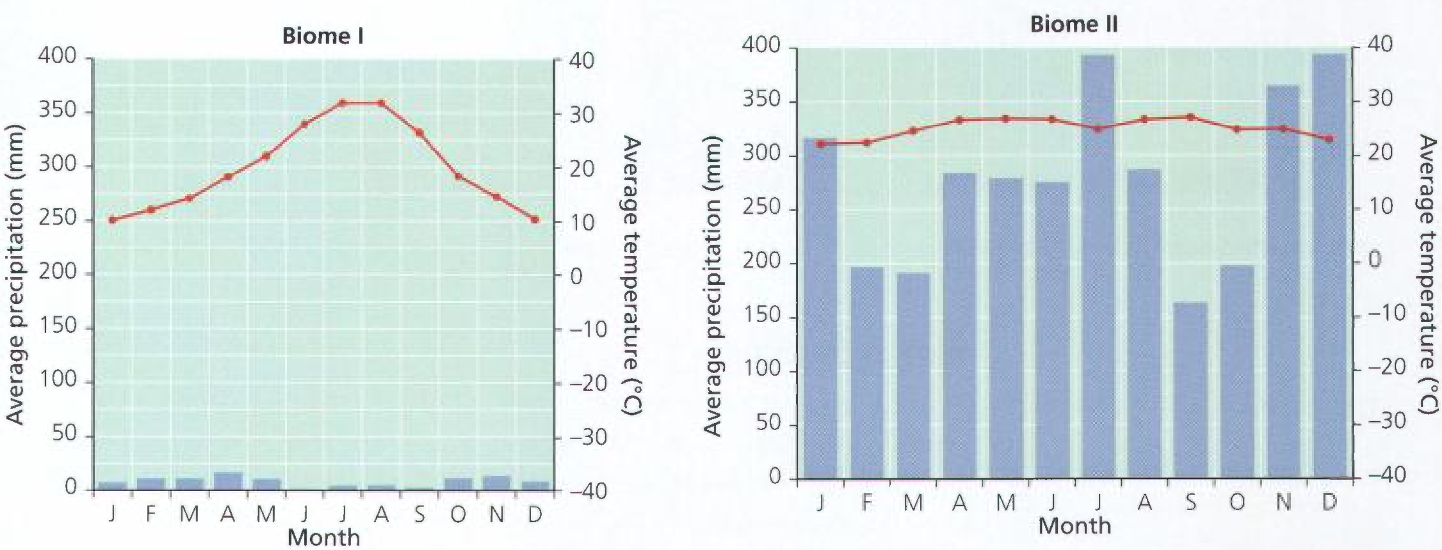


Figure 7 The two climatographs represent two very different ecosystems. Can you figure out which one is a desert and which is a tropical rainforest?

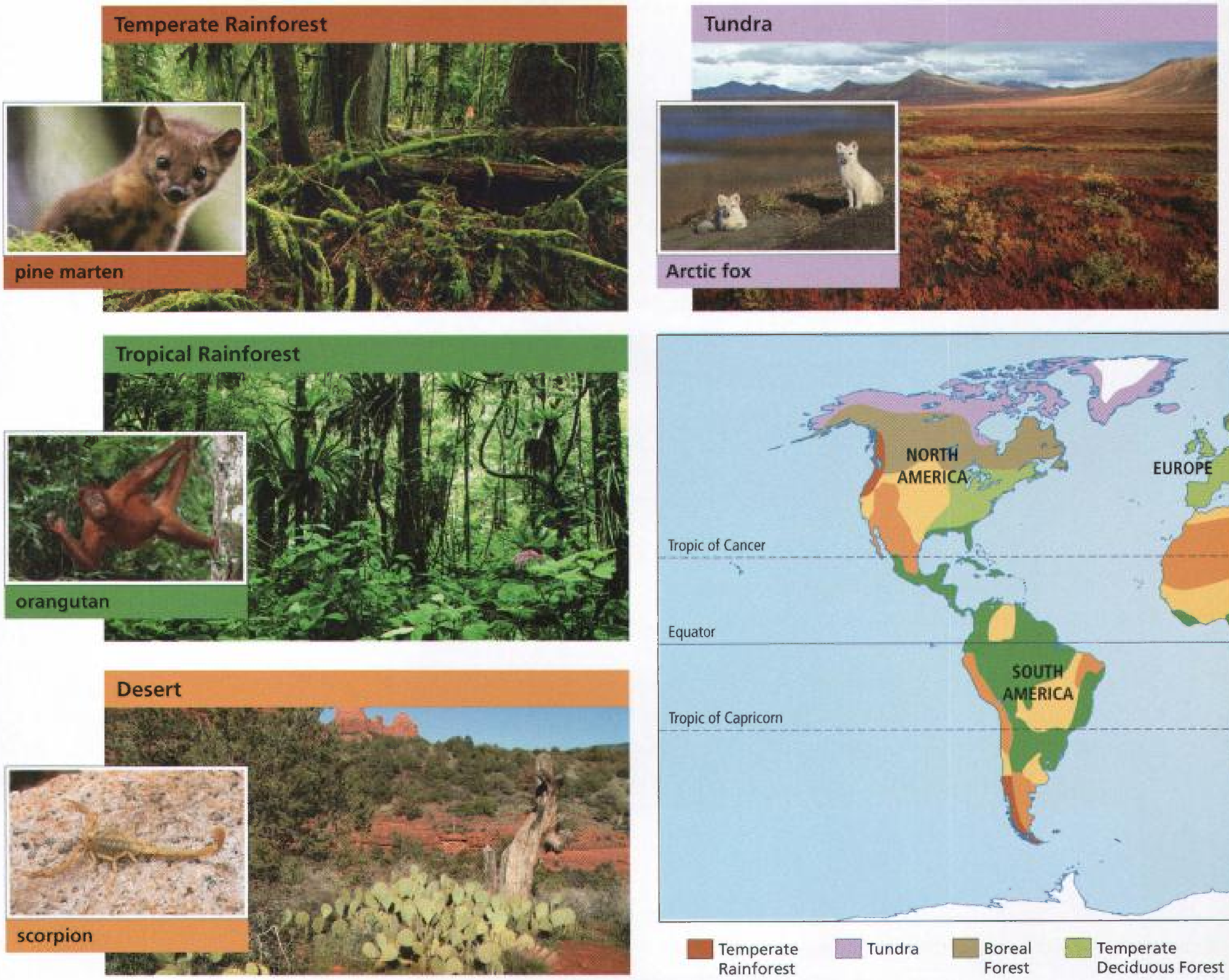


Figure 8 The distribution of Earth's major biomes indicate locations where abiotic factors are similar, resulting in similar biotic communities.

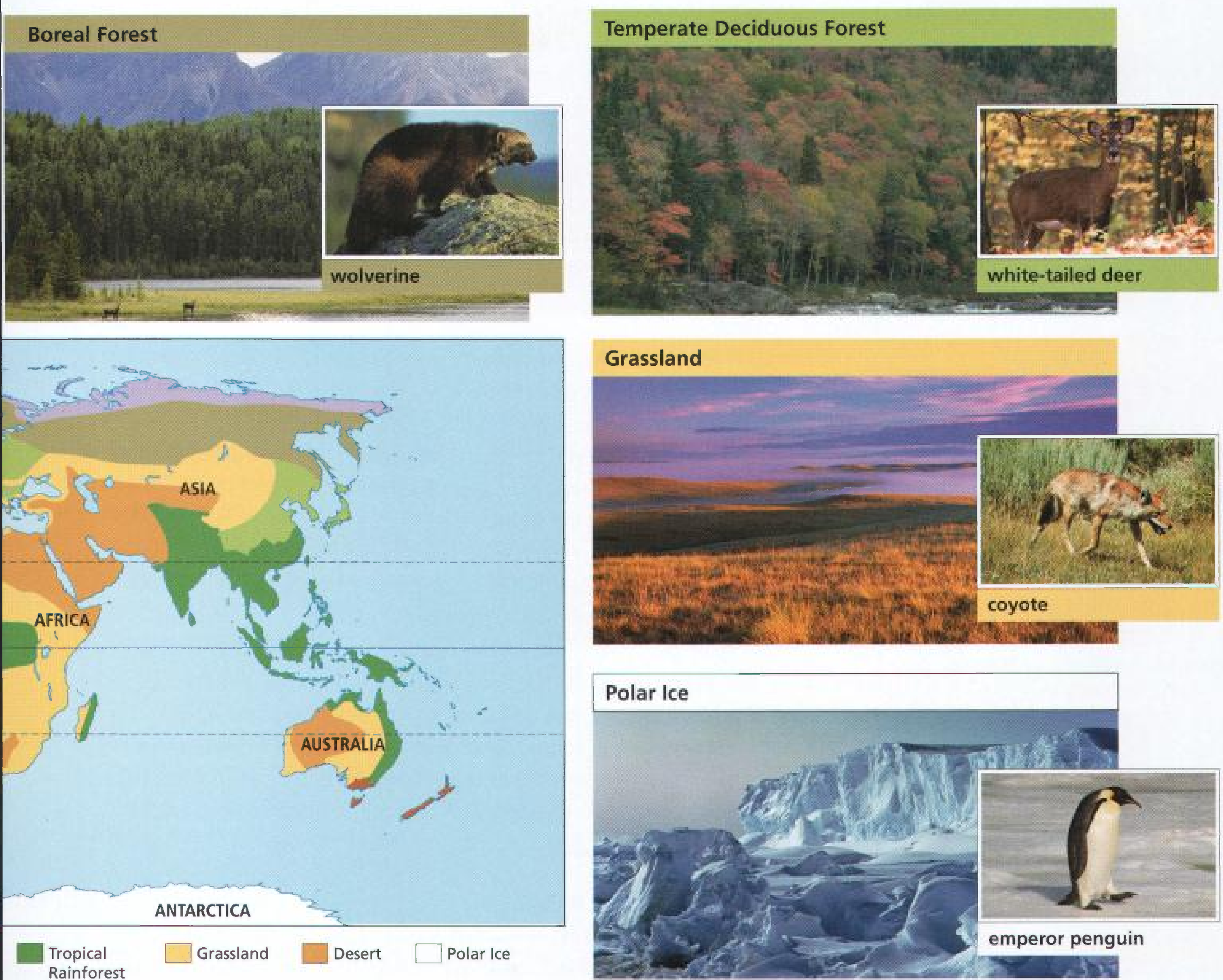
World Biomes

STUDY TIP

Making study cards is important for learning and remembering. To help you remember the information in the World Biomes section, make a study card for each biome. Include a description and examples of the species that live in each biome.

In some areas on Earth, abiotic factors are similar and create similar yet distinct ecosystems in different geographical locations. If you were to travel across Canada or visit other countries of the world, you would see some of these different environments. You would also notice an important pattern: similar organisms live in different locations that have similar environmental conditions. Each of these large terrestrial ecosystems that have similar environments and exist over a wide area is called a **biome**. There is much less variation within a biome than there is between two different biomes.

The region between two neighbouring biomes is usually a transition zone where one form of plant life might slowly give way to another form. There is some disagreement about the actual number and boundaries of the world



biomes because the lines between biomes are not always distinct. This section introduces eight terrestrial biomes: the tundra, boreal forest, temperate deciduous forest, temperate rainforest, grassland, tropical rainforest, desert, and polar ice (Figure 8).

To learn more about Earth's major biomes, view the animation found at **www.science.nelson.com**

Tundra

The **tundra** is a massive biome that extends in a continuous belt across Canada, Alaska, Asia, and Europe. There is very little precipitation, usually less than 25 cm per year. **Permafrost**, a layer of permanently frozen soil, is usually present within a metre of the surface. Small, slow-growing plants such as grasses and mosses survive in the harsh conditions, and reindeer lichen, which can grow on bare rock and absorb water without the use of roots, carpets the northern-most regions of the tundra (Figure 9). The growing season is limited to a brief period of about 8 weeks during the summer, preventing any significant tree growth.

Caribou, musk oxen, arctic foxes, arctic ground squirrels, collared lemmings, and ptarmigan survive and even thrive in the harsh climate. The summer thaw creates temporary ponds and bogs that support swarms of mosquitoes and black flies. Insect-eating birds as well as snow geese and tundra swans arrive for the summer, and predatory birds like the peregrine falcon and snowy owls find abundant food as the number of small mammals grows quickly.

Figure 9 Tuktut Nogait National Park in Northwest Territories illustrates the unique landscape of the tundra biome.

Boreal Forest

To the south of the tundra lies the **boreal forest** biome, also known as taiga. It forms a great circle around the northern reaches of the globe, stretching across North America, Asia, and northern Europe (Figure 10). It covers more than half of the land surface of Canada and is present in every province and territory. There is more moisture each year than in the tundra (35–75 cm), but the air is very dry during the winter.

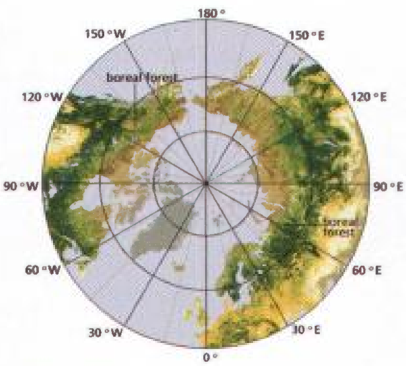


Figure 10 The world's boreal forests encircle the northern part of Earth.

Conifers (cone-bearing evergreen trees like pines, spruces, and firs) dominate this biome, and they limit the number of other species that can thrive in the boreal forest. The trees form a dense **canopy**, or cover, that prevents most sunlight from reaching the forest floor, and the soil itself is quite acidic due to the decay of fallen needles. Just a few bird and animal species can survive by eating only the conifer cones, needles, and buds. Other herbivores such as elk, moose, and deer also forage on the plants of the forest floor to get the added nutrition they require. Carnivores such as wolves, bears, lynxes, and wolverines, which live in the boreal forest, feed on small rodents and birds.

To explore the boreal forest in more depth, go to **www.science.nelson.com**

Temperate Deciduous Forest

The **temperate deciduous forest** is located south of the boreal forest, covering regions in southeastern Canada, the eastern United States, and large areas of Europe and Asia. Higher temperatures and abundant growing season rain (75–220 cm per year) support the growth of huge forests of broadleaf trees like birches, poplars, oaks, and maples. Fallen leaves and other organic matter quickly decompose, creating a richer soil than that of the boreal forest. During the early spring, flowers, small trees, shrubs, and ferns grow in the **understorey** beneath the canopy of larger trees. This is the best opportunity for them to grow rapidly before the forest canopy becomes too thick (Figure 11).

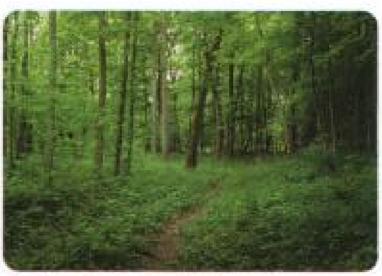


Figure 11 Broadleaf deciduous forests grow rapidly during warmer months and lose their leaves each fall.

The rich soil of the forest floor provides an ideal environment for many different insects that become food for many predators, including amphibians, reptiles, birds, and small mammals. Other herbivores, such as deer, feed on the abundant forest vegetation in the understorey, while larger predators, such as wolves, eat a wide selection of prey. The forest canopy provides food and shelter for many species of birds and mammals.

Temperate Rainforest

Temperate rainforests are among the most rare of the world's biomes. Significant areas of temperate rainforest are found only in British Columbia, New Zealand, and Chile. Coastal mountains cause moist ocean air to rise and cool, dropping between 200 cm and 350 cm of precipitation each year. The abundant moisture and mild climate cause material to decay rapidly on the forest floor, which supports the growth of shrubs and small trees (Figure 12). Many plants of the forest floor produce fruits such as huckleberries and blackberries, which provide a nutritional food source for small herbivores and larger omnivores. The thick, rich soil littered with decaying matter also provides food and shelter for many kinds of insects, supporting mammals such as shrews and voles, as well as many amphibians and birds. Small predators including weasels, raccoons, and owls feed on small mammals and birds, while larger predators like wolves, bears, and cougars are able to capture larger herbivores like deer or elk. Other large mammals, such as the spirit bear (Figure 13), can be found in the temperate rain forest.

Did You KNOW?

The Link to a Watery World

Salmon are often considered part of the temperate rainforest biome. They are closely linked to the forest through the insects and bears that live there. Once they spawn and die, the materials contained in their bodies move through the detritus food chain and provide nutrients that support the growth of these rich forests.

Figure 12 Nurse logs are common in the temperate rainforest. They provide nutrients for new growth as the fallen tree decays.

Figure 13 The Kermode, or "spirit bear," is a sub-species of black bears that inhabit some areas of the coastal temperate rainforest of British Columbia.

Grassland

In the **grassland** biome, rainfall is generally between 25 cm and 75 cm per year, insufficient to support the growth of trees. Grasses are able to grow quickly, however, because they penetrate deeply into the fertile soil. Of all the biomes, tropical grasslands called **savannas** support the greatest number and variety of large herbivores. These include elephants, giraffes, and rhinoceros. Much of the world's grasslands, including those of Canada and the tropical grasslands in Africa, have been converted into farmland and pastureland. In Canada and the United States only small, undisturbed patches of natural grassland remain. Small mammals including rabbits, mice, and ground squirrels dig burrows in which to avoid predators such as hawks, snakes, coyotes, badgers, and foxes. GO

To learn more about the grassland biome, go to www.science.nelson.com GO

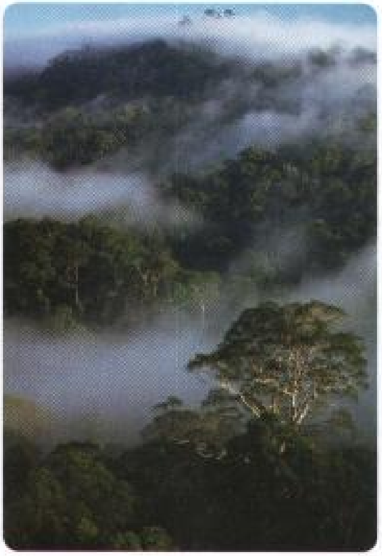


Figure 14 Tall, broad-leaved trees form a dense, leafy canopy in a tropical rainforest.

Figure 15 At over 9 000 000 km^2, the Sahara Desert is the largest in the world.

Tropical Rainforest

Tropical rainforests receive between 200 cm and 450 cm of rainfall annually, and temperatures remain between 20 °C and 35 °C throughout the year. The tropical rainforest is believed to contain at least half of Earth's terrestrial organisms. A 10 km^2 region of tropical rainforest may contain 750 species of trees! Just one of these trees could support several thousand insect species (Figure 14).

Most of the nutrients in the tropical rainforest are contained in the plants and animals themselves. The roots of enormous trees spread in the top few centimetres of soil, as it is relatively thin and infertile.

Desert

The **deserts** of North Africa, central Australia, southwestern North America, eastern Asia, and the southeast tip of South America receive less than 25 cm of precipitation each year (Figure 15). The vegetation of the desert is usually sparse and made up of small plants specialized to conserve water. Leaves are generally small and covered with a waxy layer to slow down evaporation. Some, such as cacti, store water in their fleshy tissues.

Animals, as well, are adapted to eliminate excess heat and conserve water. Most are nocturnal and are active only during the cooler nights, hiding in burrows during the day. Often the animals have large ears to improve heat loss.

Polar Ice

The most obvious feature of **polar ice** biome is the presence of permanent ice and the absence of significant terrestrial vegetation. Some microscopic algae may grow briefly on the ice and snow, but no significant plant growth exists. Herbivores are essentially non-existent on the polar ice.

In the Arctic, highly specialized predators like the polar bear are able to take advantage of the diverse marine ecosystem that lies beneath the ice (Figure 16).

The continental margins of the Antarctic ice sheet support large colonies of fish-eating sea birds such as penguins and cormorants. Some species, such as the skua, feed on the eggs or chicks of other sea birds, but like the Arctic, most life exists beneath the ice in the ocean.

Figure 16 The polar bear is one of the very few terrestrial predators living on the ice of the Arctic.

Did You KNOW?

Polar Politics

In 1925, Canada laid claim to the North Pole, and the claim has been generally undisputed. Receding polar ice has now brought renewed interest from other nations, specifically Norway, Denmark, Russia, Greenland, and the United States. Why all the interest in an isolated sheet of floating ice? The North Pole could provide easy access to huge petroleum and natural gas deposits on the ocean floor. As ice melts and shipping routes open up, the lower cost of removal will make drilling there more profitable.

Biogeoclimatic Zones of British Columbia

You have the privilege of living in Canada's most ecologically diverse province. It covers 95 million hectares of extreme landscapes. Some of Canada's wettest and driest, warmest and coldest locations, including rainforest, grassland, and desert, all exist within our borders. With this diversity come many challenges and issues related to managing and enjoying the rich resources of our province. The standard classification used for world biomes is not adequate to describe the variety of ecosystems present in British Columbia.

Beginning in the 1970s, scientists have collected data from 30 000 different study sites around the province. This data has been combined into the Biogeoclimatic Ecosystem Classification (BEC) system describing fourteen distinct ecological zones in the province. Nowhere else in the world is a more detailed level of ecosystem classification in use! The name of the system is derived from the three areas that are considered in describing the zones: plants (bio), landforms (geo), and climate (climatic). These characteristics are used to describe the ecological diversity of the province, a useful tool in managing natural resources and maintaining ecological diversity in British Columbia. Each biogeoclimatic zone has a characteristic climax community containing a predominant type of vegetation. Many of the fourteen zones are named in consideration of the dominant trees within them, such as the sub-boreal pine–spruce, spruce–willow–birch, mountain hemlock, Engelmann spruce–subalpine fir, and ponderosa pine zones. GO

Did You KNOW?

B.C. Deserts

British Columbia has a small pocket desert. The region surrounding Osoyoos is home to one of North America's most fragile and endangered ecosystems. Over 100 rare plants and over 300 invertebrates are among the at-risk species that live in this dry landscape.

www.science.nelson.com GO

To learn more about the biogeoclimatic zones of British Columbia, go to

www.science.nelson.com GO

TRY THIS: A Creature Feature

Skills Focus: questioning, communicating, analyzing

The different biomes of the world present specific challenges to the organisms that live within them. Stresses might be environmental factors such as temperature, lack of water, or flooding, but might also include competition for resources like food and living space. Animals living in each area could not survive without the special adaptations that help them survive.

Materials: common materials of your choice

1. Select one of Canada's biomes and design an organism that would survive the environmental stresses that are present. You can use common everyday materials to build your creature.
2. While you are designing the creature, consider the following questions:
    - What challenges does your organism face, living in the biome you chose?
    - What does it eat?
    - How is its mouth specialized for this kind of food?
    - How does it move?
    - What kind of limbs does it have (arms, legs, flippers, gills, wings, tail)?
    - How is it specialized to move around in its environment?
    - What kind of body covering does it have that makes it well suited for living in its environment?
    - What other special features does it have for surviving?

A. Share your creatures with the rest of your class.

B. Highlight the specializations your creature has for the biome you chose, including finding food, eating, and avoiding other organisms.

C. What threats exist to your biome? How would your creature adjust to these as well as human-made changes? Would this creature disappear or would it be able to survive?

3.1 CHECK YOUR Understanding

1. What two environmental conditions are largely responsible for the distribution of life on Earth?
2. What three characteristics of location have an impact on climate?
3. Contrast weather and climate.
4. How are the effects of increasing elevation and increasing latitude similar?
5. What is the difference between an ecosystem and a biome?
6. Which of the following biomes would be expected to have the greatest number of producers?
   A. tundra
   B. desert
   C. polar ice
   D. grassland
7. What factors are responsible for making the soil in grasslands more fertile than the soil in boreal forests?
8. For each of the following, indicate which of the world biomes is being described:
   (a) highest annual precipitation
   (b) lowest average temperature
   (c) fewest number of herbivores
   (d) most consistent annual temperature
   (e) forest with the shortest growing season
9. Why is climate considered the dominant factor in determining the composition of an ecosystem?
10. Which biome is found in the region between the polar ice and boreal forest biomes?
11. Why would it be unusual to find a tree in the tundra?
12. Which of the following is a characteristic of the tundra biome?
    A. permafrost layer
    B. deciduous forests
    C. high plant growth
    D. annual rainfall in excess of 120 cm per year
13. Provide two similarities and two differences between each of the following:
    (a) desert and tundra
    (b) climate and biome
    (c) tropical rainforest and temperate rainforest
    (d) boreal forest and temperate deciduous forest
14. Rank the six biomes found in Canada in descending order according to each of the following abiotic factors:
    (a) amount of annual precipitation
    (b) average annual temperature
    (c) length of growing season
15. Which of the following is the best explanation for seasonal change?
    A. the daily rotation of Earth on its axis
    B. the tilt of Earth as it orbits around the Sun
    C. warm, moist air falling near the equator
    D. circulation of ocean currents
16. Which of the following is responsible for the presence of temperate rainforests along the coastline of B.C.?

I	proximity to the ocean
II	presence of a stable cold air mass
III	presence of a coastal mountain range

    A. I and II only
    B. I and III only
    C. II and III only
    D. I, II, and III
17. Explain why it is important for B.C. to subdivide its biomes into biogeoclimatic zones.

3.2 Adapting to the Environment

Organisms do not live in isolation. Some interactions between organisms are obvious, like the dependence of an organism on a food source, but other interactions are more subtle and require a closer look. In this section, we will look in more detail at the ways that organisms interact.

LEARNING TIP
Preview Section 3.2 to note headings, words in bold, and graphics. Ask yourself, "What is this section about? How is it organized?"

When faced with a change in the biotic or abiotic conditions in an ecosystem, a population will adapt to the changes, leave the area, or die out. An **adaptation** is any genetic trait that improves an organism's chance of surviving and reproducing. Certain individuals will be able to survive changes in conditions better than others. **Natural selection** is a process that favours the survival of organisms with traits that make them better adapted to the environment. At the same time, natural selection tends to eliminate those individuals that are poorly adapted.

Individuals in a population may be adapted to survive a change in the environment, but it is important to realize that they were this way before the change occurred. If the organism does not have the necessary traits to adapt to the change, it will die. If more organisms with a specific characteristic survive and reproduce, then those traits become more common in the population. For example, big brown bats used to depend on trees as roosts in order to survive. Urban development for human housing has reduced the number of roost trees, but many individual big brown bats were well adapted to roosting in human structures instead of trees (Figure 1). Populations of big brown bats have increased, and in fact, many big brown bats now need human structures for roosting! So, while natural selection acts on the individual organism, it is the population as a whole that changes as a result. Individuals with characteristics that give them an advantage over other organisms manage to survive. If the characteristics are genetic, the individual may pass the trait on to its offspring.

Figure 1 Populations of big brown bats have increased after they switched to roosting in human-made structures.

Natural selection does not occur only because of abiotic factors. Predator–prey interactions are also a strong selective force. Natural selection favours adaptations that improve the ability of predators to find, capture, and consume prey. Characteristics that help predators catch prey include being faster and stronger than the prey, such as when hawks and lynx prey upon rodents and other small animals (Figure 2).

Figure 2 This hawk is highly adapted to capture this prey.

Other adaptations for predators include colouration or body shapes that provide camouflage (Figure 3). This adaptation can be quite effective and requires very little energy from the predator, since an exhausting chase is not required. GO

To learn more about camouflage in nature, go to **www.science.nelson.com** GO

Figure 3 The colouration of this fox makes it difficult for its prey to see it against the snowy background.

TRY THIS: Surviving Predation

Skills Focus: predicting, observing, measuring, recording, reporting

Materials: 40 coloured toothpicks (10 of each colour: red, green, yellow, blue), large plastic hoop, stopwatch

1. Place the plastic hoop on a section of grass.
2. Have one partner scatter the coloured toothpicks through the area enclosed by the plastic hoop. The other partner will have 30 seconds to pick up as many toothpicks as possible, one at a time. Repeat for four trials.
3. Copy Table 1 and record your team's data.

Table 1

Trial	Number of each colour toothpick			
	Red	Yellow	Green	Blue
1				
2				
3				
4				

A. Which colours of toothpicks were picked up most often?

B. Which colours of toothpicks were picked up least often?

C. How do you explain this outcome?

Natural selection also affects prey species that must adapt in order to survive. Camouflage is an adaptation that allows the prey to hide from predators and avoid being eaten (Figure 4). Other prey, such as poison dart frogs, wasps, and skunks have adapted by developing chemical defences (Figure 5). These organisms often have warning colouration to advertise that they are harmful or poisonous to predators. Predators learn very quickly to leave these organisms alone.

STUDY TIP

When you are learning many new things, it is easy for the new concepts to interfere with remembering ones you learned a week ago. To prevent this problem, build review into every study session.

Figure 4 What is the benefit of blending into the background like this stick insect?

Figure 5 What is the benefit of having warning colouration like these skunks?

To see what can happen when animals use chemical defenses, go to **www.science.nelson.com**

Some prey species have adapted a strategy called **mimicry**. In mimicry, one species resembles another that is poisonous, dangerous, or distasteful. The king snake is a well known example of a mimic because it looks very similar to the poisonous coral snake (Figure 6). Mimicry also refers to situations where two harmful species have similar colouration, such as bees and wasps. When several species have the same colouration, the message to stay away is reinforced.

(a) (b)

Figure 6 Mimicry is a successful prey defence strategy. The (a) king snake mimics the (b) poisonous coral snake, protecting it from predators.

Predator and prey species may adapt in response to each other's adaptations. This type of interaction and the adaptation of two species in response to each other is called **coevolution**.

Many plant and herbivore adaptations have co-evolved. Herbivores respond with adaptations such as specialized beaks, or teeth, as well as digestive systems that are capable of breaking down cellulose and plant toxins. Plants adaptations include sharp thorns, spines, sticky hairs, and tough leaves that make the plant more difficult to eat (Figure 7). As well, scientists have identified over 10 000 defensive chemicals in plants. Some, such as caffeine, nicotine, and cyanide, are poisonous to herbivores. Other substances, like pepper and mustard, are natural repellents.

Figure 7 Certain grazing herbivores such as cows are able to eat the sharp pointed flowers of thistle plants.

Did You KNOW?

Biodiversity Hotspots

Ecosystems with high primary productivity show very high biodiversity. Some of these regions are called biodiversity hotspots because they contain so many species relative to their area and because the region is highly threatened. About 20 % of all species live in these regions, which only cover about 1 % of Earth's surface. The island of Madagascar and the Great Barrier Reef of Australia are examples of biodiversity hotspots.

www.science.nelson.com GO

Biodiversity

Biodiversity refers to the variety of, and the variation among, organisms within a given ecosystem, biome, or for the entire Earth. Biodiversity is closely linked to **primary productivity**, which is a measure of the available energy provided by the producers in an ecosystem. The abundance of producers in turn supports a complex and diverse community of consumers. Temperate and tropical rainforests as well as estuaries (where rivers flow into the ocean) are all regions with high primary productivity and biodiversity.

In contrast, environments with low primary productivity, such as those found in deserts, high mountains, and polar regions, have low biodiversity. These ecosystems also tend to be more fragile and are easily disrupted. In areas of low biodiversity, the removal of a single species could have a major or even devastating effect on the entire ecosystem.

A decrease in one species, whether it is a predator or prey, can have a serious effect on the entire ecosystem. **Extinction** results when a species is gone completely from Earth or when so few individuals remain that reproduction is not possible. **Extirpation** refers to the phenomenon of local extinction, which occurs when a species ceases to exist in one area, but still exists elsewhere in the world.

Keystone Species

When stone arches are built, one stone at the top, called the keystone, is particularly important to support the arch. If this keystone is removed, the arch will collapse (Figure 8). **Keystone species** are species whose presence plays an important ecological role in determining the types and numbers of other species in particular communities. When these species are eliminated, the effects on the ecosystem are dramatic.

Sea otters are an important keystone species along the west coast of North America. They live in kelp forests (Figure 9) where they feed on bottom-dwelling invertebrates, such as sea urchins and crabs that live in and feed on the kelp. Kelp forests also provide important nursing grounds for juvenile

Figure 8 If the keystone of this arch is removed, the arch will collapse.

Figure 9 Sea otters are the keystone species in kelp forests. They keep the population of kelp-eating invertebrates in check.

fish of many species. This very intricate ecosystem was kept in balance by the interrelationships among the organisms. Before the arrival of Europeans, both kelp and sea otters were abundant in the intertidal zones. However, sea otters on the west coast of Vancouver Island were almost extirpated as they were hunted for their valuable pelts. As a result, the otters' prey, sea urchins that graze on the kelp, proliferated, causing the collapse of the kelp forest community. The kelp forests disappeared taking with them the habitat for others including juvenile fish.

Between 1969 and 1972, 89 sea otters from a population in Alaska were transplanted to the west coast of Vancouver Island. This new population has survived and is now upwards of 3000 sea otters.

Scientists are only beginning to understand the importance of biodiversity. It seems that biodiverse ecosystems are more stable and less affected by environmental change. They tend to recover after a disturbance such as drought, flooding, or fire. Biodiversity also provides humans with many benefits, including many of our natural resources. The foods we eat, the wood we use to build our homes, and the medicines we use to treat our diseases are only available because of biodiversity. The recreational activities we enjoy, the water we drink, the food we eat, and even the air we breathe are tied to the biodiversity of fragile ecosystems on this planet that we call home.

British Columbia has the greatest biodiversity in Canada, but that doesn't mean we shouldn't be concerned about losing species. Over the years, several species have become extinct, and many more, such as the Vancouver Island Marmot, are listed as endangered or threatened.

LEARNING TIP

Check your understanding. Ask yourself, "What are the main ideas in this section? How would I explain them in my own words? What additional information about keystone species can I get from Figures 8 and 9, on page 64?"

TRY THIS: *Exploring B.C.'s Biodiversity*

Skills Focus: evaluating, recording, identifying, communicating

Scientists at the B.C. Ministry of Environment conduct research on wildlife in B.C.'s ecosystems and estimate the risks to species. They recommend strategies for wildlife management and conservation. In this activity, you will explore the status of some of B.C.'s wildlife.

Materials: computer access

1. Log on to the Nelson website and follow the links to Exploring B.C.'s Biodiversity.

   www.science.nelson.com GO

2. Click on B.C. Species and Ecosystems Explorer.
3. Select your "search type" and species "name" or "group."
4. Select the type of list you want (red, blue, or yellow).
5. Continue to use the B.C. Species and Ecosystems Explorer to answer the following questions:

A. How many "red-list" mammal species are there in B.C.?

B. Name four endangered amphibians in B.C.

C. How many exotic vascular plants are there in B.C.?

D. Make a list of three new searches you are interested in. Perform the searches.

E. Prepare a detailed report on two B.C. species of your choice. Include a species that is threatened or endangered in your forest district or ecological zones.

3.2 CHECK YOUR Understanding

1. The relationship between predators and prey is often compared to a "weapons arms race." In what way is this comparison useful?
2. Sea stars are known to feed on two different species of mussels. Explain how the removal of the sea star from an area could lead to the elimination of one of the two mussel species.
3. Explain why humans are considered to be a keystone species.
4. Consider the two islands shown in Figure 10. One island is on the equator, and the other island is 500 km north of the equator. Which island is likely to have the greatest biodiversity? Provide two reasons to support your answer.

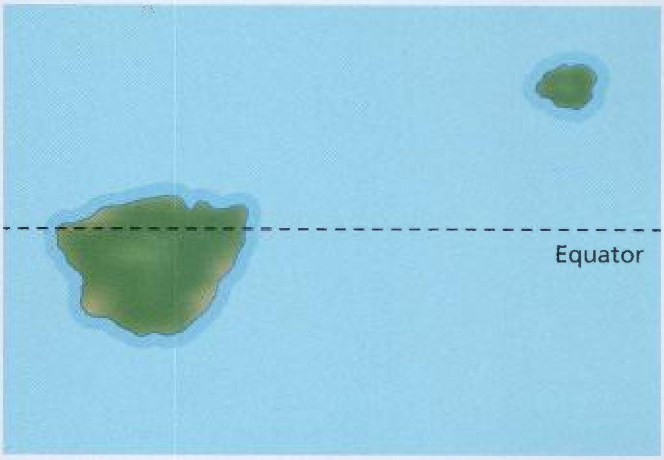


Figure 10

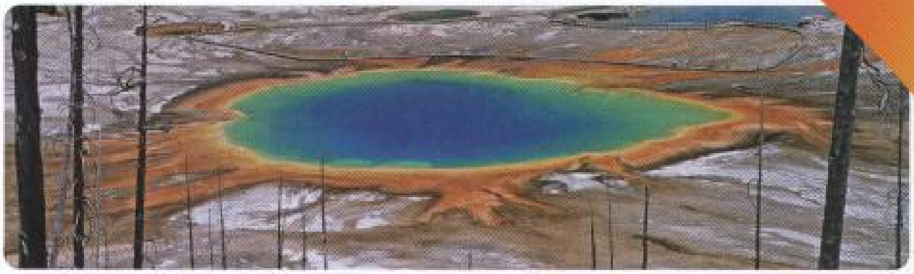
5. Which of the following characteristics applies to an organism that uses mimicry as a survival strategy?
   A. The mimic is a parasite.
   B. The mimic is always poisonous.
   C. The mimic is identical to another harmless species.
   D. The mimic is similar to another harmful species.
6. (a) Describe two predators whose adaptations improve their success.
   (b) Describe two prey whose adaptations improve their survival.
7. Some harmless flies resemble bees and wasps. What is the benefit to the fly to have this colouration? What is this survival mechanism called?
8. Explain how each of the following adaptations might improve the organism's chance of survival.
   (a) the parachute-like seed of a dandelion
   (b) the white colour of a snowshoe hare
   (c) the silent wings of a great horned owl
   (d) the rapid growth rate of tundra grasses
   (e) the keen eyesight of a bald eagle
9. Explain in your own words the link between primary productivity and biodiversity.
10. Explain in your own words the term "biodiversity."
11. Why is biodiversity important for ecosystems?
12. Explain why a tundra ecosystem is more fragile than a deciduous forest ecosystem.

LIVING LIFE TO THE EXTREME

You might expect the harshest environments on the planet to be empty of all life, but some amazing organisms exist in almost impossible conditions!

Some organisms really take living to the extreme. You couldn't survive being chilled to the core, soaked in acid, or boiled alive. But many bizarre creatures thrive in the harshest habitats on the planet, including volcanic vents on the ocean floor, where the temperatures reach 110 °C, and sub-zero temperatures of the upper reaches of the atmosphere. Some hang out inside hot rock nearly 3 km beneath Earth's surface, while others enjoy taking an acid bath in waters near hot springs or cooking in the desert Sun (Figure 1). These organisms are called extremophiles (Figure 2). There are many different categories of extremophiles, and each has its own unique name (Table 1).

Many scientists and industry researchers are very interested in extremophiles. Some acidophiles are used by mining companies to remove gold and other precious metals from rock ores. Researchers in medicine, genetics, and molecular biology use an enzyme produced by an extremophile called *Thermus aquaticus* to copy fragments of DNA. The ability of extremophiles to live in environments that would kill most organisms means that they must have adaptations to counteract the conditions. Understanding how they manage to survive could lead to many more practical uses for extremophiles and their enzymes.



(a)

(b)

Figure 1 Extremophiles not only survive but thrive in environments where other organisms cannot, including (a) acidic hot springs or (b) the baking sand of the nearly lifeless Atacama desert.

Figure 2 Most extremophiles are extremely small, like this microscopic archaebacteria.

Table 1 Some Types of Extremophiles

Acidophile	An organism that lives in acidic environments. Some could survive in battery acid.
Alkaliphile	An organism that lives in basic condition. Some could live in solutions containing ammonia.
Endolith	An organism that lives in microscopic spaces within rocks or in cracks filled with water deep within Earth.
Hyperthermophile	An organism that can thrive at temperatures between 80 °C and 121 °C, such as those found in hydrothermal areas.
Polyextremophile	An organism that is an extremophile in more than one category.
Xerophile	An organism that can grow in the driest environments on Earth.

3.3 Community Interactions

STUDY TIP

The best way to avoid test anxiety is to be well prepared. How will I improve my study habits? Write down a plan that includes:

1. How will I build review into each study session?
2. How will I distribute my studying during each week?

Within a community there are many species that live in the same general area, but each species occupies a different niche. A **niche** is the overall role of an organism in a community, including the range of biotic and abiotic conditions that the organism can tolerate. A niche is not just an organism's habitat, but also what it eats, what eats it, how it reproduces, how much water it needs, and many other factors. Two species may share the same habitat, but no two species occupy the same niche (Figure 1).


(a)


(b)

Figure 1 The (a) lynx and (b) wolf might share the same habitat, but different behaviours such as hunting strategies and daily activity patterns separate these species into different niches

Did You KNOW?

Partitioning the Coastal Waters

Several populations of killer whales occupy the coastal waters of B.C. "Resident" killer whales eat fish, and "transient" whales feed on seals and sea lions, while "off-shore" populations eat sharks and turtles. In this way they avoid direct competition for the same resources, ensuring the survival of each population.

Competition occurs when two organisms make use of the same resource so that their niches overlap. Competition between different species is called **interspecific competition**. Each species competes for a limited common resource such as food or nesting sites. When organisms of the same species compete among themselves, it is called **intraspecific competition.** This form of competition is usually more intense than interspecific competition because the requirements of each organism are more similar.

Some species develop adaptations that allow them to reduce or avoid competition for resources with other species. This can result in **resource partitioning**, where different species have different traits that allow them to use a resource at a different time, in a different way, or in a different place. For example, hawks and owls feed on similar prey, but hawks hunt during the day while owls hunt at night.

To explore how organisms use resource partitioning to exploit different parts of their shared habitat, go to **www.science.nelson.com**

When species adapt differently to changes to the environment, it is called **adaptive radiation**, and species become specialized to exploit smaller parts of the niche. One well-known example of adaptive radiation is the finches of the Galapagos Islands (Figure 2). Originally, all of the finches were similar. Over time, natural selection caused populations and species to adapt to different environments and diets with different adaptations, resulting in a partition of resources and reducing competition. **Proliferation** of species occurs as the numbers of individuals with each new trait increases.

Populations with the new adaptations will proliferate until competition increases once again and selective pressure leads to further adaptations and further resource partitioning. 3B → *Investigation*

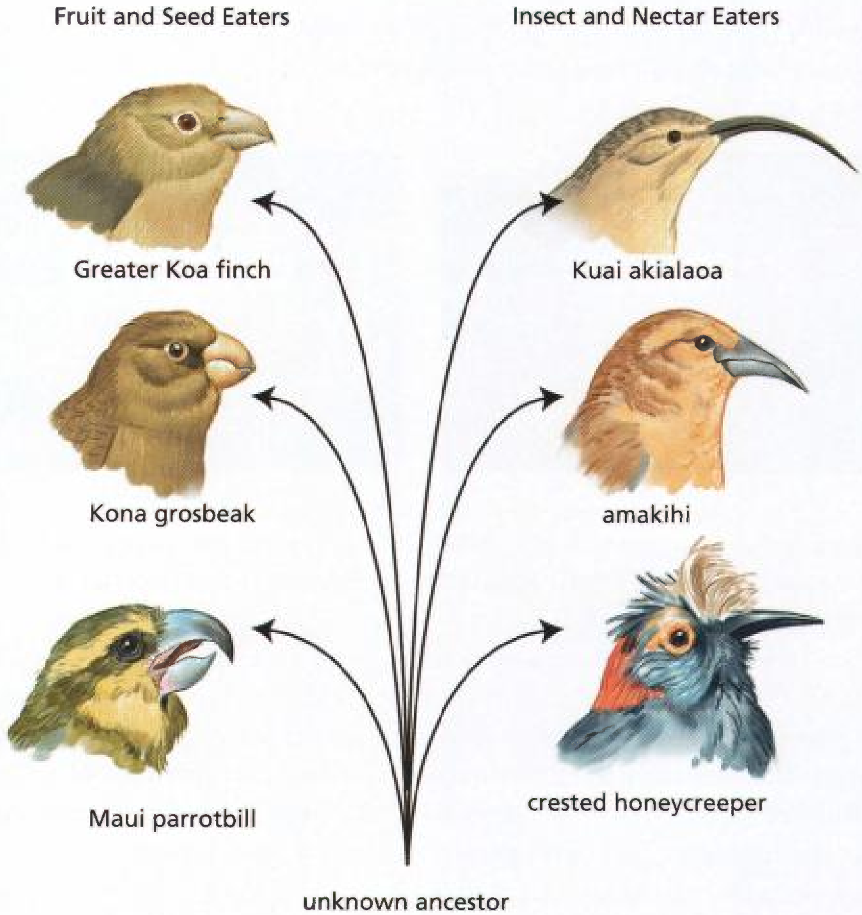


Figure 2 The beaks of finches found on the Galapagos Islands show the outcome of adaptive radiation.

3B → *Investigation*

Fine-Feathered Feeding Frenzy

To perform this investigation, turn to page 76.

In this investigation, you will investigate natural selection and 'beak' shape.

The Impact of Foreign Species

Ecosystems are dynamic; they are always changing. Animal species are mobile and can move to new ecosystems naturally when barriers are removed. Micro-organisms, fungi, and plants can be transported by wind or by animals to new ecosystems where they establish. These new species are called **foreign species** because they are not native to that particular ecosystem. Foreign species often out-compete the existing native species for a particular niche, with dramatic results since they rarely have predators in their new habitats. When this happens, the foreign species pose a serious threat to biodiversity.

Humans are responsible for the introduction of many foreign species. Some of these introductions are intentional and often beneficial. For example, many of our food crops such as corn and wheat, as well as certain tree species, have been successfully introduced without harmful effects. However, the introduction of many foreign species is often unintentional, and humans may carry these species across oceans and mountains and from one waterway to another in (or attached to) boats and ships (Figure 3).

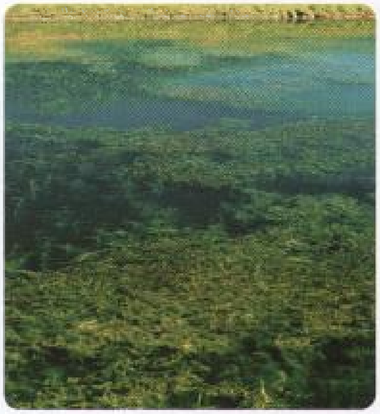


Figure 3 Eurasian watermilfoil was first observed in B.C. in 1970 in Okanagan Lake. It was probably attached to the propeller of a boat that was moved from another lake where the aquatic plant grew.

British Columbia has its share of foreign species. Purple loosestrife and Scotch broom (Figure 4) are two highly visible perennial plants that proliferate during the spring. Purple loosestrife invades wetlands, choking out native species. Scotch broom grows well in disturbed areas such as logged areas or along the sides of highways where it out-competes Douglas fir seedlings. No consumers appear to feed on either of these foreign species.

To find out more about foreign species, go to www.science.nelson.com

Did You KNOW?

Introducing Foreign Species

All of the Scotch broom in North America originates from three seeds that germinated in Sooke on Vancouver Island. The seeds, planted by Captain Walter Grant, came from Europe by way of the British consulate in Hawaii.

(a)

(b)

Figure 4 (a) Purple loosestrife probably arrived from Europe as seed in ballast soil of ships or carried by passengers to plant in gardens; (b) Scotch broom was intentionally brought from Europe.

British Columbia is also home to some foreign animal species. According to the B.C. Ministry of Environment there are sixteen foreign bird species in the province. Probably the most successful species is the European starling (Figure 5). The Pacific or Japanese oyster (Figure 6) was intentionally introduced to B.C. coastal waters in the 1920s to be farmed. Since this oyster does not reproduce well in the cooler B.C. coastal waters, oyster seed is regularly imported. Although regulated by the Department of Fisheries and Oceans, other species have been introduced inadvertently along with the Pacific oysters, including several other bivalves (two-shelled aquatic invertebrates), worms, and snails. One of these, the oyster drill snail, feeds on bivalves by drilling holes in the shell and digesting the internal organs (Figure 7).

Figure 5 All North American starlings are descendants of European starlings, intentionally introduced into New York City's Central Park.

Figure 6 Pacific oysters introduced from Japan. This is the most predominant commercially raised oyster in the world.

Figure 7 Oyster drill snails drill through the shells of other shelled animals.

Succession

Have you ever noticed that a newly cleared lot does not remain bare for long? With time, it becomes overgrown with grasses and weeds. Eventually taller weeds will replace the shorter ones, and in time shrubs and trees will appear. This gradual change in the types of plants that represent the structure of a community is called **ecological succession**. In this process, **pioneer species** arrive first and colonize the new environment. The presence of these pioneer species changes the environment, creating acceptable conditions for other species. Over time, plant species that are better adapted to the new environmental conditions arrive, out-competing and replacing the pioneer species.

Depending on the initial conditions, there are two types of ecological succession. **Primary succession** begins in an area that is lifeless and lacking nutrients, such as bare exposed rock (Figure 8). Figure 9 (a) shows primary succession occurring in such a location. Lichens and mosses arrive first and begin slowly breaking down the rock and trapping tiny pieces of wind-blown soils from nearby fertile areas. Over time, physical weathering by the Sun and water also contribute to form soil. Once the soil is deep enough and required nutrients are present, grasses and small shrubs begin to grow. Left undisturbed with sufficient water or rainfall, the community will eventually develop into a complex, stable ecosystem called a **climax community**.

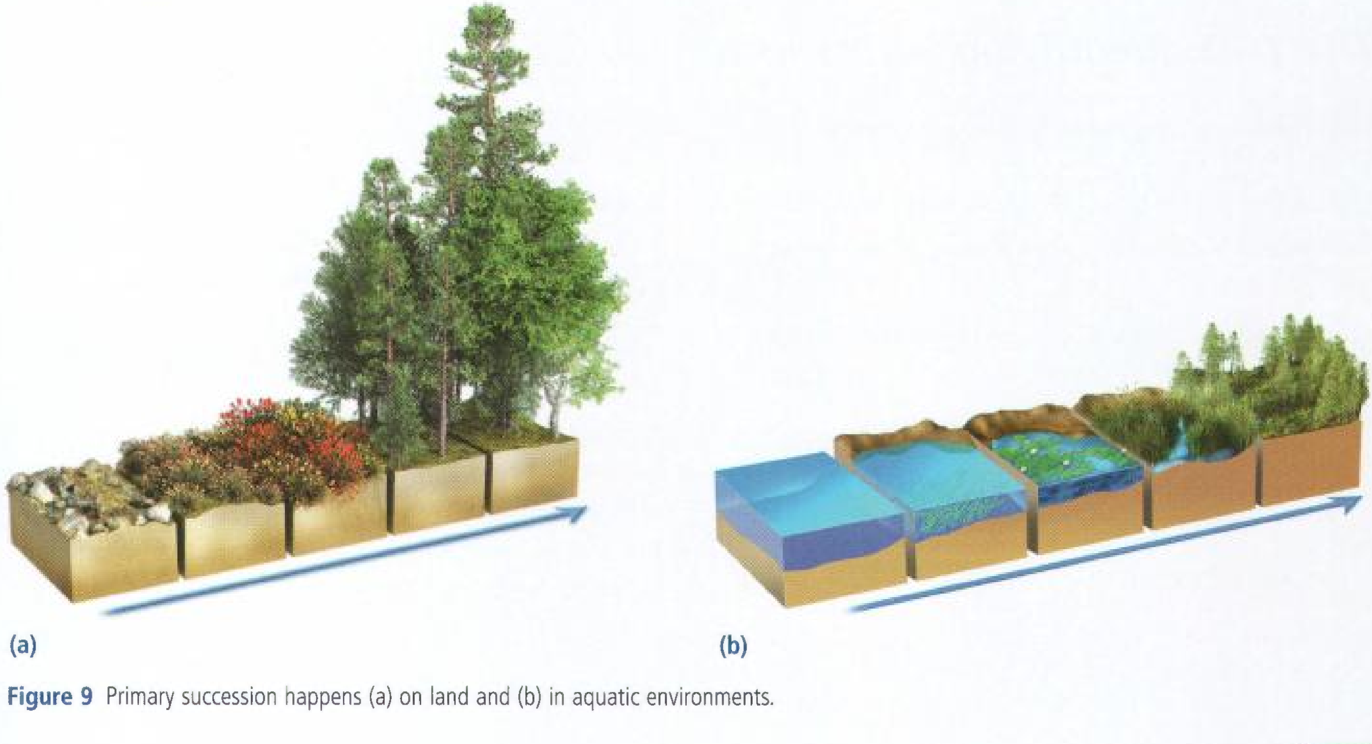
Primary succession can also occur in newly created ponds (Figure 9 (b)), beginning as sediments run into the water from surrounding land. Seeds are blown into the water or introduced by animals. In time, the plants and animals become part of a newly formed aquatic community. Eventually the waters become overgrown with vegetation. Succession continues transforming the pond into a marsh and eventually into dry land.

LEARNING TIP

Key terms are often illustrated. When you come across words in bold, examine the pictures and diagrams, along with the captions.

To find out more on the types of ecological succession, view the animation at **www.science.nelson.com**

Figure 8 Lichens often begin primary succession by breaking down rock to produce soil.



(a) (b)

Figure 9 Primary succession happens (a) on land and (b) in aquatic environments.

(a)

(b)

(c)

Figure 10 Regions disturbed by (a) fire, (b) flooding, and (c) erosion are starting points for secondary succession.

Secondary succession begins in areas that already have soil or sediments but where there has been a significant disturbance such as fire, flooding, landslides, or forest harvesting (Figure 10). The dominant plants are destroyed but the soil remains, and so new plants begin to grow within a few weeks. Seeds hidden in the soil or brought by birds and other animals become the pioneer species. As in primary succession, the process of secondary succession eventually leads to a climax community characterized by a complex mature ecosystem.

Ecological succession often focuses on changes in the plant community in an area. But it is important to realize that the consumers and decomposers in the community change as well. As changes in the plant community occur, it often becomes less suitable for the existing consumers and more suitable for others.

For example, certain species of field mice may only be able to live in the area after enough tall grasses exist to provide cover for them. In turn, the mice alter the plant community by feeding on the grasses while at the same time improving the soil with their waste. The improved soil allows other plants to take hold and grow, so in this way, the organisms in each stage alter the physical environment. Therefore, each stage of succession paves the way for the next stage.

Ecological succession is a simplified model to help us understand a very complex process. Succession has traditionally been presented as a slow steady change from a pioneer community to a stable climax community, but disruptions like fires and flooding are common and often prevent climax communities from forming. In other situations the rate of succession may be accelerated by human activity, for example if fertilizers are added to the soil.

TRY THIS: Identifying Succession

Skills Focus: observing, recording, concluding, communicating

In this activity, you will observe and record details of succession.

Materials: diagrams or photographs showing different stages of succession

1. Copy Table 1 in your notebook, and leave plenty of room for your observations. You will need one row for each diagram.

Table 1

Image	Observations	Successional stage
1		
2		

2. Visit each of the images around your classroom. Take care to record your observations in the appropriate row of your data table. You will not necessarily begin at diagram #1.
3. Look for different types of plants or animals that may be good indicators of whether the community is in the early, middle, or late stages of succession.

A. Using your observations, order the diagrams to represent the correct sequence of succession based on what you know about the stages of succession. Justify your answer.

B. If possible, state whether each image shows primary or secondary succession. Why is it sometimes difficult to tell?

3.3 CHECK YOUR Understanding

1. Describe the difference between a habitat and a niche.
2. Describe your ecological niche. Consider your habitat and your place in the food web.
3. What happens when two species with the same niche move into the same ecosystem?
4. Describe the relationship between resource partitioning and competition.
5. Explain, using examples of your own, the difference between interspecific and intraspecific competition.
6. What role do pioneer species have in primary succession?
7. Which of the following is a characteristic of many climax community producers?
   A. able to grow in the absence of soil
   B. able to grow in the shady understorey of forests
   C. able to reproduce quickly before other plants arrive
   D. able to develop effective defenses against carnivores
8. Which of the following is a characteristic of producers that grow during the middle stages of succession?
   A. able to grow in the absence of soil
   B. able to grow in the shady understorey of forests
   C. able to reproduce quickly before other plants arrive
   D. able to develop effective defenses against carnivores
9. Suggest two human activities that could lead to secondary succession.
10. What characteristics do pioneer plants have?
11. Distinguish between primary and secondary succession. Which of these two processes usually proceeds more rapidly? Explain your reasoning.
12. What characteristics would allow you to identify a climax community?
13. Describe the role of pioneer plants in the formation of soil.
14. Explain how herbivores can influence the stages of primary succession.
15. Describe the process occurring Figure 11. Can this process also occur on land? Explain your answer.

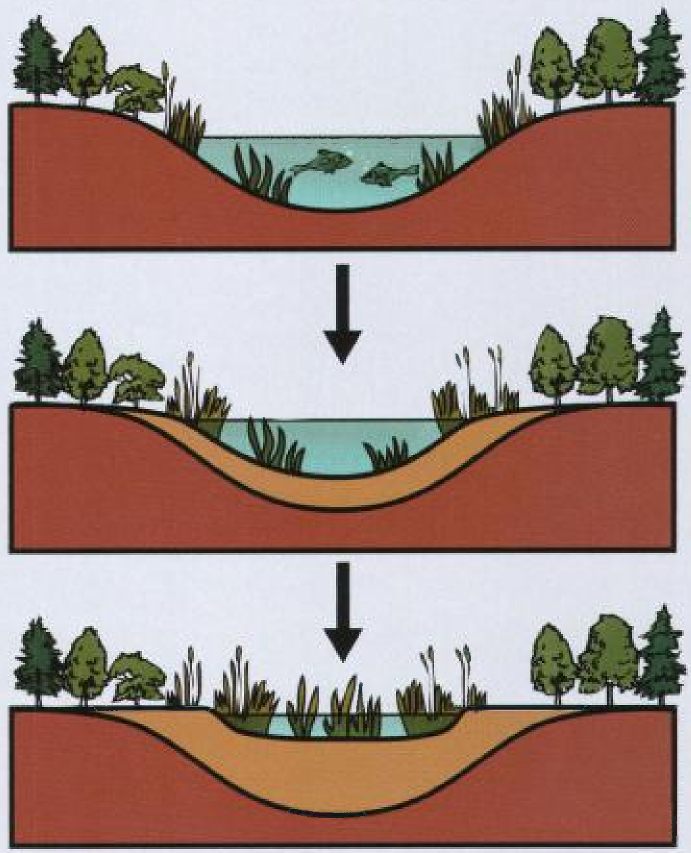


Figure 11

3A Investigation

Working with Climatographs

The distribution of living things is directly affected by the long-term climatic conditions and the ability of organisms to adapt to these conditions. The climatic trends of a biome are often expressed as a climatograph that shows the monthly changes in temperature and precipitation throughout a year (Figure 1). These two factors are effective indicators of plant and animal distribution and adaptations within the world's biomes.

In this investigation, you will use climate data to produce and analyze climatographs in order to discover trends in seasonal climate variation.

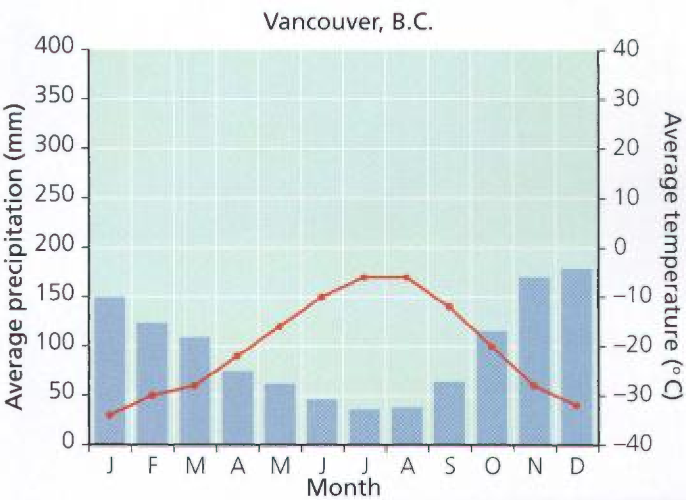


Figure 1 This climatograph for Vancouver, B.C. shows average monthly precipitation as bars, and average temperature as connected data points.

Question

Is it possible to identify biomes by analyzing climatographs?

INQUIRY SKILLS

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

Experimental Design

In this investigation, you will use five sets of climate data to produce climatographs representing some of Earth's distinct biomes. Each climatograph will be used to determine the biome that the data represents.

Materials

- graph paper
- 2 coloured pencils
- climate data

Procedure

1. On graph paper, create a blank climatograph. Draw a horizontal axis for the months of the year.
2. Draw two vertical axes. On the left-hand side, use a scale of 0 mm to 400 mm for average precipitation. On the right-hand side, use a scale of –40 °C to 40 °C for temperature data. Label each of the axes and include appropriate units.
3. Plot the climate data for Biome A found below on your blank climatograph.
4. Use coloured bars to represent average monthly precipitation.
5. Join the individual data points for temperature with a trend line.
6. Repeat Steps 1 to 5 for Biomes B through E.

Climate Data

Biome A	J	F	M	A	M	J	J	A	S	O	N	D
Average Temp. (°C)	27	25	27	26	25	24	22	25	27	27	27	27
Total Precipitation (mm)	210	199	171	123	54	16	10	11	58	115	154	194

Biome B	J	F	M	A	M	J	J	A	S	O	N	D
Average Temp. (°C)	1	3	4	6	8	11	13	13	11	8	4	2
Total Precipitation (mm)	251	217	188	181	142	120	113	163	245	379	284	270

Biome C	J	F	M	A	M	J	J	A	S	O	N	D
Average Temp. (°C)	−14	−19	−27	−29	−32	−33	−34	−35	−36	−31	−21	−14
Total Precipitation (mm)	6	4	2	1	5	3	2	1	0	1	2	3

Biome D	J	F	M	A	M	J	J	A	S	O	N	D
Average Temp. (°C)	23	25	29	32	35	34	32	32	33	32	28	25
Total Precipitation (mm)	0	0	0	0	4	5	46	75	25	5	1	0

Biome E	J	F	M	A	M	J	J	A	S	O	N	D
Average Temp. (°C)	−27	−24	−18	−5	5	13	17	14	7	0	−14	−23
Total Precipitation (mm)	15	13	11	10	17	23	35	42	29	35	24	15

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Which biome has the highest annual precipitation? Explain your answer.

(b) Which biome shows the greatest seasonal variation in temperature? Explain your answer.

(c) Which biomes have measurable snowfall? Explain your answer.

(d) Which biome has the longest growing season? Explain your answer.

(e) Which biome lies closest to the equator? Explain your answer.

(f) Which biome lies furthest from the equator? Explain your answer.

(g) Use your analysis and the climatographs you produced to predict which world biome is represented by each set of data.

Evaluation

(h) Which set of data was most difficult to match with a world biome? Why?

(i) What is the benefit of using a climatograph rather than a data table to represent climate trends in an area?

Synthesis

(j) Find climate data for a city near you and create a climatograph for the biome in which you live.

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3B Investigation

Fine-Feathered Feeding Frenzy

An adaptation is any inherited trait that improves an organism's chance of surviving and reproducing. In some cases, an adaptation is a behaviour or strategy that provides an advantage. It may also be a structure that permits organisms to take better advantage of a certain type of resource such as food. When resources are limited, organisms that are best able to exploit a resource will survive. If you have ever looked carefully at different types of birds, you will have noticed several different beak shapes (Figure 1).

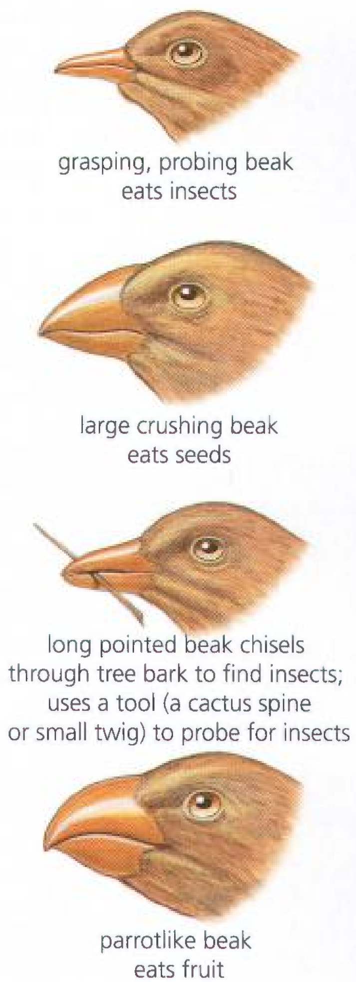


Figure 1 The shape of a bird's beak is often an adaptation to exploit food resources.

INQUIRY SKILLS

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

Question

Which beak adaptations provide the greatest feeding advantage?

Prediction

Predict which tool will provide the greatest advantage for each food type. Record your prediction before each set of data.

Experimental Design

In this investigation, you will simulate the competition for food between different birds on an island with different food sources.

Materials

- pliers
- net
- skewer
- tweezers
- eyedropper
- plastic container
- various food samples from your teacher

Procedure

1. Work as a group. First, read the procedure carefully. Look for what you need to record and prepare a blank copy of Table 1 for each station. Your teacher will direct you to a station to begin.

Table 1

Station # :					
Food source:					
Predicted winner:					
Beak Description	**Trial #1**	**Trial #2**	**Trial #3**	**Average**	**Ranking**
Pliers					
Net					
Skewer					
Tweezers					
Eyedropper					

2. Obey the following rules during this investigation:
   - Do not use your hands to pick up the food. Use the tool instead.
   - Food must be picked up and placed in your "stomach" (plastic container).
   - Your "stomach" must remain on the table.
   - You may not steal from the other "birds."
3. Each person in your group will use one of the tools—this will be your beak.
4. You will compete against the other "birds" in your group to acquire as much food as possible in 30 seconds and put it in your "stomach" (plastic container).
5. Before beginning each competition, predict which beak will win.
6. Each group will perform three competition trials at each station. Record the number of food items caught for each trial and average the result.
7. Rank each beak according to the average amount of food caught.
8. When directed by your teacher, rotate to the next station and repeat Steps 4 to 7.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Which beak shape won in each of the feeding situations?

(b) For each station, draw a bar graph that shows the average amount of food gathered by each of the beak types.

Evaluation

(c) When an organism is able to survive in several different environments, it is called a "generalist." Which of the beak types would most likely belong to a generalist?

(d) When an organism is able to do very well in one environment but performs poorly in others, it is called a "specialist." Which of the beak types would most likely belong to a specialist?

Synthesis

(e) How might the results change if the size of the food items changed? How might the results change if the size of the beak changed?

(f) The beak of a bird is also needed for nest building. Which adaptation is more likely to influence beak shape, nest building ability or feeding ability? Explain your reasoning.

(g) What is the advantage to *all* of the birds by having different beak shapes?

CHAPTER 3

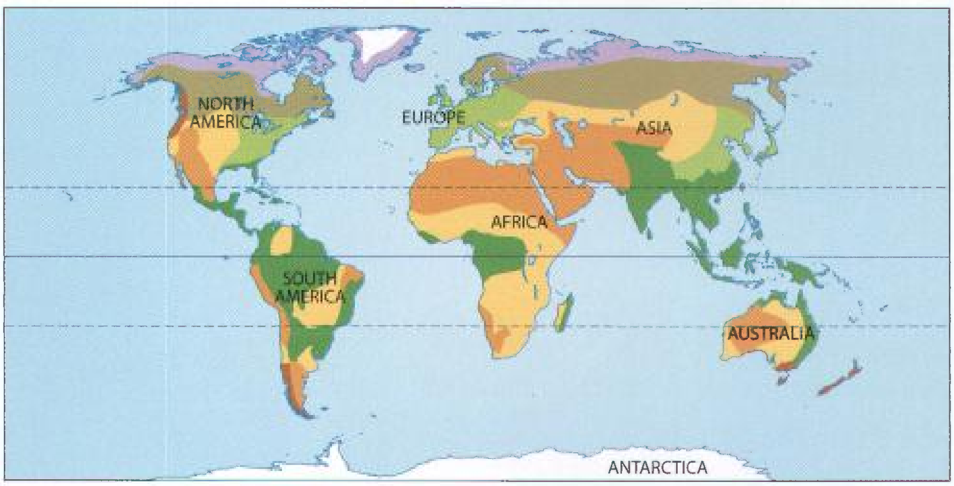
Review

Community Ecology

Key Ideas

The biosphere contains distinct biological communities.

- The distribution of living things is limited by the environmental conditions in different areas of Earth.
- Factors such as solar energy, latitude, elevation, wind patterns, and ocean currents influence climate, which in turn influences the distribution of world biomes.
- Biomes are major ecosystems with similar abiotic conditions containing similar organisms.
- British Columbia has fourteen distinct biogeoclimatic zones.



Species adapt to changes in environmental conditions and to other organisms.

- Competition leads to adaptation that allows organisms to occupy separate niches.
- In predator–prey relationships, prey populations adapt to avoid being eaten, while predator populations adapt to improve capturing prey.
- Biodiversity varies from one location to another as a function of abiotic factors.

Vocabulary

climate, p. 51
latitude, p. 51
elevation, p. 51
climatograph, p. 53
biome, p. 54
tundra, p. 55
permafrost, p. 55
boreal forest, p. 56
canopy, p. 56
temperate deciduous forest, p. 56
understorey, p. 56
temperate rainforest, p. 57
grassland, p. 57
savanna, p. 57
tropical rainforest, p. 58
desert, p. 58
polar ice, p. 58
adaptation, p. 61
natural selection, p. 61
mimicry, p. 63
coevolution, p. 63
biodiversity, p. 64
primary productivity, p. 64
extinction, p. 64
extirpation, p. 64
keystone species, p. 64
niche, p. 68
competition, p. 68
interspecific competition, p. 68
intraspecific competition, p. 68

Species in communities interact in many different ways.

- Keystone species play an important role in determining the types and numbers of other species in the community.
- Competition can occur between different species in the community or between individuals of the same species.
- Foreign species may be introduced to ecosystems and out-compete native species.

Succession is an indication of change in an ecosystem.

- Succession is a process of gradual change in the types of plants that represent the structure of a community.
- Primary succession describes the changes that occur in a newly formed habitat that has not yet sustained life.
- Secondary succession describes the changes that occur in an area where there has been previous growth such as abandoned fields or forest clearings.

resource partitioning, p. 68

adaptive radiation, p. 68

proliferation, p. 68

foreign species, p. 69

ecological succession, p. 71

pioneer species, p. 71

primary succession, p. 71

climax community, p. 71

secondary succession, p. 72

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Which of the following is an abiotic condition that could lead to low biodiversity?
A. abundant rainfall
B. poor soil conditions
C. stable annual temperature
D. few plant species growing in the area

2. Distinguish between pioneer species and climax community.

3. What is meant by the statement: "Each stage of succession paves the way for the next"?

4. Which stage of succession is most likely to exist in a dynamic equilibrium?

K 5. In which of the following situations would primary succession occur?
A. on bare rock
B. after a forest fire
C. only in terrestrial ecosystems
D. after the logging of a climax forest

6. List two chemical defences of plants.

7. Compare predator and prey (similarities and differences).

K 8. Which of the following abiotic factors is a characteristic of the tundra biome?
A. nutrient-poor soil
B. direct solar radiation
C. high average annual temperature
D. over 200 cm of precipitation each year

9. Explain how the distribution of the world's biomes are influenced by abiotic factors.

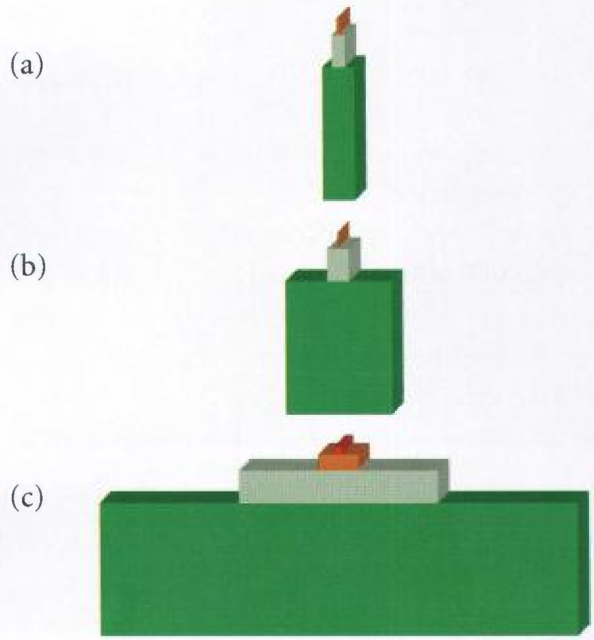
10. What characteristics do both the desert and tundra biomes share in common?

K 11. Which of these characteristics applies to the temperate rainforest?
A. thin nutrient-poor soil
B. occupy coastlines in middle-latitudes
C. approximately 75 cm of precipitation annually
D. temperatures remain near freezing throughout most of the year

Use What You've Learned

U 12. In which of the following biomes will the removal of a species have the greatest impact?
A. tundra
B. boreal forest
C. tropical rainforest
D. temperate deciduous forest

13. Match each of the energy pyramids shown below with the correct biome: tundra, grassland, or temperate rainforest.



U 14. Which of the following four ecosystems has the greatest rate of photosynthesis?
A. desert
B. polar ice
C. boreal forest
D. temperate deciduous forest

U 15. Which of the following processes is most likely to lead to a decrease in biodiversity?
A. extinction
B. biodegradation
C. adaptive radiation
D. species proliferation

U 16. Which of the following is a biome?
A. the Pacific Ocean
B. the Arctic tundra
C. the continent of North America
D. the province of British Columbia

U **17.** Which of the following processes describes an interaction between abiotic and biotic factors?
A. commensalism
B. predator–prey cycle
C. rate of photosynthesis
D. interspecific competition

18. How does the angle at which Earth is tilted on its axis relate to the distribution of tropical regions?

19. Summarize the effect of each of the following on climate patterns:
(a) solar radiation hitting Earth directly
(b) solar radiation hitting Earth at an angle
(c) annual path of Earth around the Sun
(d) the presence of mountain of near the coastline of continents
(e) effect of warm ocean currents near continents

20. For each of the following statements, indicate which of the biomes labelled in Figure 1 is described.

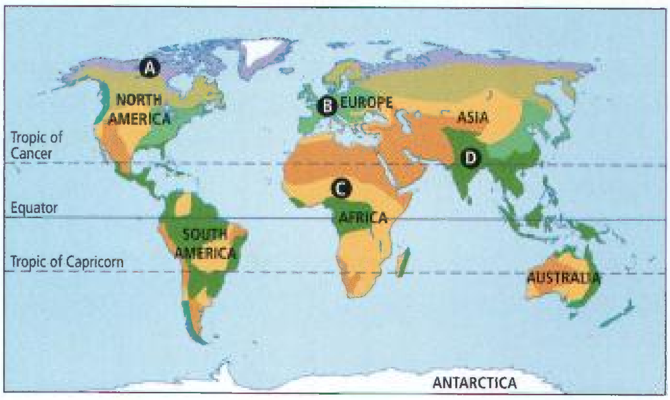


Figure 1

(a) smallest variation in seasonal temperature
(b) caribou feed on lichen and mosses
(c) producers are adapted to extreme heat and low precipitation
(d) soil with the highest nutrient levels
(e) seasonal deciduous forests dominate

21. Design an investigation that could be performed in order to determine whether an organism is a keystone species.

U **22.** Which of the following factors is responsible for the distribution of the world biomes?

I	latitude
II	altitude
III	annual precipitation
IV	average annual temperature

A. I only
B. I and III only
C. II and IV only
D. I, II, III, and IV

Think Critically

23. What factors may be responsible for fluctuations in size of the predator and prey populations?

24. Explain how specialization to a narrow niche can be both an advantage and a disadvantage to an organism.

25. Explain how a broad niche may lead to increased competition.

26. Explain why it is more likely that adaptive radiation will result from intraspecific competition than from interspecific competition.

27. Describe two host adaptations that help to defend against parasites.

28. Describe two adaptations that improve a parasite's success in occupying a host body.

Reflect on Your Learning

29. When the term "climax community" was first introduced, it referred to a final stable community. Today, most ecologists believe that no ecosystem has an end point. What types of changes do you think might continue to occur in a climax community? What types of disturbances might affect a climax community?

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

CHAPTER

4

Nature's Recycling Programs

Chapter Preview

Take a deep breath, and then exhale onto your hand. The breath you exhaled contains carbon in the form of carbon dioxide. The carbon you exhaled could be the same carbon that was exhaled 70 million years ago by a *Tyrannosaurus rex*, a carnivorous dinosaur. Look at the geological features in the limestone caves pictured here. Limestone is composed of calcium carbonate, a compound made of calcium, carbon, and oxygen. These caves provide an abiotic storage form for carbon.

Unlike energy's one-way flow through an ecosystem, matter flows in cycles. Energy in an ecosystem needs to be constantly replenished by the Sun, but the amount of matter in an ecosystem is limited. The chemicals that make up organisms are continuously broken into different forms, and then synthesized again into new compounds. The elements go through a cycle where compounds change from one form to another, and finally back to the original elements again. The elements can make up complex compounds in living things or salts in the ocean. In this chapter, you will learn about the cycling of matter between the biotic and abiotic components of ecosystems.

KEY IDEAS

- **Matter is classified as organic or inorganic.**
- **Nutrients cycle between biotic and abiotic components of ecosystems.**

TRY THIS: *Transpiration in Plants*

Skills Focus: observing, measuring, recording

Plants absorb water from the soil through their roots. In this activity, you will observe how plants are part of the water cycle.

Materials: balance, clear sandwich bags with twist ties, live trees or shrubs

1. Label two sandwich bags A and B. Determine and record the mass of each bag.
2. Place one bag around a leaf or group of leaves of a deciduous tree or shrub. Place the second bag around part of a branch of a coniferous tree or shrub. Use the twist ties to tie off the open end of the bags.
3. Remove the bags after 24 h. Take care not to spill any of the contents.
4. Measure and record the mass of the bags.

A. Was there a difference in the amount of water collected in the two bags?
Which bag collected the most water?

B. Suggest reasons for this difference.

C. If you had not collected the bags, what would normally happen to the water?

4.1 Cycling of Organic and Inorganic Matter

Since its formation, Earth has contained most of the matter it will ever have. The only new matter would come from meteorites that strike Earth's surface. The dynamic nature of life on Earth depends on how this matter is used and recycled between the abiotic and biotic components of the environment. To understand how matter cycles through ecosystems, you must first know the difference between organic and inorganic matter (Figure 1). **Organic** matter consists of compounds that always contain the elements carbon and hydrogen, although other elements may also be present. They are found in living organisms or the fossils of once living things. Carbohydrates, such as sugar, are examples of organic molecules. They contain carbon, hydrogen, and oxygen.

Inorganic matter describes matter that is not of biological origin; it may or may not contain carbon, and is often of mineral origin. Water and salts are examples of inorganic compounds. Although carbon dioxide contains carbon, it is classified as an inorganic compound because it does not contain hydrogen. You will learn more about the composition of these compounds in Unit B. Table 1 lists some common organic and inorganic compounds.

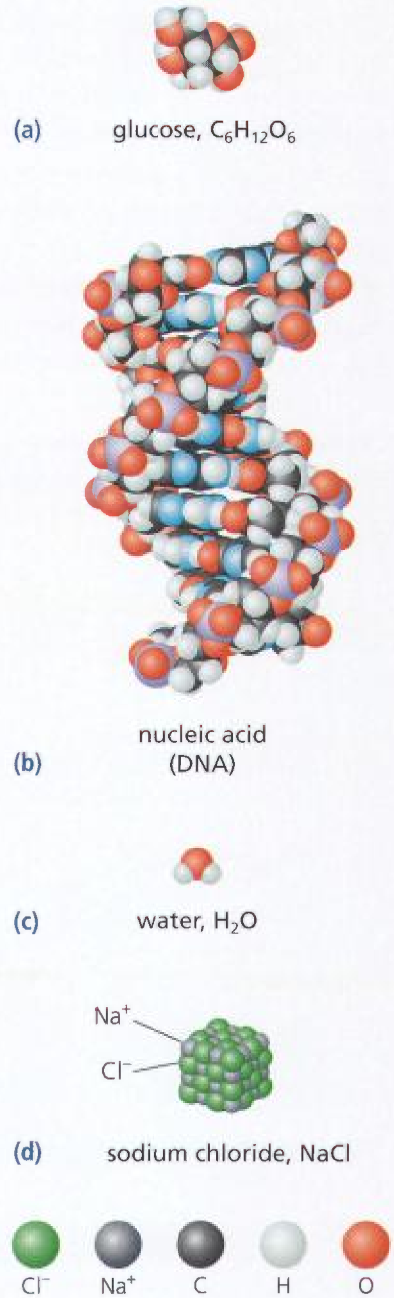


Figure 1 (a) and (b) are organic compounds, and (c) and (d) are inorganic compounds. How can you tell the difference?

Table 1 Some Common Organic and Inorganic Compounds

Organic compounds	Inorganic compounds
carbohydrates	water
proteins	salts
nucleic acids (e.g., DNA)	ammonia
lipids	oxides

Photosynthesis and Cellular Respiration

Probably the most important chemical processes on Earth are photosynthesis and cellular respiration. They are the basis for most life on Earth. **Photosynthesis** occurs when plants use the Sun's energy to convert carbon dioxide and water into carbohydrates and oxygen. The carbohydrates are used by plants to form their structures and to produce the energy required for cellular functions.

Photosynthesis makes the Sun's energy available to other organisms when these organisms consume the plant's carbohydrates as an energy source to carry out cellular respiration in their own bodies. **Cellular respiration** is the reaction between carbohydrates and oxygen that produces energy, carbon dioxide, and water. You will learn more about these two processes in the next section.

TRY THIS: Priestly's First Experiment

Skills Focus: observing, concluding, communicating

Joseph Priestley was an 18th-century scientist who performed experiments revealing some relationships between plants and animals. In this activity you will repeat Priestley's first experiment.

Materials: 2 safety candles in holders, matches or barbeque lighter, 2 bell jars or wide-mouthed jars, 1 mint plant, safety goggles, 1 stopwatch or a clock with a second hand

Be careful around flames. Tie back long hair. Remove loose jackets. Wear goggles. Place bell jars over flames quickly. Do not drop the bell jars.

1. Put on safety goggles. Work with a partner and light both candles. Be sure they are both secure in their holders.
2. Place the plant beside one candle.
3. Place one bell jar over the candle flame and the second jar over the candle flame and mint plant. Start the stopwatch.
4. Stop the stopwatch when the first candle flame goes out. Note the time and then start it again. Stop the stopwatch when the second candle flame goes out.

A. Which candle burned the longest?

B. What caused the candle flames to go out?

C. Which gas was used up in the burning?

D. Which gas was produced by the burning?

E. Explain why one candle burned longer than the other.

Priestley's Second Experiment

Priestley performed a second experiment using plants and mice. He created three sealed environments: one with a single mint plant; one with only a mouse; and one with a mint plant and a live mouse (Figure 2). You may have already predicted his results. After some time the plant by itself wilted. Both mice eventually died, but the one in the jar with the plant lived longer. Based on the experiments of Priestley and other scientists, it was soon discovered that plants used carbon dioxide and water to make carbohydrates and oxygen, and that animals needed the oxygen the plants produced to survive.

LEARNING TIP
Check your understanding. Work with a partner to answer the question raised in Figure 2.

Figure 2 Priestley's second experiment. Why do you think the mouse in the jar labelled C lived longer?

Carbon and oxygen are just two of the many nutrients required by living things. Recall that nutrients are the elements and compounds that organisms must have in order to grow and live.

4.1 CHECK YOUR Understanding

1. (a) Explain the difference between organic and inorganic compounds.
   (b) Give two examples of each.
2. Why is carbon dioxide not an organic compound?
3. Which of the following elements are contained in carbohydrates?

I	carbon
II	oxygen
III	hydrogen
IV	nitrogen

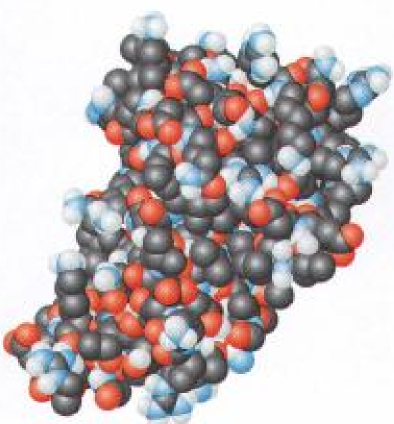
   A. I only
   B. I and II only
   C. I, II, and III only
   D. I, II, and IV only
4. Identify the following compounds as organic or inorganic:
   (a) NaCl
   (b) $C_6H_{12}O_6$
   (c) CH_4
   (d) NH_3
5. (a) Name the process that uses the Sun's energy to produce carbohydrates.
   (b) Name the process that produces energy from carbohydrates.
   (c) Explain why these two chemical processes are considered to be the most important for life on Earth.
6. (a) In Priestley's second experiment, suggest why the mint plants wilted.
   (b) Why did the mouse placed in the jar with the plant survive longer than the mouse placed in the jar by itself?
7. Using what you know about photosynthesis and cellular respiration, explain the observations in each step of Priestley's experiments. Look back to page 84 for a reminder of the experiments.
8. Name four nutrients necessary for life.
9. The fossils in Figure 3 have been preserved for millions of years. Are they examples of organic or inorganic matter? Explain your answer.

Figure 3

10. Complete the following:
   (a) carbon dioxide + water $\rightarrow$ carbohydrate + ___________
   (b) $C_6H_{12}O_6 + O_2 \rightarrow$ ___________ + water
   (c) The chemical reaction in (a) is called ___________.
   (d) The chemical reaction in (b) is called ___________.

4.2 The Carbon Cycle


(a) carbohydrate


(b) protein

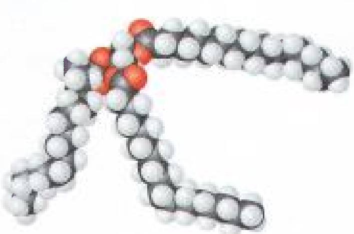

(c) lipid

Figure 1
Important organic compounds found in food include (a) carbohydrates, (b) proteins, and (c) lipids.

Carbon is important in ecosystems because it is the key element in all living organisms. Carbon compounds are the basis for most biological molecules. The food you eat contains carbon (Figure 1). Carbohydrates are carbon compounds that organisms consume to gain useable energy. Proteins are carbon molecules that form structural parts of organisms and control body functions. Lipids also contain carbon; they serve as a long-term storage of energy and provide insulation against heat loss. Through the process of digestion, these complex organic compounds are broken down into simpler molecules that your cells use to build other complex molecules that become part of your own structure.

Sources of Carbon

Carbon is found not only in the atmosphere but also in the ocean, in Earth's crust, and in all living things. **Carbon reservoirs**, such as oceans, forests, and fossil fuels, store and release carbon slowly. Reservoirs that absorb more carbon than they release are called **carbon sinks**. These include forests and oceans. Oceans store carbon in two forms. Some of the carbon dioxide from the atmosphere becomes dissolved in the water, where it is used by aquatic producers in photosynthesis. Some carbon dioxide reacts with salt water to form calcium carbonate ($CaCO_3$) that is used to make the shells and other hard structures in marine organisms such as molluscs and corals. When these organisms die, the calcium carbonate making up their skeletons becomes part of the ocean sediments that will eventually become limestone. The limestone caves shown in the chapter preview are carbon sinks. The carbon stored here is released very slowly by weathering and erosion. The bodies of living things, trees in particular, provide a large reserve of carbon. The old growth forests in British Columbia contain trees that are hundreds of years old. As they grow, each tree converts atmospheric carbon into carbohydrates, which become a significant carbon sink. Cutting down trees does not release the carbon, but it does prevent the trees from storing any more carbon. When trees are burned, carbon is then released back to the atmosphere. Many photosynthetic organisms die and are buried before they fully decompose. These organisms can become fossils that may be compressed to form **fossil fuels** such as coal, oil, and gas. These fossil fuels are an important reservoir of carbon; however, they become a **carbon source** when, during the burning of fossil fuels, more carbon is released than is stored.

The cycling of carbon through ecosystems is called the **carbon cycle**, illustrated in Figure 2. Photosynthesis and cellular respiration are responsible for most of the carbon recycling. Each year, approximately 70 billion tonnes of carbon from inorganic compounds are recycled into organic compounds through the process of photosynthesis. The processes of photosynthesis and cellular respiration complement each other. The products of photosynthesis are used as the reactants in cellular respiration. This ensures a balance of oxygen and carbon dioxide within the biosphere.

Photosynthesis occurs in the chloroplasts of green plants. The process uses light energy from the Sun to combine atmospheric carbon dioxide and water into glucose (a sugar), a carbohydrate.

The photosynthesis reaction is summarized in the following equation:

Reactants			*Products*	
$6CO_2$	$+ 6H_2O +$ energy	$\rightarrow$	$C_6H_{12}O_6$	$+ \quad 6O_2$
carbon dioxide gas	+ water + energy	$\rightarrow$	glucose (sugar)	+ oxygen gas

The carbon in the sugar (carbohydrates) is passed along food chains and webs by consumers and decomposers. It is finally released back to the atmosphere as carbon dioxide gas through the process of cellular respiration summarized below:

Reactants			*Products*	
$C_6H_{12}O_6$	$+ \quad 6O_2$	$\rightarrow$	$6CO_2$	$+ 6\ H_2O +$ energy
glucose (sugar)	+ oxygen gas	$\rightarrow$	carbon dioxide gas	+ water + energy

LEARNING TIP

Diagrams show written information in a simplified way. To prepare for reading Figure 2, survey the diagram, review the labels, and then read the caption. What does the diagram show? Follow the paths of the arrows. What do the arrows tell you? Try to visualize (make a mental picture of) the carbon cycle.

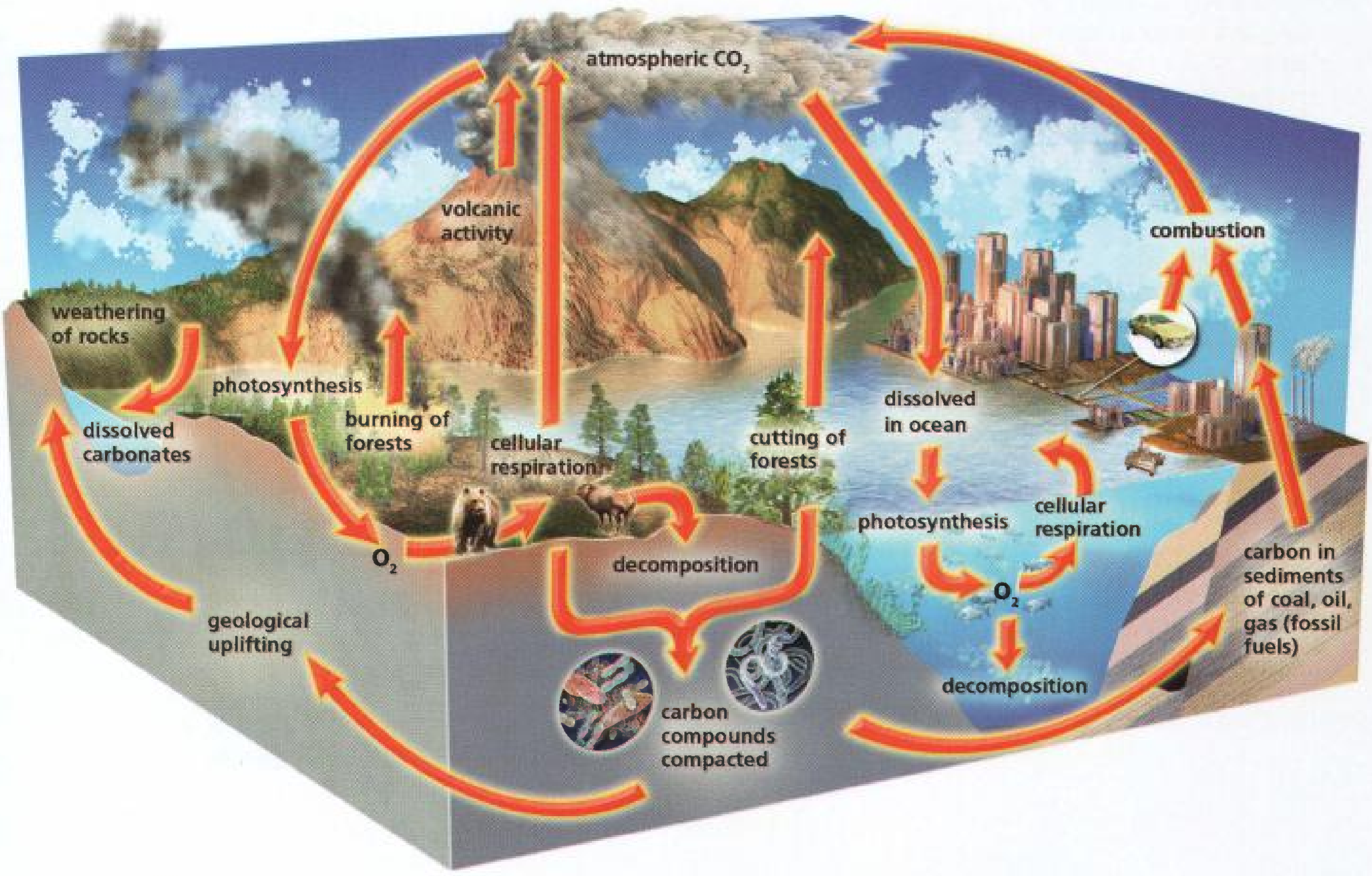


Figure 2 The carbon cycle

The carbon cycle is much more complex than the simple exchange of carbon from carbon dioxide and carbohydrates. Carbon is cycled through the biosphere in several processes other than photosynthesis and cellular respiration. For example, digestion and decomposition break down carbohydrates and return the carbon to the soil or water. Geological processes, such as volcanic activity, release carbon dioxide gas from inorganic carbon compounds such as limestone found in the crust. Erosion returns carbon compounds to the ocean where they are incorporated into ocean sediments. Human activity such as combustion or burning of fossil fuels, and cutting and burning forests, releases stored carbon into the atmosphere in the form of carbon dioxide.

To explore the carbon cycle in more detail, go to **www.science.nelson.com**

Carbon Compounds and Greenhouse Gases

Two carbon-containing compounds, carbon dioxide and methane (CH_4), are greenhouse gases. **Greenhouse gases** act like the glass of a greenhouse by trapping the heat from the Sun in the atmosphere resulting in the **greenhouse effect** (Figure 3). Without a certain amount of greenhouse gases, Earth would be too cold to sustain life as we know it. Unfortunately, too much trapped heat can cause dramatic changes to the climate. Many scientists attribute the increase in CO_2 to the steady increase in combustion of fossil fuels by humans. Also, changes in land use, such as the clearing of forests for agriculture and housing, have contributed to increased CO_2 levels by changing carbon sinks to carbon sources. Ruminant livestock, such as cows and sheep, and decomposition at landfills, produce much of the global methane emissions from human-related activities. A result of these human activities has been an increase in global temperatures. You will learn more about global climate change in Chapter 16.

STUDY TIP

Do exams make you nervous? First, define the problem. Is the problem a lack of organization and time management? Is it a lack of preparation? Or is it difficulties with note-taking and studying? Once you have defined the problem, then you can start generating solutions.

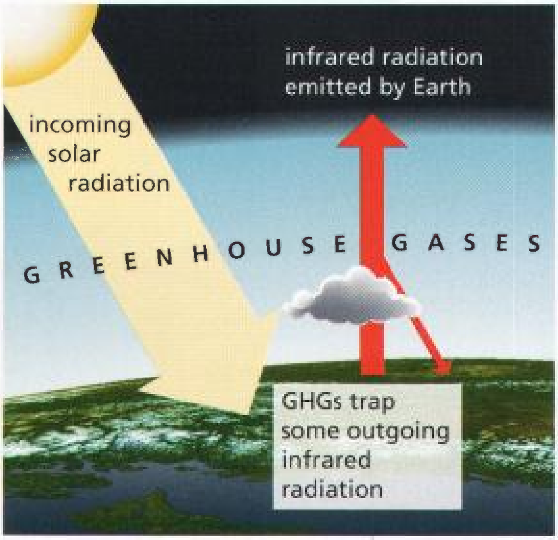


Figure 3 The greenhouse effect

TRY THIS: Carbon Dioxide and Photosynthesis

Skills Focus: predicting, recording, analyzing

In this activity, you will use plants, soda lime, and baking soda to predict and test the effects of carbon dioxide on photosynthesis.

Materials: Two similarly potted plants (such as begonias), clear plastic bags, elastic bands, ruler, one small plastic container of soda lime, one small plastic container of baking soda, apron, disposable gloves, safety goggles

Wear your apron, gloves, and goggles. Avoid touching your eyes after handling soil, soda lime, or baking soda.

1. Place a plastic container of soda lime on the soil of one plant and label accordingly.
2. Place a plastic container of baking soda on the soil of another plant and label accordingly.
3. Place the plastic bags over the plants and pots, and secure with the elastic bands as shown in Figure 4.
4. Predict what you will observe occurring to each plant over the next few days.
5. Observe, and record your observations.

A. Describe one way that you could control this experiment.

B. Describe the growth in each pot.

C. How do your results relate to your prediction?

D. Describe the effects of carbon dioxide on photosynthesis.

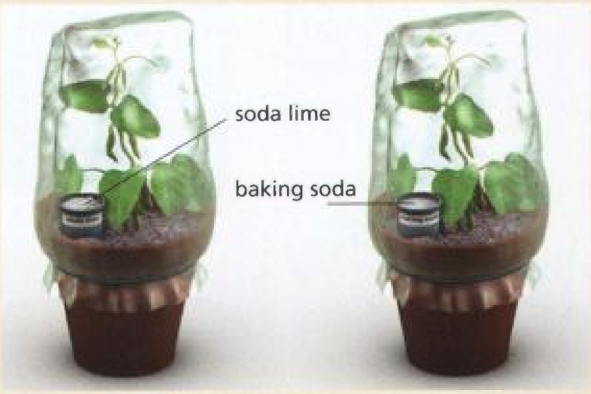


Figure 4

The Oxygen Cycle

Another vital nutrient for all organisms is oxygen. In Grade 8, you learned how the respiratory systems of humans use the oxygen from inhaled air to chemically break down food and release the energy necessary to live. Humans cannot survive very long without oxygen. After about five minutes without oxygen, human brain cells die and permanent brain damage can occur. Plants and other autotrophs also require oxygen, but they produce more than enough for their own cellular respiration and release the rest into the atmosphere or water.

The main source of oxygen is atmospheric air. Air is composed of two main gases: nitrogen (78 %) and oxygen (21 %). Other trace gases are also present (Figure 5).

Oxygen is the most abundant element in Earth's crust. It is combined with silicon along with other compounds to form silicates. Oxygen is also contained in water molecules. Oxygen gas dissolved in water is available to aquatic organisms in order for them to carry out cellular respiration. Oxygen is dissolved in water through the movement of water at the surface, for

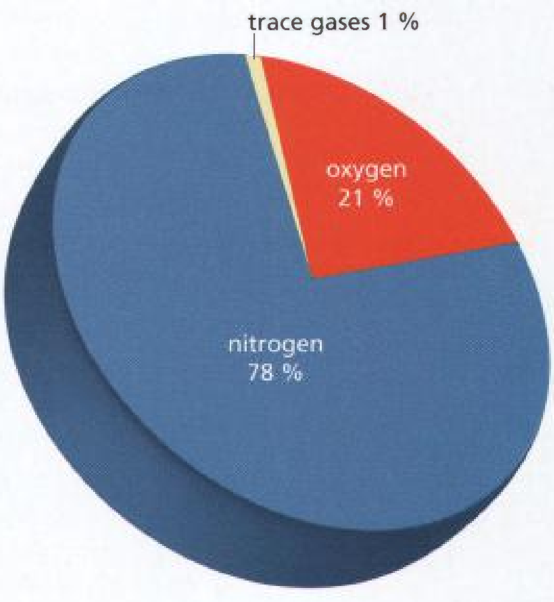


Figure 5 The composition of air

LEARNING TIP

Check your understanding. Ask yourself, "What are the most important points that I have learned about the carbon cycle?" If you have difficulty answering this question, reread the section to re-acquaint yourself with the important points.

example, when waves form (Figure 6). It is also released by aquatic plants and phytoplankton during photosynthesis. Recall from Chapter 2 that phytoplankton are photosynthetic aquatic micro-organisms that move through the water with water currents and produce much of the world's oxygen.

Figure 6 Oxygen gas is dissolved in water during movement at the surface, such as when water rushes over these rapids.

Did You KNOW?

The Night Shift

During the day when the Sun is available, plants produce 10 times more oxygen than they need. At night, however, they need to absorb oxygen from the atmosphere or water to carry out cellular respiration. This can produce low oxygen levels in some aquatic environments.

You have learned that oxygen is released into the atmosphere by plants during photosynthesis. The **oxygen cycle** describes the path of oxygen through ecosystems. It occurs in combination with the carbon cycle. Look back at Figure 2 and identify the role of oxygen within the carbon cycle. The oxygen cycle includes both photosynthesis and cellular respiration. Most organisms require oxygen to release the energy from carbohydrates, and they take in oxygen gas from the atmosphere or water. The oxygen reacts with the carbohydrates in food to produce the chemical energy necessary for life. Respiration that uses oxygen to release the energy in carbohydrates is called **aerobic respiration**.

There are some organisms, such as certain bacteria, that do not require oxygen to release energy from carbohydrates. **Anaerobic respiration** or **fermentation** occurs in the absence of oxygen. Certain bacteria use this method and instead of carbon dioxide and water, they release compounds such as methane, ethyl alcohol, and acetic acid (the main ingredient of vinegar).

Some plants and animals that usually get energy from aerobic cellular respiration are able to use anaerobic respiration when extra energy is needed. For example, human muscle cells are able to perform anaerobic respiration, but only for short periods of time, such as during intense exercise. During the anaerobic respiration, lactic acid is released, and accumulates in the muscle cells. It is this lactic acid buildup that causes sore muscles after exercise.

Plants are critical to the production of oxygen. Early in the history of life on Earth, only photosynthetic organisms existed. They could convert the carbon dioxide in the atmosphere along with water and the Sun's energy into carbohydrates and oxygen. The excess oxygen remained in the atmosphere or the oceans. Once enough oxygen was available, animals requiring a lot of oxygen could then be supported.

4.2

CHECK YOUR Understanding

1. Identify the appropriate organic molecule that matches the following descriptions:
   (a) forms structural components of organisms
   (b) provides immediate energy
   (c) controls body functions
   (d) provides insulation against heat loss
   (e) long-term storage of energy
2. List five sources of carbon. Identify if they are biotic or abiotic.
3. What are two uses for carbon dioxide in marine organisms?
4. Why are phytoplankton so important in marine ecosystems?
5. Explain how trees provide a large reserve of carbon. Give examples of animals that also store carbon.
6. Consumers release carbon dioxide as waste during cellular respiration. Give one example of how animals use carbon dioxide.
7. Why are some fossils considered to be significant reservoirs of carbon?
8. In your own words, explain why photosynthesis and cellular respiration are considered to be complementary processes.
9. Where does photosynthesis occur in plants?
10. Give the chemical formulas of the reactants and products of photosynthesis.
11. Name and complete the following word equation:
    ____________ gas + water + ____________
    produces ____________ + oxygen gas
12. Complete the following reactions by filling in the missing substances:
    $6CO_2 + 6$ ___ + energy $\rightarrow C_6H_{12}O_6 +$ ___
    Name of reaction: ___
    ___ + oxygen gas $\rightarrow$ ___ gas + water + energy
    Name of reaction: ____________
13. Name five processes that release carbon dioxide.
14. Explain the importance of decomposers in the carbon cycle.
15. Draw a simple diagram of the carbon cycle, using the following terms: consumers, photosynthesis, combustion, fossil fuels, decomposers.
16. Which of the following will add oxygen to the atmosphere?
    A. planting trees
    B. cutting down trees
    C. burning fossil fuels
    D. decomposing organisms
17. Scientists are concerned about large-scale clearing and burning of forests to make way for farmland and housing. Explain how the burning of forests could change the levels of both oxygen and carbon dioxide in the atmosphere.
18. How might changes in the oxygen levels in the atmosphere affect living things?
19. Describe the two methods by which oxygen becomes dissolved in water.
20. Describe an important role that phytoplankton play in the carbon cycle.

4.3 The Nitrogen Cycle

LEARNING TIP

Section 4.3 includes many new terms. As you read each new term, ask yourself, "Do I know the meaning of this term?" If not, write the term on a study card. On the back of the card, write the definition in a form that is meaningful for you.

All organisms need nitrogen. In living things, nitrogen atoms are used to synthesize nucleic acids and amino acids (Figure 1). As you learned in Grade 9, nucleotides are the building blocks of the nucleic acids DNA and RNA. These molecules are necessary to determine the special traits of each individual organism and to pass these traits on to offspring. Amino acids are the building blocks of proteins, which are critically important structural and functional molecules in living things.

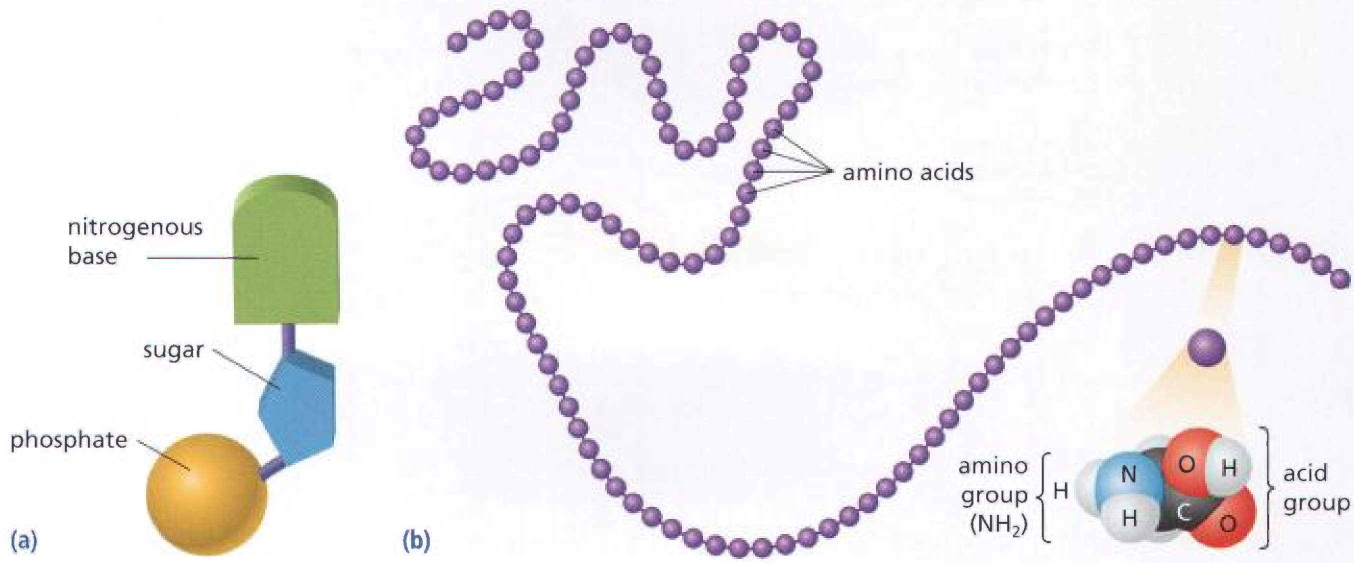


Figure 1 (a) Nucleic acids and (b) amino acids contain nitrogen.

Sources of Nitrogen

Nitrogen is the most abundant gas in the atmosphere. However, nitrogen gas (N_2) is a very stable molecule and is unavailable to most organisms because it is difficult to break the strong bonds within the nitrogen molecule. The movement of nitrogen between the abiotic and biotic components of the biosphere is called the **nitrogen cycle** (Figure 2). In order to be useful to organisms, nitrogen gas must first be converted to usable nitrogen compounds. 4A *Investigation*

4A *Investigation*

Effects of Nitrogen on Algal Growth

To perform this investigation, turn to page 101.

In this investigation, you will explore the effects of fertilizer on algal growth.

Nitrogen Fixation

The first step in the nitrogen cycle occurs when nitrogen from nitrogen gas is "fixed" or combined with hydrogen to produce ammonia (NH_3). This process is known as **nitrogen fixation**. Certain bacteria are capable of fixing nitrogen and they produce the majority of ammonia in water and soil. These nitrogen-fixing bacteria are also found in nodules on the roots of certain plants called **legumes**, which include crops such as peas, peanuts, soybeans,

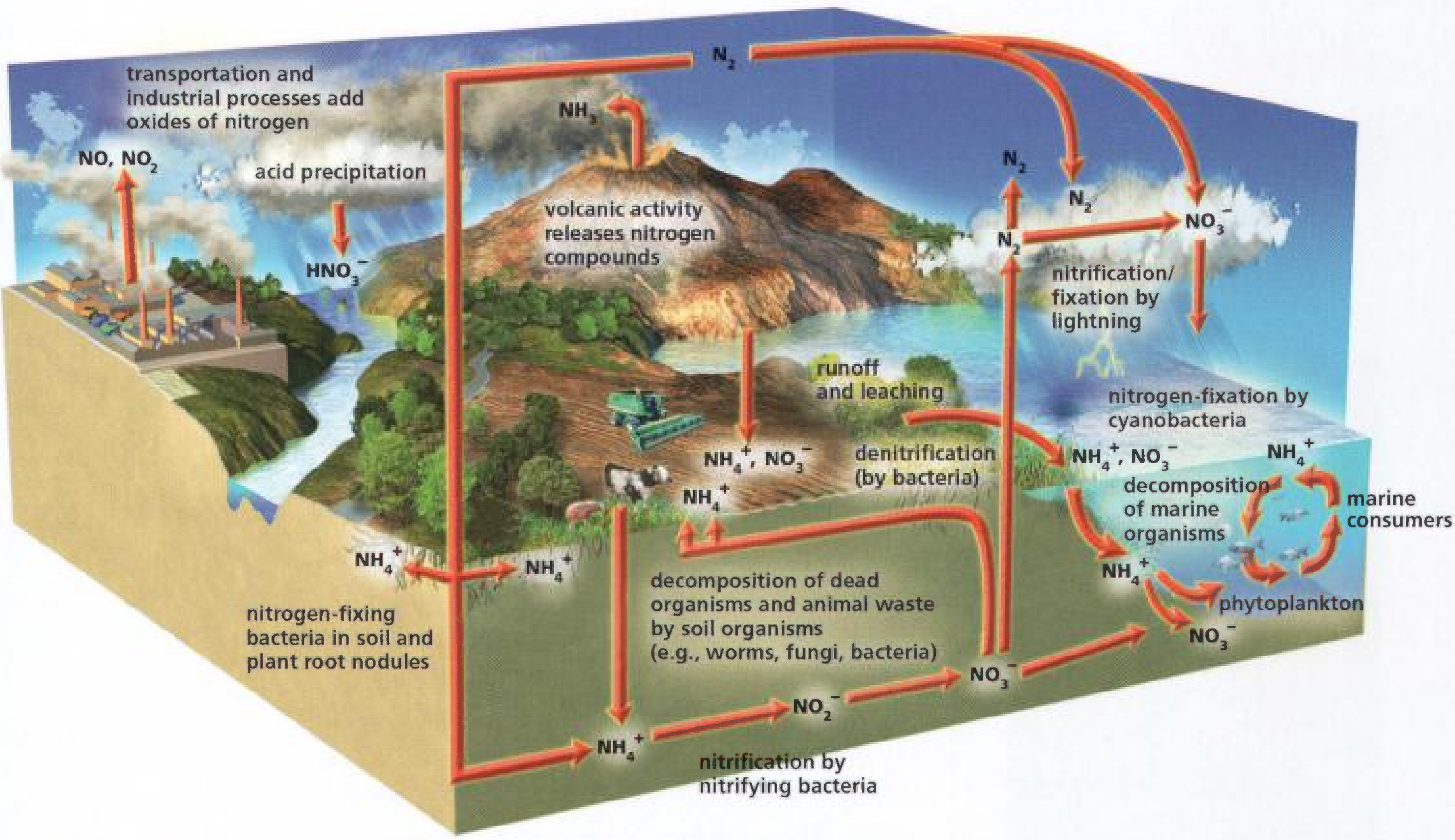


Figure 2 Nitrogen moves in a cycle through ecosystems from the environment through food chains and back into the environment.

clover, and alfalfa, and wild plants such as alders and lupins (Figure 3). The relationship between the plants and the bacteria is symbiotic and benefits both organisms, as well as other plants.

There is usually much more ammonia produced during nitrogen fixation than either the bacteria or plant require. The excess ammonia moves into the soil, where it dissolves in water and becomes available as ammonium ions (NH_4^+). On land, certain lichens, in a symbiotic partnership between fungus and cyanobacteria, can also fix nitrogen. These cyanobacteria also carry out the process of nitrogen fixing in aquatic ecosystems by converting nitrogen into ammonia that phytoplankton and multicellular aquatic plants absorb. Non-biological nitrogen fixation by lightning and cosmic radiation also makes atmospheric nitrogen available for plants, but in much lower quantities than from biological nitrogen fixers.

Figure 3 Nodules in the roots of this pea plant contain nitrogen-fixing bacteria.

Nitrification

Most plants require a combination of ammonium ions (NH_4^+) and nitrate ions (NO_3^-) for optimal growth. **Nitrate** is a highly soluble form of nitrogen containing both nitrogen and oxygen. It is produced from ammonium by bacteria in the soil. As shown in Figure 2, the process that produces nitrate from ammonium, is called **nitrification**. Nitrate is taken up by plants through their roots. Plants use the nitrate to synthesize the

Did You KNOW?

What's the Difference?

The polyatomic nitrate ion (NO_3^-) is often referred to as "nitrate" or "nitrates." Nitrite ions (NO_2^-) are often referred to as "nitrite" or "nitrites."

Figure 4 Insect-eating plants like this B.C. sundew can grow in nitrogen-poor soil.

nitrogen bases in nucleic acids (DNA and RNA), as well as the amino acids that are then assembled into proteins.

Animals obtain their nitrogen by consuming plants or by consuming other organisms that have consumed plants. The plant proteins are broken down into amino acids and reassembled into the specific proteins that the animals need. The nucleic acids are also digested into individual nitrogen bases and used to form the animal's own unique strands of DNA and RNA.

Decomposition and Denitrification

As you learned in Chapter 2, when organisms die, they decompose. Nitrogen compounds in nucleic acids and proteins are broken down by decomposers such as bacteria and fungi into the simpler ammonia and nitrate. These dissolve in water in the soil or other water sources, and are once again available to be absorbed by plants.

Another group of bacteria convert ammonia and nitrate back to nitrogen gas in the process of **denitrification.** These bacteria are anaerobic and grow best in the absence of oxygen. Aerating lawns in the spring adds more oxygen to the soil, which slows the growth of these bacteria and reduces the breakdown of nitrates into nitrogen gas. This keeps the nitrates available for plants and reduces the need for fertilizer use. Bogs are environments with low levels of useful nitrogen. This is because denitrification speeds up when the soil is very acidic or waterlogged and is therefore low in oxygen. Bogs only support certain types of plants that can tolerate low nitrogen levels. Unique to this environment are carnivorous plants such as pitcher plants and sundews (Figure 4). These plants actually trap insects and obtain part of their nitrogen by digesting them.

TRY THIS: Upsetting the Balance

Skills Focus: creating models, observing, recording

Materials: 2 1 L wide-mouth jars, pond water, 2 strands (10–15 cm) of aquatic plant (e.g., *Elodea*), 6 pond snails, 5 mL lawn fertilizer (10–20–10)

Fertilizers are toxic. Your teacher will give you specific information about the fertilizer that you are using. Clean any spills, especially on skin or clothing, with water. Wash your hands after the activity.

1. Label one jar "control" and the other "experimental."
2. Fill both jars with pond water.
3. Add one strand of aquatic plant and three snails to each jar.
4. Add 5 mL of fertilizer to the experimental jar.
5. Put both jars on the windowsill or in a bright location.
6. Record observations each day for 2 weeks.

A. Identify the roles of the aquatic plant and the snails in your ecosystem.
B. What other organisms may be present in your ecosystems?
C. Describe the purpose of the control jar.
D. Explain the changes you observed.
E. Explain how sewage entering a lake could have an effect on the plant growth in the lake.

4.3 CHECK YOUR Understanding

1. Name three compounds that contain nitrogen.
2. Nitrogen gas is the most abundant gas in the atmosphere. Explain why it is not useful to most organisms in its atmospheric state.
3. What are nitrogen-fixing bacteria? Where are they found?
4. Name the nitrogen molecule that results from nitrogen fixation. Write its formula.
5. Explain the symbiotic relationship between nitrogen-fixing bacteria and the plants they inhabit.
6. List four plants that carry out nitrogen fixation.
7. Name the following nitrogen polyatomic ions or compounds.
   (a) NO_3^-
   (b) NO_2^-
   (c) N_2
   (d) NH_3
   (e) NH_4^+
8. How do most plants get their nitrogen? How do animals get nitrogen? Explain the difference.
9. What do plants do with nitrogen?
10. Explain the difference between nitrogen fixation and nitrification.
11. Name two ways that nitrification occurs.
12. Plant and animal proteins are not all the same. Explain how animals can get the proteins they need by consuming plants.
13. An experiment was performed on bacteria living in the roots of certain plants. The results showed that during the nitrogen cycle, the bacteria
    A. denitrify nitrogen compounds.
    B. convert nitrogen gas into ammonia.
    C. convert nitrogen gas into plant proteins.
    D. convert nitrogen compounds into nitrogen gas.
14. What adaptations do plants that live in low nitrogen habitats, such as the tundra ecosystem in Figure 5, possess?

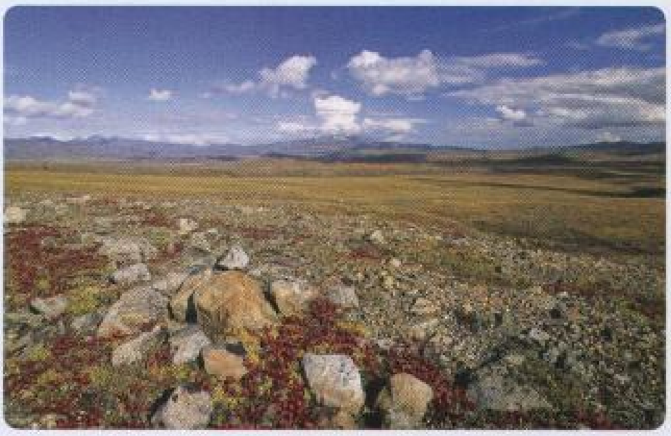


Figure 5

15. Farmers sometimes alternate crops that require large amounts of nitrogen, such as corn, with alfalfa that usually is less valuable in the market than corn. Explain why farmers would plant a crop that provides less economic value.
16. Draw a simple diagram of the nitrogen cycle using the following terms: nitrogen fixation, nitrification, decomposition, and denitrification.
17. For each description, indicate whether the process is nitrification, denitrification, or nitrogen fixation.
    a) occurs as material decomposes
    b) can be caused by lightning
    c) increases levels of nitrate in soil
    d) involves root nodules of legumes
    e) occurs as bacteria convert ammonium ions to nitrate ions
    f) occurs as bacteria convert nitrogen gas to ammonium ions
    g) increases levels of atmospheric nitrogen

4.4

Explore an Issue

DECISION MAKING SKILLS

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

Sustainable Agriculture

Over the past 60 years, numerous technologies have allowed for a dramatic increase in world food production. These include improvements in equipment for farming and fishing, genetically engineered high-yield and disease-resistant crops, and chemical pesticides and fertilizers to enhance crop yield. While these technologies have been effective in increasing the amount of food produced, they have also had significant impacts on the environment.

Did You KNOW?

Adding to the Cycle

N–P–K fertilizers are composed of combinations of nitrogen, phosphorus, potassium, and other minor nutrients, all necessary for healthy plant growth. For example, a 10–15–10 fertilizer contains 10 % nitrogen, 15 % phosphorus (as P_2O_5), and 10 % potassium (as K_2O). The other 65 % is filler that may or may not contain other nutrients. A 10 kg bag of 10–15–10 fertilizer would have 1.0 kg of nitrogen, 1.5 kg of P_2O_5, and 1.0 kg of K_2O.

The Issue: The Impact of Agricultural Practices

The current use of fertilizers is not healthy for the environment. Long-term effects of using fertilizers are known to damage ecosystems, including those that are located some distance from where the fertilizers were applied. On the other hand, the advantage of this agricultural practice is that fertilizers increase crop yields and are cost efficient. However, sustainable agriculture must produce enough crops for the world's increasing population, as well as produce crops without causing permanent damage to the environment. As a result, the agriculture industry is being challenged to develop and use alternatives that will not interfere with the natural cycling of Earth's matter.

Statement

Agriculture in British Columbia should apply only sustainable, environmentally friendly fertilizers for its agricultural crops.

Background to the Issue

The present methods used to grow food to meet the needs of the world's population include the use of chemical fertilizers. Fertilizers are added to the soil when naturally occurring nutrients have become depleted because the same crops are harvested on the same fields from year to year. Chemical fertilizers replace nutrients such as nitrogen, phosphorus, and potassium (Figure 1). Unfortunately, these added chemicals disrupt the normal cycling of matter in ecosystems. The main problem is the contamination of soil and water. Nitrogen from fertilizers is converted to nitrates in the soil, and can leach into ground water, affecting drinking water supplies and bodies of water far from the fields. Chemical fertilizers also add phosphorus to the soil. When the phosphorus leaches into the ground water and gets transported to other bodies of water, it promotes increased algal growth. When the algae die populations of decomposers increase, depleting the

Figure 1 Many of the world's crops are produced with the help of chemical fertilizers.

oxygen in the water and causing problems for other aquatic organisms, such as fish and amphibians (Figure 2).

Clearly, there are both advantages and disadvantages of using chemical fertilizers. Table 1 outlines some of these.

Table 1 Advantages and Disadvantages of Chemical Fertilizers

Advantages	Disadvantages
increases crop yields	no organic material is added to the soil
lowers production costs	only three essential nutrients are added to the soil
makes nutrients immediately available to plants	makes nutrients available for only a short period of time, and leaches into soil and ground water
makes farming profitable	uses large amounts of energy for production
	releases nitrous oxide, a damaging greenhouse gas

Figure 2 When algae decompose in fresh water, the oxygen in the water is used up and other aquatic organisms may die from lack of oxygen.

What Can Be Done?

There is no doubt that current agricultural practices are damaging the environment. However, the world's population is growing and enough food must be produced to avoid widespread starvation. A balance must be found between permanently damaging the environment and not producing enough food to feed the growing population.

There are some alternatives to chemical fertilizers, including the use of organic fertilizers such as compost and manure. Other techniques, such as crop rotation, can be used to increase sustainable agriculture but they require more time and money. This is important because agricultural practices must be profitable in order to be sustainable. Research is focusing on other alternatives to increase yields.

Make a Decision

1. In groups, research the issue to learn more about perspectives on current sustainable agriculture practices and the use of chemical fertilizers. Consider the present and future environmental benefits of these practices, as well as impacts on the economy.

   www.science.nelson.com GO

2. Discuss which perspectives are the most important. Explain or justify your position using your research to support your decision. Do the benefits of your position outweigh the risks, or vice versa?
3. Decide whether you agree or disagree with the statement.

Communicate Your Position

4. Prepare a presentation that summarizes your position on the issue. Prepare your presentation as either a debate or a position paper. Be sure to support your position with evidence. Be prepared to answer questions to support your position.

LEARNING TIP

When taking a position on an issue, it is helpful to step into the person's shoes and imagine what it is like to be him or her.

4.5 The Phosphorus Cycle

Phosphorus is an important element in several biological molecules. For example, the nucleic acids, DNA and RNA, have backbones of sugar and phosphates. Animals incorporate phosphates into their shells, bones, and teeth. As well, all cells are surrounded by a selectively permeable membrane made of phospholipids (Figure 1). Phospholipids are made of fat molecules with a phosphate group attached. Energy in all organisms is stored in a molecule called adenosine triphosphate (ATP) that includes three phosphate groups (Figure 2).

To learn more about the phospholipid bilayer in cell membranes, go to www.science.nelson.com

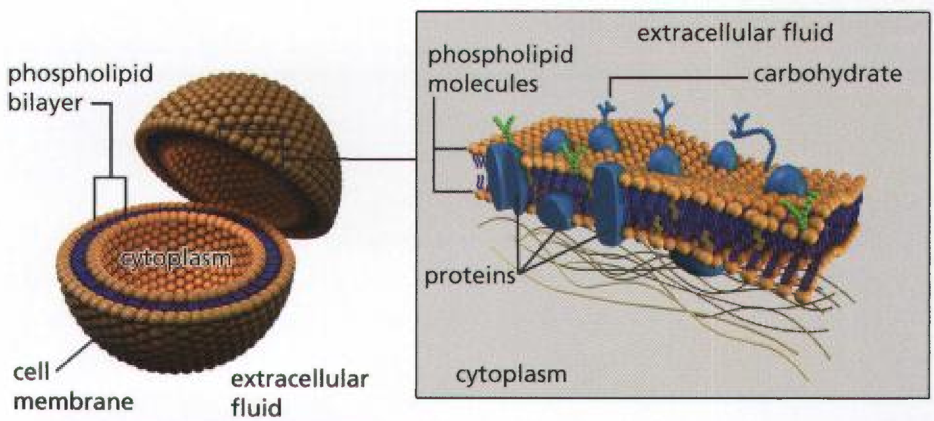


Figure 1 Cell membranes are composed of two layers of phospholipids, along with proteins and carbohydrates.

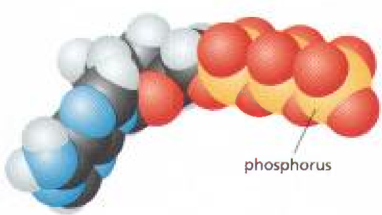


Figure 2 ATP (adenosine triphosphate) contains phosphorus. Energy is released when the bonds between the phosphate (PO_4) groups are broken.

Sources of Phosphorus

Unlike carbon, oxygen, and nitrogen, phosphorus does not have a gaseous atmospheric form. The **phosphorus cycle** describes the path of phosphorus through ecosystems (Figure 3). All phosphorus originates from the weathering of sedimentary and metamorphic bedrock in Earth's crust. **Phosphate ions** (PO_4^{3-}) are soluble in water and can be dissolved out of rock into soil or water environments through the process of weathering. Producers absorb the phosphate ions from the soil, making them available to other organisms in the food chain.

Dissolved phosphates are also carried to the ocean from the land via rivers and runoff. Algae and other aquatic plants absorb these phosphates before they become trapped in sediments. Animals eat the plants and use the phosphates to grow shells, bones, and teeth, as well as the biological molecules described above. The cycle continues in two directions.

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 details about something.

The Short and the Long Phosphorus Cycle

A relatively short cycle occurs when organisms die and decompose. The phosphates are released by decomposers, become dissolved in water, and are made available to producers. A longer cycle occurs when animals die and the

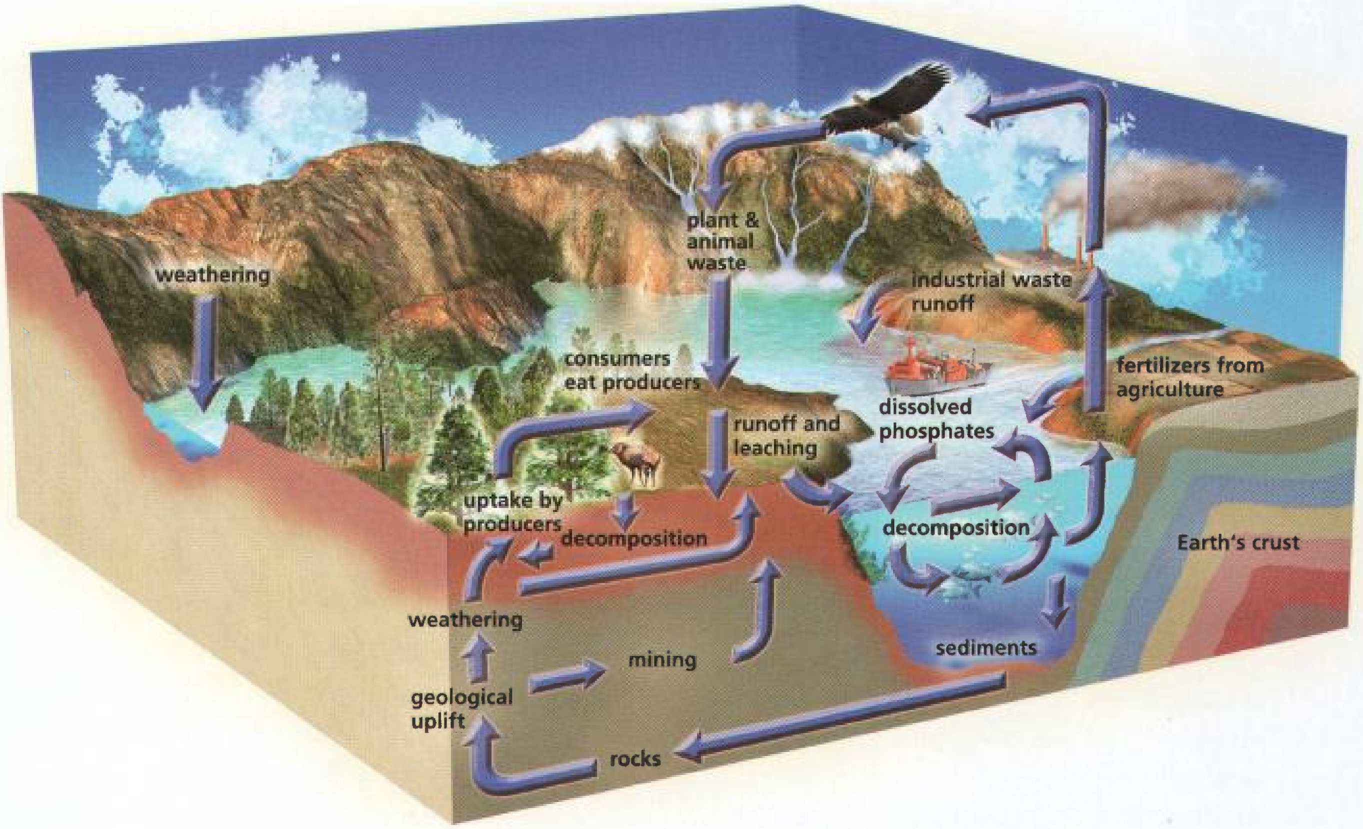


Figure 3 Phosphorus cycles both in a short time and in a longer geological time.

elements in their bodies that contain phosphates sink and are deposited on the ocean floor. Once these phospates are covered with sediments, they will eventually become rock. The phosphates remain trapped until a geological event, such as an upheaval or a geological uplift exposes the sedimentary rock to weathering once more. This route cycles the phosphorus over geological time.

To learn more about the phosphorus cycle, view the animation found at
www.science.nelson.com

Mycorrhizae

A symbiotic relationship exists between certain microscopic fungi and the roots of most plants. These fungi are called **mycorrhizae;** *myco* means "fungus" and *rhizae* means "roots" (Figure 4). The fungus increases the solubility of phosphate, making it more readily available for the plant. In return, the plant provides carbohydrates produced during photosynthesis for the fungus. Mycorrhizae increase the solubility of natural soil phosphates as well as the added phosphates that are present in fertilizers.

Figure 4 Symbiotic fungi living in the roots of most plants enhance the uptake of phosphates by the plants.

Humans and Phosphorus

Human activity can also add phosphorus to ecosystems. Farmers add commercially prepared fertilizers made with phosphorus as well as nitrogen and potassium to their fields. Animal manure, containing phosphorus, is also applied to enrich the soil. Outflows from human sewage treatment plants and industrial processes also add phosphates to water sources.

4.5 CHECK YOUR Understanding

1. Name three places where phosphorus is found in living things.
2. What is the original source of all phosphorus?
3. Explain the role of weathering and the rock cycle in making phosphorus available for living organisms.
4. Describe the form of phosphorus that plants can absorb.
5. Which of the following describes how phosphorus is made available to producers?
   A. weathering releases phosphorus from rocks
   B. lightning fixes phosphorus in the atmosphere
   C. respiration releases phosphorus into the atmosphere
   D. photosynthesis releases phosphorus into the atmosphere
6. How do consumers acquire their phosphorus?
7. Explain the short phosphorus cycle and the long phosphorus cycle.
8. Which of the following are true for phosphorus?

I	dissolved in water
II	present in the atmosphere
III	stored in sediments

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II, and III
9. Draw a simple diagram of the phosphorus cycle using the following terms: weathering, decomposers, ocean sediments, geological uplift.
10. How is the phosphorus cycle different from the carbon, oxygen, and nitrogen cycles?
   A. phosphorus has no atmospheric form
   B. phosphorus does not dissolve in water
   C. phosphorus does not form compounds
   D. phosphorus only forms solid compounds
11. Explain the symbiotic relationship of mycorrhizae with plants.
12. Phosphorus is sometimes called a limiting nutrient because without it, plants cannot grow properly. Explain how there could be a shortage of phosphorus in some soils.
13. Animal manure is often spread over agricultural fields before planting. Explain how this enhances crop growth.
14. The rate of phosphorus cycling is linked to the rate of decomposition. Explain this statement.
15. Which of the following processes would cause a decrease in phosphate levels of soil?
   A. decomposition of animal waste
   B. leaching of phosphate into soil
   C. formation of deep ocean sediments
   D. uptake of phosphates by terrestrial organisms
16. Which of the following processes would cause an increase in phosphate levels of soil?
   A. runoff and leaching
   B. mining of phosphates in soil
   C. growth of terrestrial vegetation
   D. application of fertilizer to farmland

4A Investigation

Effects of Nitrogen on Algal Growth

In the spring, runoff from melting snow that reaches lakes can contain nitrogen fertilizers from farms.

Question

How does fertilizer in aquatic ecosystems affect the growth of algae?

Hypothesis

Write a hypothesis that explains the effects of fertilizer on algal growth.

Prediction

Make a prediction about how nitrogen will affect the growth of algae.

Experimental Design

You will design and build two identical aquatic ecosystems. You will design an experiment to test the effects of fertilizers on algal growth.

Materials

- balance
- various containers
- pond water
- filters
- funnels
- ring stand
- beakers
- fertilizer sample
- other materials you feel necessary

Fertilizers are toxic. Your teacher will give you specific information about the fertilizers that you are using. Clean any spills, especially on skin or clothing, with water. Wash your hands after the activity.

Procedure

1. With a partner, design and draw your ecosystems and have them approved by your teacher.
2. Build your ecosystems.
3. Design your experiment and have it approved by your teacher.
4. Design a data table to record your results. Observe, and record your observations each day for one week.

INQUIRY SKILLS

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

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Which ecosystem had the most algal growth? How did you determine this?

(b) What did you observe in the ecosystem with the most algal growth?

(c) Was your prediction correct? Explain.

(d) Do your results support your hypothesis?

(e) Examine the original container that the fertilizer came in. Explain what the numbers stand for.

(f) List some of the molecules in plants that contain the chemicals in the fertilizer.

Evaluation

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

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

(i) List the factors that affected the growth of the algae.

(j) Name the nutrients you tested.

Synthesis

(k) Explain any differences in the algal growth.

(l) What effects could increased algal growth have on aquatic ecosystems?

CHAPTER 4

Review

Nature's Recycling Programs

Key Ideas

Matter is classified as organic or inorganic.

- There is a finite amount of matter on Earth.
- Organic matter always contains the elements carbon and hydrogen, although other elements may also be present.
- Inorganic matter does not contain both carbon and hydrogen.

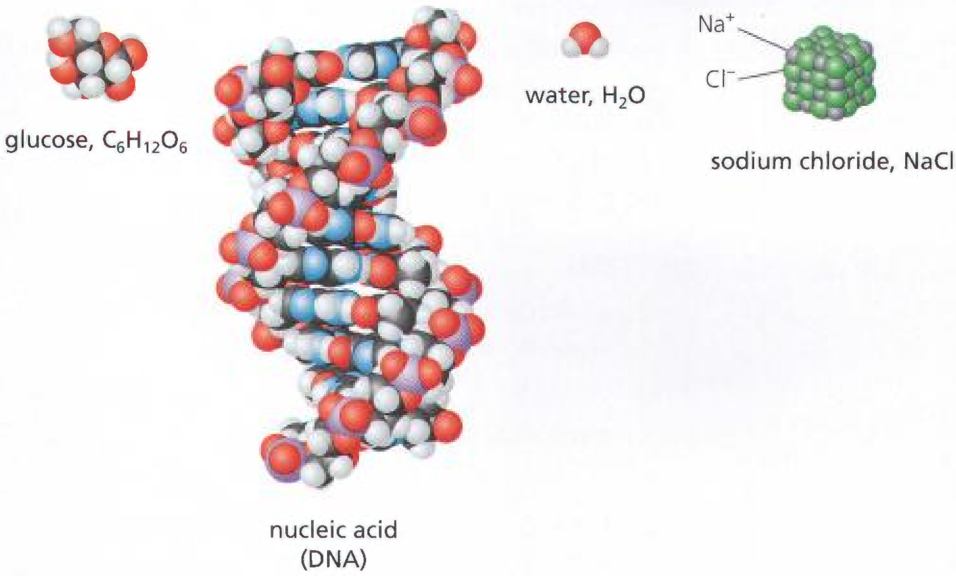


Table 1 Some Common Organic and Inorganic Compounds

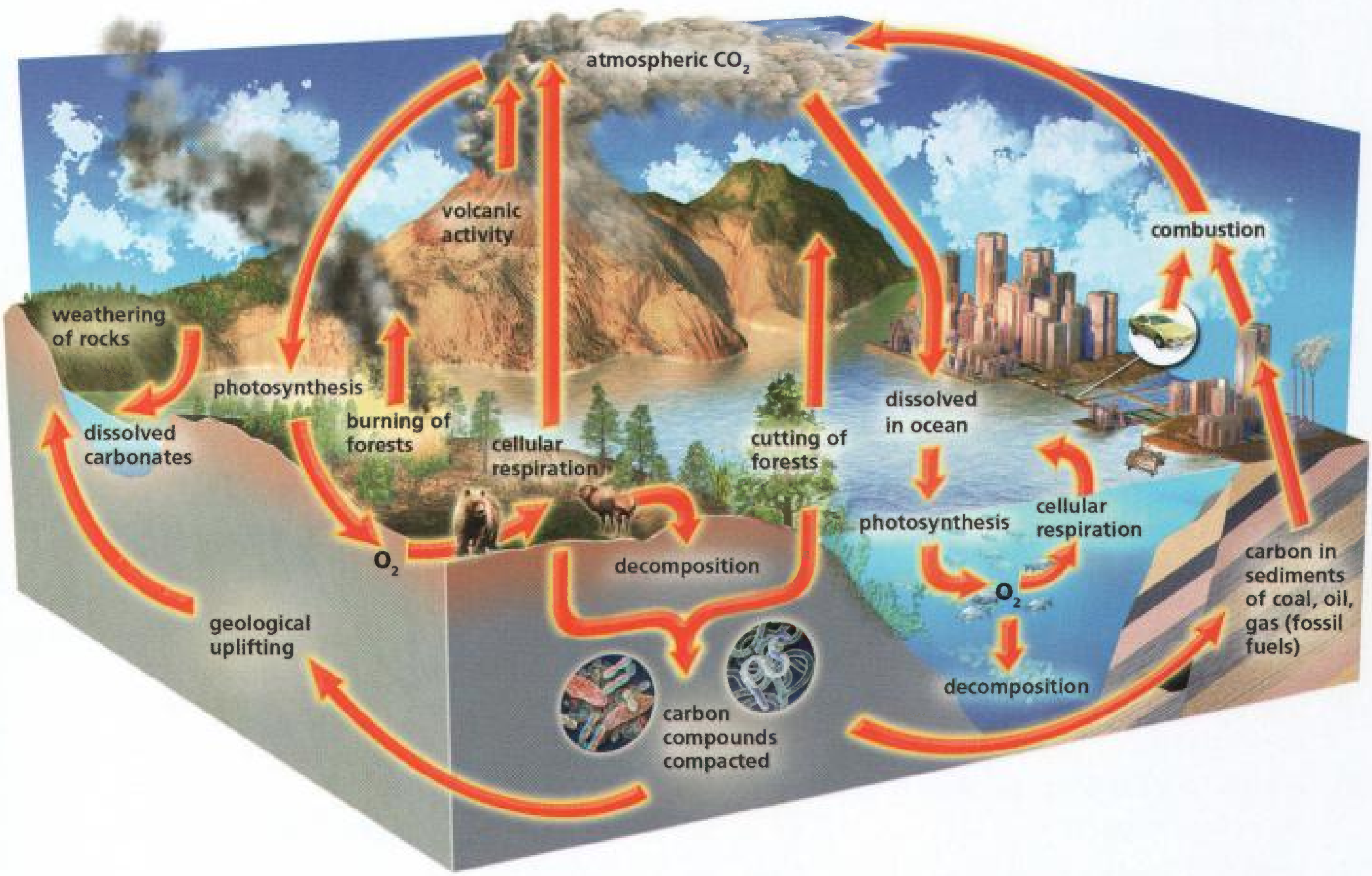
Organic compounds	Inorganic compounds
carbohydrates	water
proteins	salts
nucleic acids (e.g., DNA)	ammonia
lipids	oxides

Vocabulary

organic, p. 83
inorganic, p. 83
photosynthesis, p. 83
cellular respiration, p. 83
carbon reservoir, p. 86
carbon sink, p. 86
fossil fuel, p. 86
carbon source, p. 86
carbon cycle, p. 86
greenhouse gases, p. 88
greenhouse effect, p. 88
oxygen cycle, p. 90
aerobic respiration, p. 90
anaerobic respiration, p. 90
fermentation, p. 90
nitrogen cycle, p. 92
nitrogen fixation, p. 92
legume, p. 92
nitrate, p. 93
nitrification, p. 93
denitrification, p. 94
phosphorus cycle, p. 98
phosphate ion, p. 98
mycorrhizae, p. 99

Nutrients cycle between biotic and abiotic components of ecosystems.

- All organisms contain the nutrients carbon, oxygen, nitrogen, and phosphorus.
- The carbon cycle and the oxygen cycle are connected through the processes of photosynthesis and cellular respiration.
- The nitrogen cycle moves from nitrogen fixation to nitrification to denitrification.
- Phosphorus does not have an atmospheric form. The phosphorus cycle begins with phosphorus released from rocks.



Many of these questions are in the style of the Science 10 Provincial Exam.
The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Which of the following groups include only organic compounds?
   A. CH_4, CO_2, NH_3, H_20
   B. CO_2, H_2O, $C_2H_4O_2$, $C_3H_6O_3$
   C. CO_2, $C_6H_{12}O_6$, $C_2H_4O_2$, CH_4
   D. $C_6H_{12}O_6$, CH_4, $C_3H_8O_3$, $C_9H_{18}O_2$

2. Draw a two-column table and classify these substances as organic or inorganic.
   (a) sugar
   (b) water
   (c) gasoline
   (d) ammonia
   (e) carbon dioxide
   (f) protein

3. List the reactants of photosynthesis.

4. List the reactants of cellular respiration.

5. For each of the following nutrients, list two compounds or polyatomic ions where each is found:
   (a) carbon
   (b) oxygen
   (c) nitrogen
   (d) phosphorus

6. What are fossil fuels? Explain how they are formed.

7. Explain how carbonates form in the ocean.

8. How do oceans act as carbon reservoirs?

9. Describe the role that bacteria play in the nitrogen cycle.

10. Explain how lightning can make nitrogen available to organisms.

11. Describe how the phosphorus cycle is different from the carbon, oxygen, and nitrogen cycles.

12. What is the main source of phosphorus?

13. Explain how the phosphorus in animals re-enters the phosphorus cycle.

K 14. Which of the following contain phosphorus?

I	Carbohydrates
II	ATP
III	Cell membranes

   A. I only
   B. I and II only
   C. II and III only
   D. I, II, and III

Use What You've Learned

U 15. Which of the following processes and events may release carbon into the atmosphere?
   A. photosynthesis, cellular respiration, nitrogen fixing
   B. volcanic eruptions, cellular respiration, forest fires
   C. nitrification, burning of fossil fuels, greenhouse effect
   D. forest fires, photosynthesis, decomposition of dead organisms

16. How are digestion and decomposition similar? How are they different?

17. Forests are often described as carbon sinks or reservoirs. Explain what this means.

18. Explain the importance of decomposers in the carbon and oxygen cycles.

U 19. Which of the following groups of molecules all contain nitrogen?
   A. carbohydrates, carbonates, nitrates, gasoline
   B. proteins, enzymes, hormones, carbohydrates
   C. nucleic acids, proteins, ammonia, amino acids
   D. nucleic acids, amino acids, carbohydrates, carbon dioxide

20. Space probes sent to the Moon and Mars collected soil samples that were examined for organic compounds. Why would scientists want to know if organic substances were present in these soil samples?

21. Fertilizers contain nitrates and phosphates that are both necessary for plant growth. Explain how the application of fertilizers can cause environmental problems.

Think Critically

22. Three different ecosystems—tropical rainforest, temperate rain forest, and grassland—were analyzed for their nitrate levels during the same month. The amount of nitrates in the top layer of each soil were determined. Using the same method, the masses of nitrates in living things (biomass nitrates) in each study area were also calculated. Table 1 shows the results for each ecosystem identified by a number.

Table 1

Study area	Soil nitrates	Biomass nitrates (kg/ha)	Soil temperature
1	30	90	25
2	10	175	19
3	2	270	30
tundra	?	?	?

(a) Identify each numbered ecosystem as tropical rainforest, temperate rainforest, or grassland. Give reasons to support your answers.
(b) In which ecosystem does nitrogen cycle most rapidly?
(c) Predict what data might be collected from a tundra ecosystem. Explain your prediction.

23. Earthworms are important soil invertebrates that help decomposition and improve soil quality. Ploughing fields actually reduces the population of earthworms. Use the Internet to research the role of earthworms.

www.science.nelson.com GO

24. Table 2 shows the mass of carbon that moves through the biosphere per year.

Table 2

Carbon movement	Mass of carbon per year (10^{13} kg)
From atmosphere to oceans	107
To atmosphere from oceans	105
To atmosphere from fossil fuel burning	5
From atmosphere to plants	120
To atmosphere from net burning of plants	2
To oceans from runoff	0.4
To atmosphere from soil	60
To atmosphere from plants	60

(a) Draw a bar graph showing the factors that increase and decrease the levels of CO_2 in the atmosphere.
(b) Calculate the amount of carbon entering the atmosphere as CO_2 each year, and the amount of carbon leaving the atmosphere. Is the amount of atmospheric CO_2 increasing or decreasing?
(c) How much carbon is contributed to the atmosphere by burning forests? What other factor would be affected by burning trees?
(d) Make a list of actions that would reduce the flow of carbon dioxide into the atmosphere. How would these affect your life? Which actions are possible in your lifetime?

Reflect On Your Learning

25. Matter cycles endlessly through biotic and abiotic states. Think about an ecosystem close to you. Describe what it would look like in ten years if matter did not cycle?

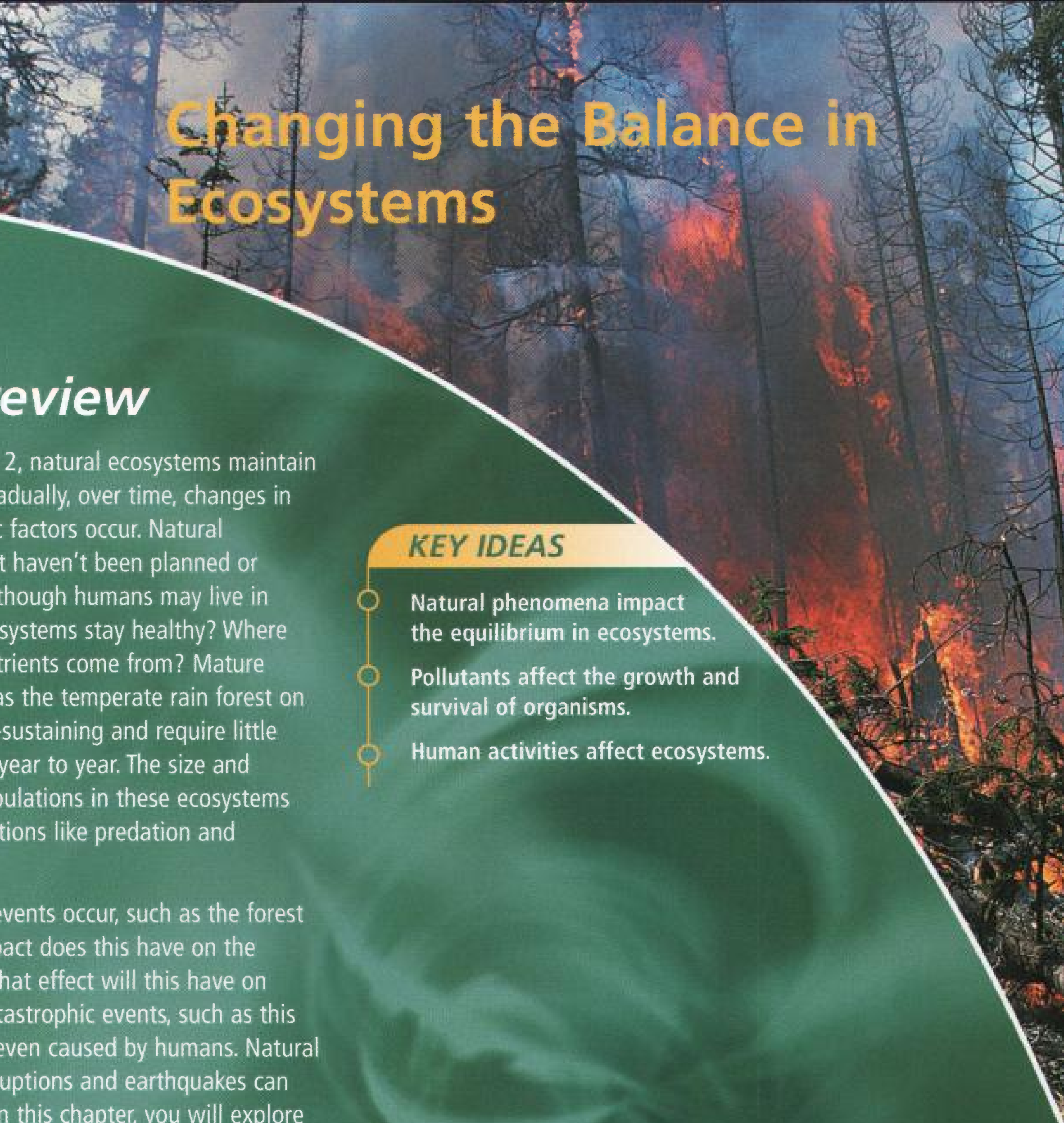
26. In your own words, describe the role of photosynthesis and cellular respiration in the cycling of matter. Why do you think these processes are often described as the most important processes on Earth?

Visit the Quiz Centre at

www.science.nelson.com GO

CHAPTER 5

Changing the Balance in Ecosystems



Chapter Preview

As you learned in Chapter 2, natural ecosystems maintain a dynamic equilibrium. Gradually, over time, changes in both the biotic and abiotic factors occur. Natural ecosystems are places that haven't been planned or maintained by humans, although humans may live in them. How do natural ecosystems stay healthy? Where do all of the necessary nutrients come from? Mature natural ecosystems, such as the temperate rain forest on Vancouver Island, are self-sustaining and require little additional materials from year to year. The size and number of the various populations in these ecosystems is kept in check by interactions like predation and competition.

Sometimes disastrous events occur, such as the forest fire shown here. What impact does this have on the organisms living there? What effect will this have on nutrient cycling? Some catastrophic events, such as this fire, can be influenced or even caused by humans. Natural events such as volcanic eruptions and earthquakes can also destroy ecosystems. In this chapter, you will explore the impacts of both natural and human events on ecosystems.

KEY IDEAS

- Natural phenomena impact the equilibrium in ecosystems.
- Pollutants affect the growth and survival of organisms.
- Human activities affect ecosystems.

TRY THIS: Extreme Events

Skills Focus: questioning, recording, communicating

In this activity, you will describe the characteristics of natural disasters in an acrostic poem. An acrostic is a word poem made of single letters, each letter taken from another word. For example,

Flames burning
Into the sky
Red and orange
Erasing the darkness

Materials: coloured felt markers or pencils, pen and paper

1. In your group or class, generate a list of natural disasters that might impact ecosystems. Choose one disaster to focus on.
2. Assign a group recorder and brainstorm a list of the characteristics of your disaster. Include possible impacts on ecosystems in your list.
3. Expand each characteristic so that the first letter of the phrase is one of the letters of your disaster.
4. Use the paper provided to make your acrostic poem. Include graphics.

5.1 Natural Phenomena and Ecosystems

Natural events, such as volcanic eruptions or earthquakes, are part of the dynamic quality of Earth and its ecosystems. These phenomena range in their impact on the environment. From mild earthquakes that affect few organisms to disastrous tsunamis that wipe out entire islands, healthy ecosystems will respond by adapting. Recovery may be immediate, occurring in a single growing cycle, or it may take decades or centuries for ecosystems to go through the stages of succession. Over time, natural succession may create similar ecosystems to those before the event, but not necessarily. The volcanic eruption of Mount St. Helens in Washington State in 1980 wiped out the surrounding ecosystems, destroying the living and changing the non-living (Figure 1).

LEARNING TIP

Preview Chapter 5 to note the headings, diagrams, tables, photographs, and words in bold. Based on your preview, make a prediction about what you expect to learn in this chapter.

(a)

(b)

Figure 1 (a) The May 18, 1980 eruption of Mount St. Helens caused debris flows that filled in river valleys and (b) created new lakes like Castle Lake.

Natural events are often described by their impact on humans since any damage they cause can be expressed in monetary terms. Property must be repaired or replaced. Economic loss due to forest fires or pine beetle infestations in B.C. is often significant in the affected communities. But, what about the impact on natural environments and the organisms living there? The immediate loss of life in natural populations is apparent, but these events also have positive ecological benefits when the ecosystems regenerate.

Loss of human life may be a consequence of natural events and cannot be described only in economic terms. The December 26, 2004 Indian Ocean tsunami, a large ocean wave generated by an earthquake beneath the ocean floor, resulted in approximately 230 000 human deaths in a single day (Figure 2)!

You can test your tsunami knowledge by going to **www.science.nelson.com** GO

(a) **(b)**

Figure 2 The town of Banda Aceh on the island of Sumatra, Indonesia, was literally wiped out by the December 26, 2004 tsunami. (a) Before the tsunami, and (b) after.

Weather-Related Phenomena

One of the serious natural disasters caused by changing climate in B.C. is the mountain pine beetle infestation. Historically, pine beetles only survived on older or weaker lodgepole pine trees. Adult pine beetles prefer large-diameter pine trees that are usually over 80 years old. However, the bark of these larger trees produces large amounts of resin that can kill the adult beetles. The population of pine beetles was kept in check as many larvae were killed off during the sustained colder winters.

Recent winters in central B.C. have been milder. This has allowed the larvae to survive inside the bark and digest the **sapwood.** Sapwood is the younger wood just inside the bark where most of the tree's nutrients are transported. The trees eventually die, leaving the forest with a red hue (Figure 3). The adult beetles can also introduce a fungus that colonizes the sapwood of the tree, obstructing water movement and preventing the tree's

LEARNING TIP

When you read critically you read to identify the writer's most important points, to recognize how they fit together, and to note your response to them. What are the important points in this section? What questions do you still have?

(a) **(b)**

Figure 3 Mountain pine beetle infested forests are easy to identify from the air. How can you tell which photo, (a) or (b), contains infected trees?

natural response of producing more resin. This parasitic fungus is called "bluestain" because of the blue colour that results in the damaged lumber. The most recent outbreak is the largest ever recorded in B.C., and the effects are spreading quickly, even beyond the borders into Alberta.

The death of countless lodgepole pine trees affects many other organisms in the ecosystem. Populations that rely on healthy forests for survival either move, diminish in size, or adapt. As well, there may be a succession-like shift in the natural variety of organisms as other wildlife moves in and takes advantage of the changing ecosystem. For example, woodpeckers that have adapted to eating the beetles below the bark are now more abundant.

Many other natural events are caused by extreme weather conditions. These include floods, droughts, fires, tornadoes, hurricanes, and ice storms. Table 1 summarizes the causes and impacts of a variety of natural weather events.

To learn more about the mountain pine beetle infestation in B.C., follow the links at **www.science.nelson.com**

Table 1 The Causes and Impacts of Natural Weather Events

Natural event	Cause	Description	Possible impacts on ecosystems positive (+) or negative (–)
Floods	• heavy rains • melting of heavy snowpacks • high tides and storms	• unusually large amounts of water overflow the banks of rivers and flood low-lying coastal areas	• habitat destroyed (–) • organisms drown or are washed away (–) • vegetation (food supply) damaged (–) • floodplains rejuvenated (+) • groundwater supplies replenished (+)
Droughts	• high temperatures and little rainfall over several seasons	• soil dries and becomes hard packed • water sources dry up • plants lose more water to evaporation	• habitat destroyed (–) • vegetation dies (–) • mobile organisms leave (–) • survivors are better adapted for adverse conditions (+)
Fires	• lightning strikes due to storms • dry conditions	• large stands of forests or grassland are burned	• habitat lost (–) • food sources destroyed (–) • mobile organisms leave or die (–) • pests killed (–) (+) • allows for germination of certain plants such as pine (+)
Tornadoes	• high winds and low pressure	• swirling funnel cloud that acts like a vacuum cleaner when it touches the ground	• tears up soil, vegetation, and organisms in its path (–)
Hurricanes	• low pressure area with rising warm air over tropical oceans	• heavy rain, high winds over the land	• habitat lost due to vegetation damaged by high winds and flooding (–)
Blizzards	• winter storms with high winds and cold temperatures	• lots of snow with drifts and ice forming	• habitats and food covered up (–) • organisms freeze or starve to death (–)
Infestations	• warmer than normal winters • longer summers • fire suppression	• overpopulation of pest species • some pests survive winter and continue to increase the population	• animal species continue to digest host plants (–) • micro-organisms continue growing on host causing damage (–) • destroys old and weaker individuals (+)

Geological Events

To view the various stages of Mount St. Helens before and immediately after the eruption, as well as more recently, go to **www.science.nelson.com**

Some natural phenomena are the result of geological activity in Earth's crust and below the surface. The eruption of Mount St. Helens and the Indian Ocean tsunami pictured earlier are two examples. Although both caused loss of human life and devastating environmental impact, they are both natural occurrences that are part of a dynamic Earth. Organisms were destroyed but new ecosystems are returning as the damaged areas go through the stages of succession (Figure 4).

Figure 4 The new soil created by the addition of ash from the eruption of Mount St. Helens provides nutrients for new plant species to take root. How did these plants get here?

TRY THIS: *Modelling a Tsunami*

Skills Focus: predicting, observing

In this activity, you will build a model of a tsunami.

Materials: a small plate, a rectangular pan, an 18 cm long small wooden dowel (or an unsharpened pencil, or chopstick), paper, masking tape, permanent marker

1. Cut a small piece of paper the width and height of the pan, so that the paper will fit on the inside edge (side) of the pan. Draw a landscape or a small town in the middle of the paper. Tape the paper securely to the inside edge of the pan.
2. Place the plate in the pan, upside down with one edge touching the opposite end of the pan from the paper. Tape the touching edge of the plate to the bottom of the pan. Make sure the other edge of the plate, which will be near the middle of the pan, is able to move up and down freely.
3. Tape the end of the dowel to the free edge of the plate so the dowel acts like a handle.
4. Fill the pan about halfway with water, so that the water is at the bottom edge of the landscape or town in your drawing.
5. Use the dowel to lift and lower the plate several times to create the tsunami.

A. Predict what will happen to the water and to your landscape.

B. What happens to the water level when you lift and lower the plate?

C. Predict what would happen to the wave if the water at the town end of the pan were shallower than the water where the wave was formed. If a deep water tank is available, test your prediction.

Earthquakes are another geological process that can have devastating effects on ecosystems. The displacement of the ground damages habitats and causes loss of life. Secondary effects such as landslides, flooding, and liquefaction also change ecosystems. Liquefaction occurs when the shaking causes saturated soil particles to behave like a liquid. Solid structures and vegetation sink. GO

Earthquakes that happen on Earth's crust under the ocean can produce tsunamis. Most of the damage occurs in coastal areas where the huge waves, generated when the moving water hits shallows, causing severe flooding. These geological processes are part of the natural recycling of Earth's nutrients. Table 2 describes common natural geological events.

To find out about the earthquakes near your home, go to **www.science.nelson.com** GO

Table 2 Impacts of Natural Geological Events

Natural event	Cause	Description	Possible impacts on ecosystems positive (+) or negative (–)
Volcanic eruptions	• movement below Earth's crust causing molten rock to ooze or erupt above surface	• release of rocks, lava, soot, mineral ash, and gases	• habitat destroyed (–) • vegetation covered by volcanic material, debris, and mudslides (–) • ash can remain in the atmosphere affecting weather (–) • mobile organisms leave (–) • ash deposits and weathering of lava deposits can yield new soils (+) • new lakes created (+)
Earthquakes	• movement of rock masses on Earth's continental crust	• severe shaking of crust results in landslides, liquefaction, and fissures	• habitat destroyed (–) • organisms covered by landslides (–) • vegetation (food supply) damaged (–) • populations of species separated and isolated (–)(+)
Tsunamis	• movement of rock masses on the ocean floor caused by earthquakes, volcanic eruptions, and landslides	• giant ocean waves that travel up to 800 km/h; when in shallow water close to shore, they can be as high as 30 m	• massive destruction and flooding to coastal areas (–) • wildlife destroyed or washed away (–) • sediment is carried inland by the high water providing new components for soil (+)(–)
Landslides	• movement of rock masses on Earth's continental crust causing soil and rock to loosen	• sudden downward movement of masses of rock and soil and vegetation	• habitat destroyed and wildlife killed (–) • soil, vegetation, and organisms torn up in its path (–) • water sources filled (+)
Avalanches	• movement of rock and snow masses on Earth's continental crust	• rapid movement of snow, ice, and rock down a mountainside	• habitat destroyed and wildlife killed or swept away (–)

5.1

CHECK YOUR Understanding

1. Name the two main categories of natural events.
2. For each of the following natural disasters, give one cause and one detrimental impact on ecosystems:
   (a) flood
   (b) fire
   (c) hurricane
3. For each of the following natural disasters, give one beneficial impact on ecosystems:
   (a) drought
   (b) tsunamis
   (c) infestations
4. Which of the following describes a tornado?

I	swirling funnel cloud
II	high winds
III	heavy rain

   A. I only
   B. I and II only
   C. II and III only
   D. I, II, and III
5. What factors have caused the mountain pine beetle (Figure 5) to have a devastating impact on B.C. forests over the last five years?

Figure 5

6. Which stage in the life cycle of the mountain pine beetle causes the most harm to pine trees? Explain your answer.
7. Some geological events can lead to the proliferation of species. Identify one event and explain how the proliferation can occur.
8. How are landslides and avalanches similar and how are they different?
9. Explain why areas around volcanoes are sometimes called "succession laboratories."
10. How can volcanic eruptions improve the makeup of soil?
11. (a) What is a tsunami?
    (b) Where does a tsunami originate?
12. Suggest why natural disasters are often described by their impact on humans and not on the ecosystem damage that results.
13. Explain how forest fires can lead to succession.
14. Snowstorms are common natural events that cause many problems for people in B.C. Refer to Table 1 on page 109 and create a row for snowstorms. Complete the row by adding at least one positive and one negative possible impact on ecosystems.
15. Refer to Table 2 on page 111 and examine the column of the possible impacts on ecosystems, both positive and negative. Choose two possible negative impacts, and describe a situation where they could be positive. Choose two possible positive impacts, and describe a situation where they could be negative.
16. Geological events often cause habitat loss. Choose a geological event and an animal, and speculate on how the animal might survive the event.

5.2 Pollutants in Ecosystems

Healthy natural ecosystems exist in a dynamic equilibrium. The abiotic and biotic components are kept in balance by the complex interactions in the ecosystem. This balance is seen in the cycling of nutrients when organisms die and decomposers make their components available to other organisms. As you learned in Chapter 2, biodegradation by living organisms such as bacteria reduces waste materials, converting them into useful substances for other organisms. Another example of balance in ecosystems is the cycling of carbon you learned about in Chapter 4, where carbon dioxide, which is a waste product of cellular respiration in most organisms, becomes a vital reactant for photosynthesis in producers (Figure 1).

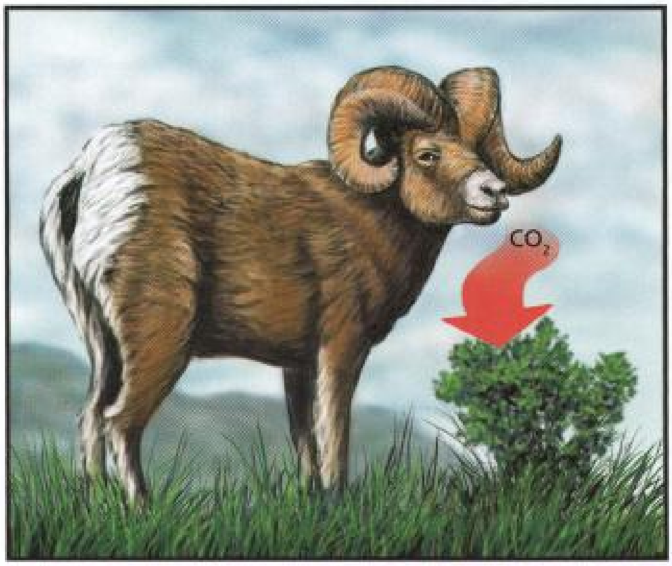


Figure 1 The waste of one organism becomes a necessary reactant for another.

Certain natural events, such as volcanic eruptions, can disrupt the balance in ecosystems by introducing pollutants such as ash and sulfur dioxide into the atmosphere. These cannot be recycled immediately and are harmful to living things in the short term. **Pollutants** are substances introduced into air, water, soil, or food in concentrations that threaten the health or survival of organisms. They can affect natural population growth by destroying habitat and food sources or by killing organisms. Many pollutants are not natural, but are a result of human technology.

Pollutants are often classified according to the part of the environment that they affect. Air pollution is composed of gases and suspended materials that are added to the atmosphere. Water pollution includes substances that ultimately end up in fresh and salt water. Land pollutants contaminate the soil. However, due to the cycling of matter, pollutants often move between the air, water, and land.

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.

Air Pollutants

Recall from Chapter 4 that atmospheric air is composed of mostly nitrogen gas (78 %) and oxygen gas (21 %) with trace amounts of other gases including carbon dioxide and water vapour. Pollutants in air that can occur naturally include pollen, spores, and volcanic materials. Most air pollutants, however, are the result of human activities. Table 1 describes some common air pollutants.

Table 1 Common Air Pollutants

Pollutant	Description	Source	Impact on ecosystems
Volatile Organic Compounds (VOCs)	• compounds of hydrogen and carbon (e.g., gasoline, propane)	• unburned fuels of internal combustion engine vehicles (cars, buses, etc.)	• combines with other air pollutants to form smog and ground-level ozone
Carbon monoxide	• poisonous, odourless, colourless gas	• incomplete combustion of hydrocarbons (fuels)	• interferes with respiration • causes death in high concentrations • forms ozone
Sulfur dioxide	• colourless gas, odour like burnt matches	• volcanic eruptions • burning of coal and oil • copper smelting	• forms acid rain • dissolves in water and soil • interferes with plant growth
Nitrogen monoxide and dioxide	• colourless to brown gas • NO – sweet odour • NO_2 – harsh odour	• burning of fossil fuels • industrial processes (welding, electroplating)	• reacts in air to form acid rain and ozone • causes brown haze in cities • causes corrosion of metals • contributes to nutrient overload (acts as fertilizer)
Ground-level ozone	• colourless gas	• produced by a chemical reaction with NOs, VOCs, and sunlight	• interferes with plant growth • component of smog • causes respiratory problems in animals
Particulate matter	• tiny (~ 2.5 μm) liquid or solid particles in air	• dust, soot, smoke, fuel droplets, tar, pesticides, asbestos	• reduces visibility • causes respiratory problems in animals

STUDY TIP

When making notes from your textbook, be alert to the key ideas and note only what you need to prompt your memory. Keep your notes in order and in one place, preferably a three-ring binder.

One important consequence of air pollution is the formation of **acid precipitation**, commonly called acid rain. The air-borne pollutants, particularly sulfur dioxide and nitrogen monoxide, react with water vapour in the atmosphere forming acidic compounds, and return to Earth in the form of rain, sleet, hail, snow, and even fog. The consequences of acid precipitation are often seen far away from the source because once airborne, these pollutants travel with the prevailing winds before falling as precipitation.

Organisms within ecosystems are adapted to survive within a certain pH range, or range of acidity. The **pH scale** represents the concentration of hydrogen ions in solutions. Water has a pH of 7. A lower than 7 pH value is acidic and a higher than 7 pH is basic. You will learn more about the pH scale in Chapter 8. Although all organisms exposed to acid precipitation are affected, aquatic organisms are more susceptible to changes in the acidity of their environments. In fact, in the spring, when acidic snow melts and flows into lakes, entire populations of fish can be killed. The water in acidic lakes is crystal clear due to the absence of most of the organisms that previously lived there. In terrestrial ecosystems, acid precipitation can damage leaves directly, and leave the damaged tissue more susceptible to fungal or bacterial infections (Figure 2). Acid precipitation affects soils as well. Limestone in many B.C. mountains is dissolved in rivers, and because it is basic, it helps to neutralize the effects of the acid precipitation. In places where this does not happen naturally, a basic substance such as lime is sometimes added to neutralize an acidic lake and allow regrowth (Figure 3). Technologies exist to reduce the amount of nitrogen and sulfur oxides released from factories as acid emissions, but they tend to be expensive. Regulations exist in Canada that somewhat control the emissions, but many other industrial countries do not have the same environmental standards.

Did You KNOW?

Naturally Acid Rain

Unpolluted rainwater has a pH of between 5.5 and 6.0. It is acidic because some of the carbon dioxide in air is dissolved. Any rainwater below pH 5.5 is considered to be acid precipitation.

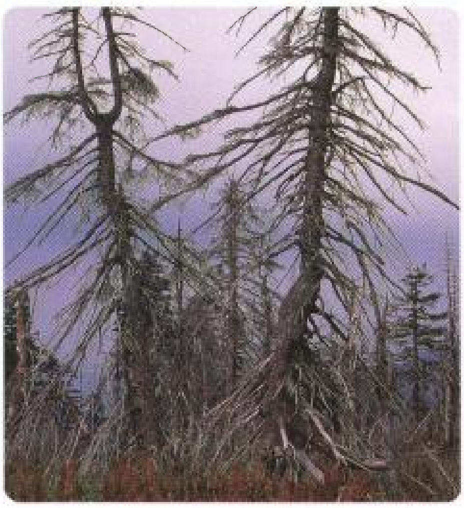


Figure 2 These trees have been killed by acid rain.

Figure 3 Helicopters can add a basic substance, such as lime, to a dying lake.

TRY THIS: How Acidic is Your Precipitation?

Skills Focus: conducting, observing, recording, concluding, communicating

In this activity, you will determine the acidity of different samples of precipitation and compare them to other water samples.

Materials: pH meter, pH paper, collecting jars, distilled water, tap water

1. Before beginning this activity, set out collecting jars around your neighbourhood to collect a variety of precipitation samples from different areas and different times. Label the jars following your teacher's instructions.
2. Using the method provided by your teacher, determine the pH of your school's tap water, the distilled water, and your collected precipitation samples.
3. Copy Table 2 and record your results.

Table 2

Source of water sample	pH
Tap water	
Distilled water	
Sample A	

A. What was the highest pH you observed? The lowest pH?

B. Which samples were most acidic?

C. Explain the differences among the precipitation samples.

D. What pH would you expect if you were to collect a sample outside a mill or industrial site?

Water Pollution

Pollutants in the air can also end up in water, such as acid precipitation. Pollutants also enter water sources through runoff from land, or when substances are added directly to the water, such as oil spills and sewage. Water pollutants can generally be classified into five categories as shown in Table 3.

Table 3 Types of Water Pollution

Pollutant	Description	Source	Impact on ecosystems
Organic solid waste	• sewage and food waste	• humans and other animals • food processing	• depletes oxygen as matter decomposes
Dissolved and liquid organic compounds	• oil and other petroleum products • pesticides • detergents • dioxins	• motor vehicles • oil exploration and transportation • agriculture • household and industrial waste • paper bleaching	• oil coats birds and covers surfaces preventing sun from penetrating • toxic to aquatic organisms • some pollutants accumulate in the food chain • phosphates promote algae growth resulting in oxygen depletion
Disease-causing organisms	• micro-organisms such as bacteria and protists	• human and other animal waste	• outbreaks of disease in animals that drink water
Inorganic solids and dissolved elements	• heavy metals	• mining, industry, agriculture, road runoff	• immediately toxic • can accumulate in the food chain
Thermal energy	• hot water added to natural water	• electrical generating stations, industry	• decreases solubility of oxygen in water

Did You KNOW?

Indicators of Pollution

The types and amounts of aquatic life can be used as indicators of water quality and pollution. The presence of healthy trout in a lake indicates high levels of dissolved oxygen, whereas an abundance of carp and catfish indicate lower oxygen levels.

As the number of organisms in an ecosystem increases, the demand for oxygen also increases. Therefore, the more organisms there are present, the lower the levels of dissolved oxygen. This can occur when sewage is discharged into the ocean as is done in Victoria, B.C., Halifax, N.S., and St. John's, N.L. (Figure 4). The additional nutrients provided by the sewage promote the growth of aquatic plants. It might seem odd that this can have

Figure 4 This sewage contains waste and nutrients that promote the growth of algae and bacteria and deplete the dissolved oxygen.

a negative effect; however, recall from Chapter 4 that the plants eventually die and populations of bacteria increase to decompose the waste. Since bacteria need oxygen, the amount of dissolved oxygen available to other aquatic organisms is reduced. Fish and plants may die from lack of oxygen, adding more waste to the ecosystem. More bacteria grow and less oxygen is available. So, when organic matter is added to aquatic ecosystems, levels of oxygen are ultimately reduced. 5A Investigation

5A Investigation

Oxygen Demand and Organic Pollutants

To perform this investigation, turn to page 134.

In this investigation, you will examine the amount of dissolved oxygen needed by aquatic organisms.

Land Pollution

Most of the technologies used to provide humans with the needs and wants of life produce waste that often ends up in the land. For example, the packaging on most of the products we use every day ends up as solid waste that cannot be broken down. It is thrown out, creating giant piles of garbage in landfills. Table 4 describes three types of land pollution.

Human communities are constantly dealing with removing and reducing land pollution. Regulations exist that control what can and cannot be dumped, but waste is still disposed of illegally almost everywhere, including parks, forests, and waterways. Much of this waste can be reused or recycled. Recycling programs exist in most cities for many household wastes such as paper, metal, plastic, and glass. Special disposal sites are provided for hazardous wastes. There is often an enormous cost to recover waste after it has been created. The first priority should be consuming less, followed by reusing waste (such as refilling glass bottles), and finally, recycling, if the first two are already in place. Waste reduction programs should include these three R's—Reduce, Reuse, and Recycle. The success of these programs in reducing land pollution depends on participation by everyone. GO

Did You KNOW?

Pollution Sources

Pollution can also be classified as either point or non-point. Point source pollution comes from a single source such as a factory, a sewage treatment plant, or an oil spill. Non-point source pollution comes from a variety of sources such as roads, lawns, and farms, and ends up in waterways after it rains. Point source pollution is easier to regulate because the source of the pollution is known.

To learn ways to reduce waste, go to www.science.nelson.com GO

Table 4 Types of Land Pollution

Pollutant	Description	Sources	Impact on ecosystems
Hazardous wastes	• toxic organic chemicals (PBDEs – polybrominated diphenyl ethers, PCBs – polychlorinated biphenyls) • pest control chemicals (diazinon, DDT) • heavy metals (mercury, lead)	• fire retardant • electrical transformers • hydraulic systems • pest control • coal or copper mining	• causes reproductive problems in animals • causes cancer in animals • stunts plant growth • accumulates in top consumers
Radioactive wastes	• radioactive chemicals	• used fuel rods in nuclear energy plants • medical radiation procedures	• stored underground • seeps into soil • accumulates in consumers
Solid wastes	• unwanted or discarded materials • garbage/trash	• household waste • agricultural, commercial, and industrial waste	• landfills take up space and cover land • leaches out waste into surrounding soil or waterways • produces methane gas during decomposition • pollutes air (burning waste) • attracts wild animals

5.2 CHECK YOUR Understanding

1. Give an example of a resource that can also be waste.
2. Explain the meaning of biodegradation as it applies to pollutants.
3. Explain how natural events can cause pollution.
4. Name the three categories of pollution.
5. Which of the following pollutants results from burning of fossil fuels?

I	carbon monoxide
II	sulfur dioxide
III	volatile organic compounds
IV	nitrogen monoxide

   A. I and II only
   B. II and III only
   C. I, II, and III only
   D. I, II, III, and IV
6. What are volatile organic compounds and why are they so harmful?
7. What is the source of ground-level ozone?
   A. volcanic activity
   B. burning fossil fuels
   C. pesticide application
   D. sunlight and nitrogen monoxide
8. Describe how acid precipitation forms.
9. Copy and complete Table 5 on water pollution.

Table 5

Pollutant name	Source	Impact
		Depletes oxygen
Disease-causing organisms		
		Decreases solubility of oxygen

10. Explain how adding more nutrients to water can be detrimental.
11. List four hazardous wastes and their source. Try to represent at least two categories of hazardous wastes. Use a table to display your answers.
12. Describe the impacts of solid waste on ecosystems.
13. Increased plant growth often leads to decreased oxygen levels in aquatic ecosystems. Explain how this can be true when plants produce more oxygen than they can use.
14. Draw a flow chart to show how an increase in nutrients can cause death to organisms.
15. Look at the landfill in Figure 5. Describe possible impacts on the ecosystem, including the birds shown.

Figure 5

16. Explain why it is often difficult to find the source of air and water pollution.
17. Why should we be concerned with water and air pollution that is happening on the other side of the world to where we live?

INTO THE DEEP: ASSESSING THE HEALTH OF OUR OCEANS

Pollutants have a major impact far from their source, and can cause damage in even the most remote locations on Earth.

A diver adjusts his mask and respirator for safety and comfort before rocking backwards from his perch on the side of an inflatable zodiac hull. Equipped with scuba tanks and cameras, oceanographers open a window on a world so unique and complex that it really is the new frontier. It appears as though Earth's oceans are far more sensitive than we had ever imagined. Scientists are concerned about the potential for climate change to threaten this vast and inspiring ecosystem.

Modern oceanography has brought about an understanding of the delicate ecology of our oceans. From the strange anglerfish (Figure 1) to elusive giant squid, ocean exploration has revealed a world more complex than the terrestrial environment humans inhabit.

Today's oceanographers employ a wide array of technology in their quest to continue exploring life in the deep, and also to prevent further degradation and even restore the health of our oceans. In British Columbia, the University of Victoria operates real-time underwater systems to reveal more of the secrets of the ocean's floor. One system, called VENUS, is comprised of many physical and chemical sensors buried in the sediment of the floor and on an elevator that rises through the water column, collecting data at various depths (Figure 2). Fibre-optic cables relay the information to computers on shore for analysis. VENUS is set up in three locations on the sea floor: Saanich Inlet, the Strait of Georgia, and the Fraser Delta.

Another underwater observatory called NEPTUNE (North-East Pacific Time-series Undersea Networked Experiments) combines data from multiple sea floor laboratories called nodes. On shore, scientists use NEPTUNE to monitor sampling, video cameras, and remote operated vehicles (ROVs) as they investigate the effect of events such as storms, plankton blooms, fish migrations, earthquakes, tsunamis, and underwater volcanic eruptions. Information and images gathered by NEPTUNE flow instantly via the Internet to shore stations in Port Alberni and Victoria. It is hoped that data gained from the modern tools of today's oceanographers can be used to help repair yesterday's damage to our precious oceans. To learn more about these technologies, go to

www.science.nelson.com GO

Figure 1 The anglerfish is one of the amazing creatures found deep under the ocean.

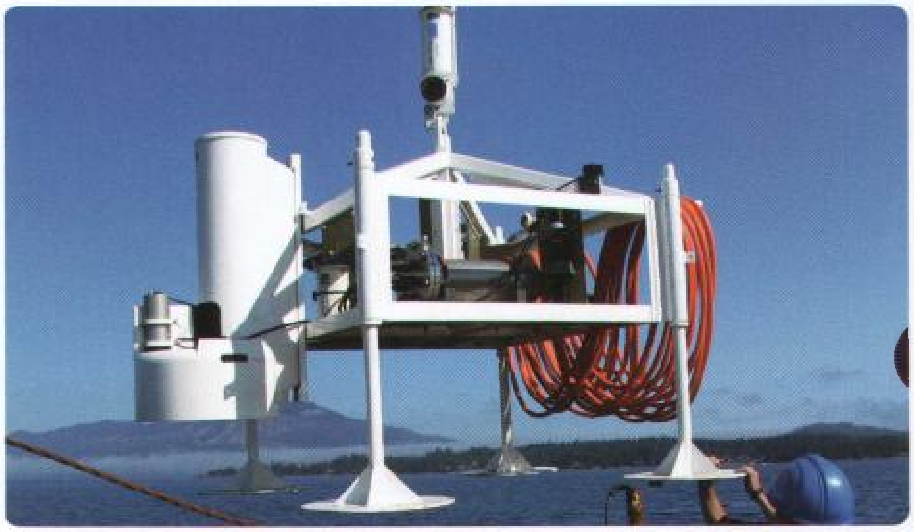


Figure 2 The VENUS (Victoria Experimental Network Under the Sea) equipment can relay data from the ocean floor to computers at the University of Victoria.

5.3 Bioaccumulation and Biomagnification

STUDY TIP
Critical readers do three things as they read. They set a purpose for their reading, they annotate or make notes on the most important ideas, and they reread for clarification. What parts of the text do you need to better understand?

In Chapter 2, you learned about food chains and how energy and matter moves from one organism to another. Pollutants also move from one trophic level to another in a food chain. If the pollutants are not degraded, or broken down, they can build up and accumulate inside the organisms. This buildup of chemical substances within the tissues of organisms over time is called **bioaccumulation.**

A related process, called **biomagnification**, results in higher concentrations of a pollutant in organisms that are at higher levels of the food chain. Even small concentrations of pollutants in the environment are of concern because they become more concentrated at each trophic level due to the increased number of organisms consumed by those organisms closer to the top of the food chain (Figure 1).

Natural pollutants can also bioaccumulate. Red tides are one type of naturally occurring pollutant, where the ocean takes on a red hue caused by blooms of certain toxic species of unicellular algae. Zooplankton eat these producers. Filter-feeding invertebrates such as oysters, clams, and mussels, accumulate the toxins as they consume the algae and the zooplankton. Humans who eat these contaminated shellfish get sick or even die from the toxin that causes a condition called paralytic shellfish poisoning.

LEARNING TIP
Make connections. The prefix *bio* means life or living, and the word *accumulation* means the "process of gathering." Explain to a partner why bioaccumulation is a good word to describe the process.

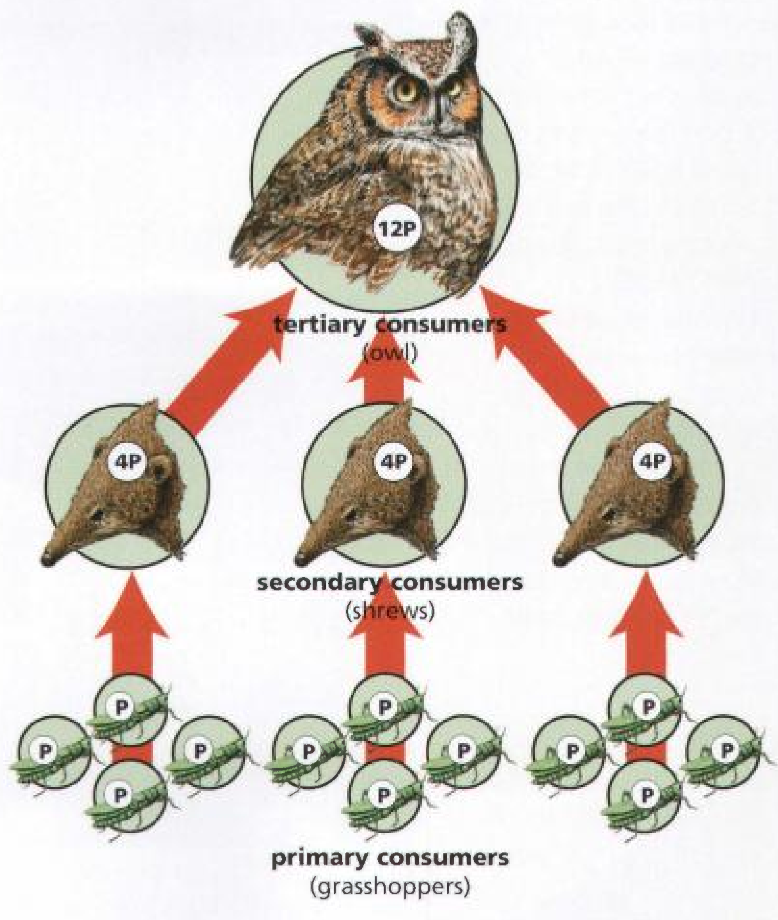


Figure 1 The concentration of a fat-soluble pesticide (P) increases as it moves up the food chain. The pesticide bioaccumulates in small concentrations in the primary consumer (grasshopper), biomagnifies (increases in concentration) in the secondary consumer (shrew), and continues to biomagnify in the tertiary consumer (owls). The greater the number of trophic levels, the greater the biomagnification.

A recent study in B.C. has shown that the bioaccumulation of PCBs, PBDEs, and chlordanes was significantly higher in coastal grizzly bears that fed mainly on salmon, compared to interior grizzly bears that had a mainly vegetarian diet (Figure 2).

Pesticides

Chemical substances called **pesticides** are used to control organisms that humans consider to be pests. There are different categories of pesticides depending on the type of pest they target. For example, insecticides are used for insect pests, herbicides for plant pests, and fungicides for fungal pests.

Pesticides often bioaccumulate in consumers. The presence of toxic chemicals in consumers was first observed in the 1950s and 1960s. During this time, the synthetic pesticide, **DDT** (dichloro-diphenyl-trichloroethane) was widely used to control insect pests. DDT was also used during and after World War II to kill mosquitoes that carried the malaria parasite, but it is now banned in Canada. DDT is soluble in fat but not in water, so the chemical is not released through urine or sweating but rather accumulates in the fatty tissues of the consumers. The amount of chemical actually accumulated is very small, measured in **parts per million (ppm)** or even parts per billion (ppb), but the effects are significant.

DDT remains in the environment where it moves through food chains by accumulating in the fatty tissues of consumers at each trophic level (Figure 3). The effects of bioaccumulation became evident when it was discovered that birds of prey, such as eagles and osprey, that had consumed fish contaminated with DDT, were unable to reproduce due to thin and fragile eggshells.

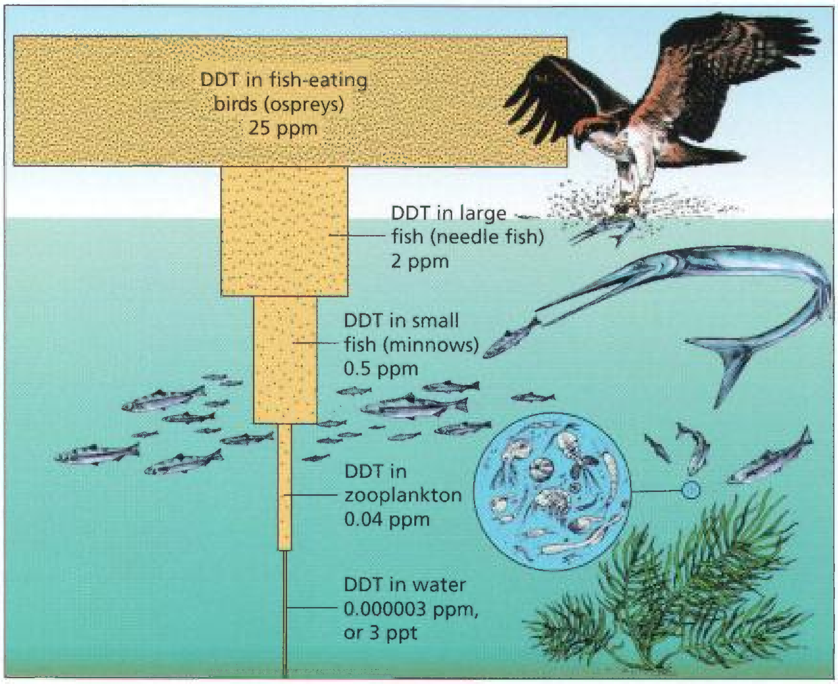
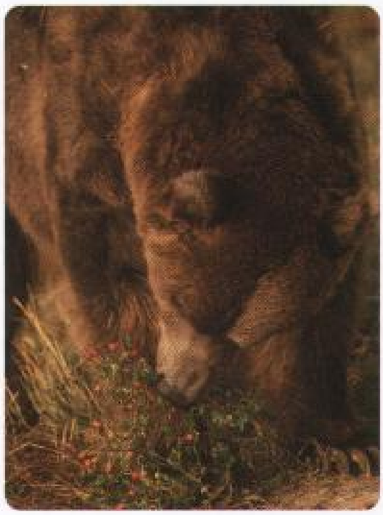


Figure 3 DDT, a fat-soluble chemical, accumulates in the fatty tissues of animals. It is biomagnified in the bodies of consumers at each higher trophic level.

(a)



(b)

Figure 2 Bioaccumulation is higher in (a) coastal grizzly bears than in (b) interior grizzly bears.

Did You KNOW?

Swamp Fever

Malaria is not just a disease found in tropical climates. During the construction of the Rideau Canal near Ottawa between the years 1826–32 many workers died from malaria carried in mosquitoes. At that time, malaria was known as swamp fever.

Did You KNOW?

Dr. Paul Müller, a scientist studying insects, was awarded the Nobel Prize in Medicine in 1948 for discovering DDT. At that time, there was no way of knowing the future negative impact of DDT and other pesticides.

DDT interferes with the deposition of calcium that makes the shells hard. Unfortunately, DDT also accumulates in humans, who are one of the top consumers. As a result of biomagnification, bioaccumulation is more severe in long-lived organisms like humans and whales. Even though DDT was banned in Canada in 1971, it is still in use in other countries.

Many pesticides have been found to bioaccumulate in secondary consumers, such as the great blue heron. Environment Canada studies the great blue heron in the Georgia Basin of B.C. because the coastal populations do not migrate and the birds consume mainly fish. Pesticides such as chlordane have been detected in the great blue herons. These pesticides have been banned, but still persist in the soil. The pesticides do not break down, and make their way into water where they enter the food chain. The highest concentrations are found in birds at the mouth of the Fraser River, where runoff from agriculture is greatest.

Not all pesticides bioaccumulate. Instead, they may be extremely and immediately toxic to certain organisms. For example, organophosphates like diazinon and malathion do not bioaccumulate, but are directly toxic to birds and aquatic organisms. The domestic use of diazinon was banned in Canada in 2002 and commercial use was banned in 2005, reducing human exposure to these pesticides.

TRY THIS: Parts per Million or Billion

Skills Focus: predicting, creating models

Very small concentrations are often measured in units called parts per million (ppm), parts per billion (ppb), and even parts per trillion (ppt).

Materials: letter-size blank sheet of paper, a metric ruler, a pen or pencil, millilitre-marked pipette, beaker of water

Part A

1. Without measuring, estimate how many square centimetres are contained on a single sheet of paper.
2. Use the metric ruler and mark both the length and the width of the paper in centimetres.
3. Shade in one square centimetre on your paper.

A. Calculate the number of square centimetres on the paper.

B. How close was your estimate?

C. Calculate how many sheets of the same size paper you would need to have 1 million square centimetres.

D. How many sheets of paper would you need to have one part per billion?

Part B

1. Fill a pipette with exactly 2 mL of water.
2. Squeezing slowly and counting each drop, reduce the level in the pipette to 1 mL. Record the number of drops that came out.

A. Using the results from the class, calculate the average number of drops per millilitre.

B. Calculate the number of drops per litre.

C. Calculate the number of litres required to hold one million drops.

D. If your bathtub holds 230 L of water, how many drops of food colouring would bring the concentration to 1 ppm? 1 ppb?

Heavy Metals

Industrial processes often produce toxic waste chemicals that ultimately end up in the environment. **Heavy metals** are a group of metal elements found in the middle of the periodic table and have relatively high densities. They occur naturally in the Earth's crust, are commonly used in industry, and are toxic or poisonous to organisms in relatively low concentrations (Table 1).

Table 1 Common Heavy Metals

Metal	Sources and uses	Effect on animals
Arsenic	• wood preservation (pressure treated lumber), pesticides, copper and lead smelting	• causes damage to respiratory, endocrine, and circulatory systems, and to skin • carcinogen
Cadmium	• batteries, pigments, plastics, metal coatings, cigarette smoke, mining, burning coal, phosphate fertilizers, contaminated food (shellfish, liver, kidney meat)	• causes damage to respiratory, digestive, endocrine, and excretory systems • bioaccumulates
Chromium	• chrome-plating, steel production, dyes and pigments, wood preservation, leather tanning	• essential nutrient in humans in small amounts • causes damage to digestive and excretory systems, and skin
Copper	• electrical wiring, plumbing, sheet metal, pesticides, wood, leather and fabric preservation, mining	• essential nutrient in humans in small amounts • causes damage to respiratory, digestive, excretory systems • bioaccumulates
Lead	• batteries, ammunition, computers and other electronic devices, lead-based paints, solder of water pipes, burning fossil fuels, mining	• causes damage to nervous, reproductive, and excretory systems of animals • bioaccumulates
Mercury	• production of chlorine gas and caustic soda, batteries, dental fillings, thermometers, contaminated foods (shellfish, fish)	• causes damage to nervous, respiratory, digestive, reproductive, excretory systems, and skin • bioaccumulates

Mercury is a heavy metal that occurs naturally, but is also released into the atmosphere through the burning of fossil fuels, particularly coal. Mercury is used to produce a variety of products such as barometers and thermometers, dry cell batteries, electrical switches, and fluorescent bulbs. Dentists fill cavities with an alloy of silver and mercury called dental amalgam. Mercury-based pesticides have been used to control fungal growth on the greens and fairways of golf courses.

Metallic mercury is converted into organic methylmercury by sulfur bacteria. It is taken up directly by both phytoplankton and zooplankton and moves through the food chain in invertebrates to fish, and then to humans, where it bioaccumulates by binding to proteins.

Belugas in northern Canada contain high concentrations of mercury and other chemicals (Figure 4). Individuals from Inuit communities that hunt and eat beluga meat have much higher levels of mercury than other Aboriginal populations. The symptoms of mercury poisoning in mammals include abnormal behaviour, loss of balance and coordination, and even paralysis. 5B *Investigation*

Figure 4 Beluga whales contain high levels of mercury.

5B *Investigation*

Biological Indicators of Pollution in Streams

To perform this investigation, turn to page 136.

In this investigation, you will determine if organisms can be used to indicate water quality in a stream.

Figure 5 Leaded gasoline for use in automobiles has not been available since 1990.

Lead is another heavy metal that is persistent in living things after exposure. Lead-based paint used in older buildings (built prior to 1950) is one source of lead. Leaded gasoline was available for automobiles until 1990 (Figure 5), and is still used in agricultural vehicles and airplanes. Lead can also be found in old plumbing where it was used for solder and pipe joints. Industrial sources of lead include smelting, auto body and paint shops, and construction. Bridges are still painted with lead-based paint.

Lead enters the food chain from the air, either from industrial processes or dust from painted surfaces. It can be present on the leaves of plants that are then eaten by consumers. Recently, certain toys were banned in Canada due to the lead content in the paint. Lead poisoning in young children can cause irreversible learning difficulties and delayed physical and neurological development. Exposure in adults can affect the peripheral nervous system and impair vision and hearing, and can also affect the muscular, excretory, circulatory, and reproductive systems.

Endocrine-Disrupting Compounds

Many of the chemicals that bioaccumulate have another troubling effect on animals. They either mimic or disrupt the normal functioning of certain hormones. Hormones are chemicals produced by organisms that control specific physiological or developmental events such as reproduction. **Endocrine-disrupting compounds (EDCs)** including DDT, PCBs, chlordanes, and PBDEs (polybrominated diphenyl ethers) affect developing embryos and young individuals by mimicking natural hormones. These EDC's have been identified in breast milk of humans and killer whales. The gender of reptiles such as alligators and turtles is determined by hormones and in part by the temperature at which the eggs are incubated (Figure 6). Exposure to pesticides such as PCBs, DDT, and chlordane can change this gender determination. These pesticides mimic estrogen and cause turtle eggs incubated at cooler temperatures to become female rather than male as they would naturally.

Did You KNOW?

Killers of Whales

Even though they were banned more than 30 years ago, PCBs continue to bioaccumulate in top predators including the southern resident killer whales off the west coast of B.C. Studies show that they may be responsible for impaired normal reproduction, abnormalities in skeletal development, and endocrine disruption.

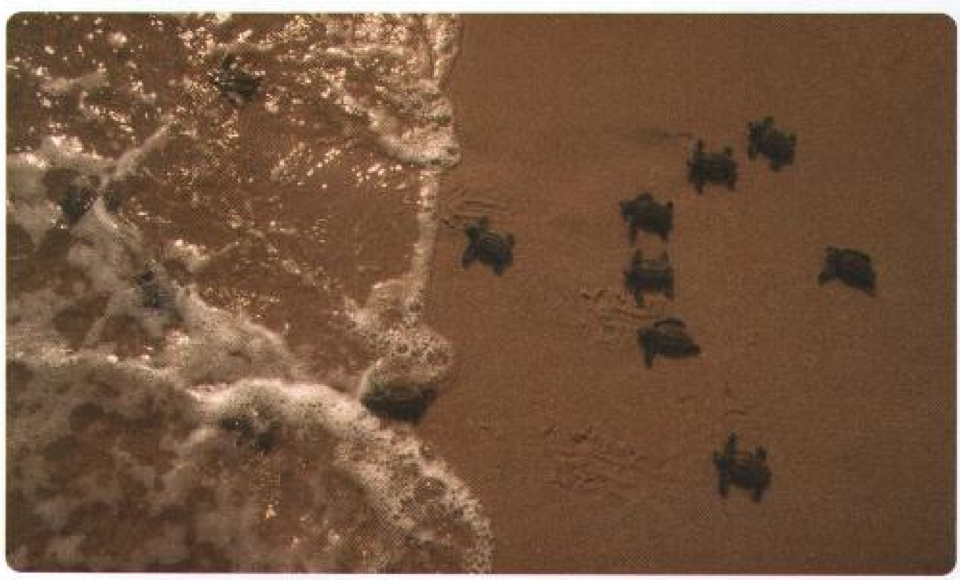


Figure 6 Sea turtle eggs incubated in warmer sand become female, while cooler sand produces male hatchlings. EDCs change this, and the hatchlings from the cooler sand become female.

5.3 CHECK YOUR *Understanding*

1. Use a dictionary to look up the word "accumulation" and the prefix "bio." Explain why bioaccumulation is a good word to describe the process.
2. Distinguish between bioaccumulation and biomagnification.
3. Using the concept of trophic levels, explain why toxins and pollutants bioaccumulate more in organisms at the top of the food chain. Use examples.
4. (a) What causes paralytic shellfish poisoning (PSP)?
   (b) Draw a food chain to show the path of the PSP toxin to humans.
   (c) Explain why humans are affected by the PSP toxin and the clams and mussels they consume are not.
5. What is the purpose of pesticides?
6. Where does DDT accumulate in consumers?
7. Although DDT is currently banned in Canada, it is still present in the environment. What specific impact does DDT have on the eggs of birds of prey?
8. Give two reasons why DDT is still being detected in Canadian birds.
9. Why are birds whose habitats are the mouths of rivers more susceptible to bioaccumulation of pesticides?
10. (a) Name the form of mercury that is toxic.
    (b) How is metallic mercury converted to this?
11. Which biological molecules does mercury bind to?
12. What are endocrine-disrupting compounds (EDC)? Give two examples.
13. Explain how gender is determined in some reptiles and how EDCs affect this.
14. Research the heavy metals zinc and nickel. In your notebook, add two rows, one for each new heavy metal, to Table 1 on page 123.
15. Using Figure 1 on page 120, fill in the levels with three other organsism that could illustrate bioaccumulation and biomagnification.
16. Assuming that mercury bioaccumulates in a similar pattern to DDT, how many parts per million (ppm) of mercury would be in the bear in the food chain shown in Figure 7?

zooplankton → herring → salmon → bear
0.08 ppm

Figure 7

17. Which of the following situations could indicate biomagnification of a pollutant?
    A. an increase in global temperatures
    B. a decrease in a population of phytoplankton
    C. a decrease in the population of a tertiary consumer
    D. an increase in the pH of an aquatic ecosystem

5.4 The Impacts of Human Industry on Ecosystems

LEARNING TIP

Summarizing (condensing main points in your own words) helps you to stay focused when you read. As you read Section 5.4, summarize each section in point-form notes.

There is no question that human activity impacts ecosystems. Take a look around the environment near your home. Whether you live in a rural or urban area, the environment has the distinct marks of human presence. In this section, we will examine how humans have altered abiotic factors and the impact that this has had on the biotic elements in ecosystems.

Ecosystems and Agriculture

For at least 12 000 years, humans have been cultivating crops and domesticating animals. This agricultural revolution allowed humans to settle in villages instead of roaming in search of food. Farming increased the food-producing capacity of the land. All farming uses basic farming techniques such as ploughing, fertilization, irrigation, and pest control. As the demographics of human population changed from rural living to urban life, larger farms were needed to produce food for urban dwellers. Machinery replaced humans and animals. Biotechnology has introduced genetically modified organisms that are hardier and disease-resistant. Animal reproductive technologies allow farmers to control the genetics of their livestock (Figure 1). The agricultural industry impacts ecosystems in several ways, including clearing natural vegetation, depleting soil nutrients, spraying chemical pesticides, and rerouting natural water flow for irrigation.

Figure 1 Rideau Arcott is a Canadian sheep bred to reproduce very quickly. They can produce lambs in 8 months, often triplets. The sheep is 40 % Finnish Landrace, 20 % Suffold, 14 % East Friesian, 9 % Shropshire, 8 % Dorset horn, and 9 % Border Leicester, North Country Cheviot, Romnelet, and Corriedale.

There is a finite amount of fertile land that crops can grow on. Much of this farmland is now being covered by houses, roads, factories, power plants, and other buildings needed by humans. Once covered, this land is no longer available for farming. Much of the fertile land is in river valleys and deltas, and contains rich soil that is constantly being replenished by the deposition of sediments carried by rivers. The image of the Fraser Valley makes it clear that human housing is encroaching on fertile farmland (Figure 2).

Figure 2 Aerial photograph of the Fraser Valley shows the reduction in fertile land along the Fraser River.

To produce high yields of agricultural crops, a steady supply of nutrients such as nitrogen, phosphorus, and potassium is required. If the same crops are planted in the same fields from year to year, fertilizers may be applied to the soil. The excess fertilizers leach into the soil and contaminate the waterways, affecting the cycling of nutrients in the affected ecosystems.

Sometimes, fields are left fallow, and no crops are planted. The exposed topsoil can be blown away by the wind or washed away by rain. Unless the field is covered with some type of vegetation, the fertile topsoil can be lost. **Soil degradation** results when fertile topsoil is lost to erosion and when soil nutrients are depleted. One strategy that reduces soil degradation by erosion is to plough ridges and curves in the fields (Figure 3).

Figure 3 Erosion of topsoil can be reduced by ploughing in curves and leaving ridges between rows.

Ecosystems and Forestry

Visitors come to British Columbia to enjoy our wilderness along the coast, in the mountains, and in the forests. B.C. has an abundance of trees; in fact, two thirds of B.C. is covered by boreal forest and temperate rainforest biomes. Forestry is one of the most important industries in B.C., especially in rural communities. Although less than 1 % of B.C. forests are logged each year, this harvesting targets the oldest and largest trees. Consider that many of B.C.'s forests need in excess of 350 years to regenerate after a fire; regeneration to mature forest after logging will probably take as long.

If 1 % of B.C.'s forests are logged every year, this means that all of B.C.'s forests will be logged long before the first stands regenerating have the time to undergo succession to climax old growth! It is also important to realize that this 1 % harvesting is not spread uniformly across the province and doesn't include activities such as salvage logging and fall down due to the mountain pine beetle epidemic. Since 95 % of forests are publicly owned, the government needs to manage the forests to balance economic, environmental, and social concerns. The law requires that all publicly owned logged forests must be replanted with native species.

Figure 4 Almost half of the wood harvested in the world each year is used for fuel.

Worldwide today, forests are used mainly to manufacture paper products and lumber for building houses and furniture. However, some communities in developing countries still use the wood for fuel (Figure 4). There is also increasing interest in harvesting other forest species such as mushrooms and berries. The public also uses forests for recreation and tourism (Figure 5).

(a)

(b)

Figure 5 Forests can be used for many purposes including (a) harvesting food and (b) recreational hiking.

As the human population increases, there is a need for more land for housing and food. Forests are often cut down to make way for new communities. **Deforestation** occurs when the trees are cut down without being replaced. Much more is lost than just the trees because forests provide habitats for a very diverse assortment of organisms, and deforestation destroys these habitats (Figure 6).

Figure 6 Logging displaces other wildlife. If this tree is cut, the eagle will have to relocate to survive, and will take years to build a nest of this size.

Forests act as carbon reservoirs or sinks, producing huge amounts of oxygen as well as absorbing great amounts of carbon dioxide gas. When forests are logged, the carbon sink is also removed and the balance of carbon dioxide on Earth is affected. This is important because carbon dioxide is one of the greenhouse gases believed to contribute to global warming. You will learn more about the causes and impacts of global warming in Unit E.

Ecosystems and Fisheries

LEARNING TIP

Critical readers take charge of their own reading. Ask yourself, "Am I focused on the main ideas? Am I remembering to pose questions to help me understand what I read?"

Humans have long treated the world's oceans as an inexhaustible resource. However, over-fishing of wild aquatic species has caused some fisheries to collapse. The Atlantic cod is a classic example. The cod fishery was once the backbone of many coastal Atlantic Canadian communities. The methods used in earlier times were mostly sustainable and there were always enough reproducing adults left to maintain or even increase the population. Modern industrialized fishing fleets from Canada and around the world have fully depleted several fish species. Not only are the target fish taken, but the type of nets used ensures that many other species are also caught, including marine vertebrates such as sea turtles, seals, and dolphins. For example, drift nets (named because they drift with ocean currents and wind) used offshore can be up to 60 km long. Many are made of non-biodegradable plastic or nylon, and when lost or abandoned become ghost nets, continually catching fish.

Although aquaculture is receiving a lot of media attention in B.C., the industry has a long history. China has been fish-farming freshwater fish for thousands of years. Coastal Aboriginal peoples in B.C. created "clam gardens" using rock walls about 2 m high and up to 1.5 km long. These raised terraces created prime habitat for butter clams.

The recent increase in the number of Atlantic salmon farms in B.C. has produced some controversy. Atlantic salmon grow quickly in ocean pens. Unfortunately, the pens are located in the calmer waters of river estuaries that are also the route taken by wild pacific salmon fry from their birth place up the river to the open ocean where they feed for 3–5 years. Recent research on these young fry has revealed a higher concentration of sea lice than on fry that do not have to pass near fish farms (Figure 7). The sea lice are more abundant where the Atlantic salmon farms are located. The wild fry are more susceptible to the lice than the adult salmon, and often do not survive the attachment of the lice.

Figure 7 Sea lice attach onto the salmon fry by penetrating the young fish's scales.

Traditional Ecological Knowledge and Wisdom

People of indigenous cultures around the world have understood the importance of their environment and have practised sustainable lifestyles. As you learned in Chapter 1, traditional ecological knowledge and wisdom (TEKW) is the knowledge, experiences, and wisdom gained over generations of interacting with the living and non-living components of the environment. This knowledge is passed on from elders to the young in practice, in stories, and in language.

British Columbia has a rich diversity of First Nations who possess traditional ecological knowledge of their local environment. Before European contact in the 1700s and 1800s, B.C.'s Aboriginal people lived off of the land sustainably. Many European explorers relied heavily on this knowledge to find their way and survive the harsh conditions in B.C. and other parts of Canada. Alexander Mackenzie, accompanied by both Aboriginal guides and French voyageurs, was able to reach the Pacific Ocean near Bella Coola. GO

To follow Alexander Mackenzie's route from Montreal to the Pacific Ocean, go to **www.science.nelson.com** GO

Many hunters use TEKW when hunting deer. For example, bucks have deer beds that are used by several deer. When an Aboriginal hunter spotted a buck resting in a known deer bed, the hunter would break a twig to attract the buck. When the buck moved away from the deer bed, the hunter would shoot. The bed would not be disturbed and the hunter would know the location where other deer could be found in the future. In the spring, they knew the does and fawns would be found at lower elevations, closer to the water and the young softer plants. Aboriginal people drew maps of hunting and food collection sites. These maps, as well as stories, were passed down to younger generations by the elders. This knowledge made subsistence hunting more efficient, and maintained the existing biodiversity.

Although TEKW is most often associated with Aboriginal people, other people have taken advantage of this knowledge. For example, many western medicines are derived from plants that have been used by Aboriginal people for thousands of years. The active ingredient in ASA (acetylsalicylic acid) is derived from salicylic acid, which was originally extracted from the bark of a willow tree and made into tea by Aboriginal people.

Did You KNOW?

Traditional Language

The Haida word for the last run of coho salmon in November is *Gaayda dahlgyang* which means "needlefish in the belly of coho," because needlefish were plentiful at that time. *Ts'iing k'ii ga* means "sharp tooth," the name given to the coho that have already been in fresh water in January and February.

5.4 CHECK YOUR Understanding

1. Which of the following are negative impacts of modern agriculture?

I	spraying chemical pesticides
II	rerouting natural water flow
III	clearing natural vegetation
IV	using chemical fertilizers

   A. I and II only
   B. II and III only
   C. I and IV only
   D. I, II, III, and IV

2. Why did the cultivation of crops and the domestication of animals allow the human population to increase rapidly?
3. Where is the most fertile agricultural land usually located? Explain your reasoning.
4. Explain the difference between an insecticide and a herbicide.
5. Why are humans concerned about the effects of forestry in B.C. if only 1 % of B.C.'s old growth forests are logged every year?
6. Describe how fertilizers can have a negative effect on ecosystems.
7. List two methods to prevent erosion of ploughed fields.
8. How does agriculture on land cause water contamination in lakes and streams?

I	Excess fertilizers run into waterways.
II	Animal waste runs into waterways.
III	Water is depleted by irrigation.
IV	Soil nutrients are depleted.

   A. I only
   B. I and II only
   C. II and III only
   D. I, II, III, and IV

9. List four impacts that modern agriculture has on ecosystems.
10. Describe three uses of forests other than forestry.
11. Reforestation cannot restore the forest ecosystem to its pre-logging state. Explain why this statement is probably true.
12. Explain two ways that deforestation can affect the levels of carbon dioxide in the atmosphere.
13. Explain how the TEKW method of using breathing holes in the ice to hunt seals is an example of sustainable hunting.
14. Biological pest control is becoming increasingly popular. Many garden centres now sell ladybugs for home gardens. Research to find out which pests ladybugs control. Find one other example of biological pest control.
15. Farmers add fertilizers that contain nitrogen and phosphorous to their crops. Why don't they add carbon as well?
16. Which of the following organisms are raised using aquaculture?

I	seals
II	oysters
III	salmon
IV	clams

   A. I and II only
   B. II and III only
   C. II, III, and IV only
   D. I, II, III, and IV

THE MARBLED MURRELET: A SPECIES IN DECLINE

Water pollution and deforestation are severely threatening the habitat of the marbled murrelet. Can recovery efforts help change the future of this plucky sea bird?

The marbled murrelet is a small, chunky, diving sea bird weighing approximately 200 g (Figure 1). Unlike most sea bird species that spend their entire lives at sea, the marbled murrelet flies inland to nest. Historically, these sea birds have inhabited most of the Pacific coast from southern Alaska to northern California as this species depends upon both marine and forested ecosystems.

Old growth forest in particular is crucial to the marbled murrelet's survival, as the marbled murrelets require these areas for nesting. These birds have short, pointed wings and they display a clumsy flying technique. They have limited manoeuvrability, so that they literally crash into their moss-padded nests in the old growth canopy or forest floor. This awkward approach to their nests requires a clear, wide path that only the open branches of an old growth forest can provide.

Unfortunately, the future is not bright for marbled murrelets as their populations are in decline in all areas they inhabit. The annual mortality due to salmon gillnetting practised in B.C. alone is estimated to be in the thousands. Chronic oil pollution from vessel traffic near shoreline habitats contaminates the waters where the sea birds forage.

Figure 1 Science and ongoing research may be able to protect the marbled murrelet.

Perhaps the most significant factor in the reduction in marbled murrelet populations is the loss of nearly half of the suitable nesting habitat due to deforestation.

The overall impact to the numbers of marbled murrelet has been the subject of much controversy in recent decades. In 1990, the marbled murrelet was listed as Threatened by COSEWIC (Committee on Status of Endangered Wildlife in Canada). This status has resulted in special advocacy from the B.C. and federal governments, logging industry, universities, and non-government environmental groups that form the Marbled Murrelet Recovery Team. The recovery team uses the findings of new scientific field studies to improve the status of the species by providing advice to the government about policies that impact the marbled murrelet. Furthermore, these sea birds are designated as one of the species listed within the B.C. Forest Practices Code Act, which translates into special considerations and protection for the nesting grounds by logging companies. At the federal level, the marbled murrelet has received legal protection under the Migratory Bird Conservation Act.

With the continued efforts by researchers working in the field and the Marbled Murrelet Recovery Team, the populations of marbled murrelet may one day thrive.

To learn more about the marbled murrelet, go to

www.science.nelson.com GO

5.5 Explore an Issue

DECISION MAKING SKILLS

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

Banning the Use of Pesticides in Urban Environments

LEARNING TIP

As you read the Explore an Issue, establish a purpose for reading each section. What do the subheadings tell you about what you will be reading and thinking about?

Pesticides are used extensively across British Columbia and the rest of Canada in the agricultural and forestry industries, and along highway, railway, and power line rights-of-way. In agriculture and forestry, pesticides are used for insect and plant pest management in order to increase crop or timber yields. Herbicides, pesticides that target plants, are often applied along rights-of-way to control the growth of vegetation that might pose a safety risk. In urban settings, municipalities, homeowners, and commercial businesses often apply pesticides for cosmetic purposes to control plants they find unattractive.

The Issue

Concerns about the risks to humans resulting from widespread use of pesticides are becoming more and more evident as city and municipality governments across Canada pass legislation to ban their use (Figure 1).

Figure 1 Pesticide use in urban areas can be a controversial issue.

Some individuals worry about the impact of pesticides on both humans and wildlife. The bioaccumulative effects of DDT are still being observed in humans and wildlife and in the environment, even though its use in Canada has been banned for decades. Diazinon, an insecticide commonly used on golf courses and lawns, was banned due to its negative effect on birds and aquatic organisms.

Statement

The use of pesticides should be banned in urban areas.

Background to the Issue

Homeowners, golf course maintenance staff, and municipalities apply pesticides to control weeds and to maintain the quality of lawns, fairways, and parks. Arguments in support of cosmetic pesticides include that the proper use and application does not threaten health, that pesticides are approved by the government, and that money can be saved by spraying rather than paying to have the plant pests weeded by hand.

While some understand the importance of pesticide use in forestry and agriculture, opposition to cosmetic use on private and public lawns, as well as in parks, is rising. Pesticides have far-reaching effects. They are found in distant and pristine ecosystems far away from the point source of the application. The ospreys of the Queen Charlottes, polar bears in the Arctic, and whales in all of the world's oceans are contaminated with pesticides. Some citizens argue that the risks to the environment and the health of humans and other organisms are far too high a price to pay for a dandelion-free lawn (Figure 2).

Figure 2 Warning signs are often posted following the application of pesticides.

Make a Decision

1. Carefully read the statement and the background information.
2. Your class will be divided into an even number of groups. Half of the groups will support the statement and the other half will oppose the statement.
3. Research information on plant pesticides commonly used in urban areas. Include information on alternatives to pesticides and other Canadian jurisdictions that have pesticide bans in place.

   www.science.nelson.com GO
4. Contact your local government office to find out what if any legislation exists on pesticides.
5. Make a list of the points and counterpoints that your group considered, then prepare your position paper.

Communicate Your Decision

6. Your teacher will decide how your position will be presented. If presented to the class followed by a class vote, be prepared to change your position based on the evidence presented.

5A Investigation

Oxygen Demand and Organic Pollutants

Thermal energy and excess nutrients can deplete dissolved oxygen in aquatic ecosystems. As oxygen levels drop, the communities able to survive in the new environmental conditions may change. The biological oxygen demand (BOD) is the amount of dissolved oxygen needed by decomposers to break down the organic matter in the water. As more organic matter is added to the water, the population of bacteria will increase, requiring more oxygen.

INQUIRY SKILLS

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

Question

How do heat and nutrients affect the amount of dissolved oxygen?

Prediction

Predict how heat and concentration of nutrients will affect the amount of dissolved oxygen in water.

Hypothesis

Formulate a hypothesis that explains your prediction.

Experimental Design

In this investigation, you will use methylene blue indicator to detect a change in oxygen levels. The indicator turns from blue to colourless when the oxygen content of the sample drops below a threshold level. The time taken for the colour change is a measure of BOD.

Materials

- safety goggles and apron
- water
- 500 ml beaker
- hot plate
- thermometer
- brewer's yeast
- mass balance
- 10 ml graduated cylinder
- 2 50 ml flasks
- stirring rod
- waterproof marker
- 11 ml of homogenized milk
- 4 20 ml test tubes
- test tube rack
- dropping pipette
- methylene blue indicator
- timer
- beaker clamp

Always handle hot plates and heated items with care.

Procedure

1. Put on safety goggles and apron.
2. Prepare a hot water bath with approximately 400 mL of water in the 500 mL beaker (Figure 1). Heat the water until the temperature reaches 40 °C. Turn down the hot plate temperature. Use the thermometer to periodically check that the temperature is maintained at 40 °C.

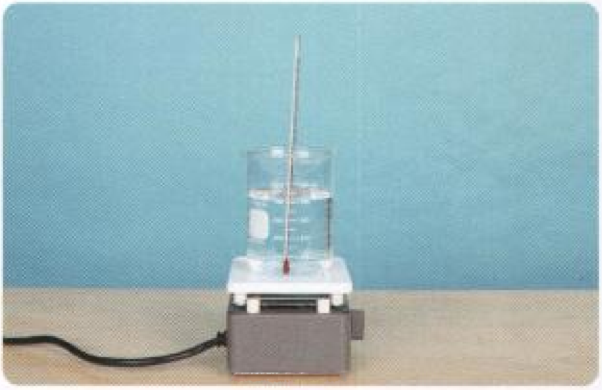


Figure 1

3. Copy Table 1 in your notebook to record the results in the 4 test tubes.

Table 1

Test tube	Description	Time
1	homogenized milk (in hot water bath)	
2	homogenized milk	
3	25 % milk solution (in hot water bath)	
4	25 % milk solution	

4. Using the mass balance, measure 5 g of brewer's yeast using the method provided by your teacher.
5. Add the yeast to 20 mL of water in a 50 mL flask labelled "yeast." Gently stir the yeast until it dissolves.
6. Prepare a 25 % milk solution by mixing 5 mL of milk and 15 mL of water in a 50 mL flask. Label the flask "25 % milk solution."
7. Label the test tubes 1 to 4, and place in test tube rack.
8. Using the graduated cylinder, add 3 mL of the homogenized milk to test tubes 1 and 2. Rinse the graduated cylinder with tap water.
9. Using the graduated cylinder, add 3 mL of the 25 % milk solution to test tubes 3 and 4.
10. When the temperature of the water bath is 40 °C, add two drops of methylene blue to each test tube (Figure 2).

Figure 2

11. Rinse the graduated cylinder and add 2 mL of the yeast mixture to each of the test tubes.
12. Place test tubes 1 and 3 into the 40 °C hot water bath. Record the time as "0." Leave test tubes 2 and 4 in the rack.
13. Record the time when the methylene blue indicator turns colourless in each test tube.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) What was the source of organic matter used in this investigation?

(b) How does the concentration of nutrients affect BOD?

(c) How does the water temperature affect the BOD?

(d) Identify the dependent and independent variables.

(e) Identify the control for thermal pollution.

(f) Yeast is a living organism. What purpose did the yeast serve in this investigation?

Evaluation

(g) Was your prediction correct? If you were wrong, offer an explanation why.

(h) Suggest some sources of error that may have affected the outcomes.

(i) A control was not used for the effects of nutrients on BOD. Suggest such a control.

5B Investigation

Biological Indicators of Pollution in Streams

Many different pollutants can affect water quality. However, it is expensive and time-consuming to perform all of the possible tests. The organisms found in aquatic ecosystems can be used as indicators of pollution in streams. Certain species, such as trout, are very active and require lots of oxygen, while those that are less active, such as worms, need less oxygen. When aquatic ecosystems contain high levels of oxygen, the active species have the advantage in the competition for food and space. When oxygen levels are low, less active species gain the advantage. Table 1 shows the correlation of oxygen levels to the expected species in freshwater systems.

Table 1

Oxygen level (mg/L)	Description	Species present
8 and above	• high level of dissolved oxygen is positive for most species, resulting in high biodiversity	• fish: trout, kokonee, coho, smolts, whitefish • invertebrates: mayfly larvae, caddis fly larvae, beetles, waterboatmen
6 and above	• dissolved oxygen is sufficient for most species, although the presence of active fish such as trout is less likely	• fish: perch, bottom feeders such as catfish • invertebrates: few mayfly larvae, some beetles, more worms (including leeches)
4 and below	• critical level for most fish; the invertebrate population increases	• fish: few • invertebrates: freshwater shrimp, many midge larvae, leeches
2 and below	• too low for fish	• invertebrates: some midge larvae, many small protozoans (e.g., amoebae)

INQUIRY SKILLS

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

Oxygen concentration is only one indicator of pollution. Any pollution caused by heavy metals, such as mercury, will not be detected by monitoring oxygen levels. Low oxygen levels are not always associated with pollution. Bogs and swamps naturally contain less oxygen as there is much more decomposition of organic matter occurring, resulting in less dissolved oxygen. The low pH of the bog and swamp also causes less O_2 to be dissolved in the water.

It is also important to note that the presence of a species associated with less oxygen does not mean that the water is polluted or that the oxygen levels are low. Slugworms can be found in oxygen-rich water but in lower numbers.

Question

Can organisms be used to indicate water quality in a stream?

Experimental Design

In this investigation, you will explore the community of a local stream.

Materials

- field guides to birds, fish, and invertebrates
- plankton net or a screen
- hand lens
- bottom dredger
- shovel
- 3 white dishpans
- bucket with lid
- forceps
- pipettes
- dissolved oxygen kit (or probe)

Practise safe behaviour around water.

Procedure

1. In your classroom, create guidelines for your behaviour during this investigation. It is important to respect the habitat of the organisms living in the stream and to minimize your impact on the ecosystem. Have your teacher approve your guidelines before moving to the stream environment.
2. Observe the area around the stream for signs of birds and other vertebrates. Look at the water for signs of fish. Using the field guides provided, identify the species if possible or record characteristics for later identification.
3. Use a plankton net or a screen to take samples of the surface water. Turn the net or screen inside out and rinse off into the white dishpan. Examine the sample with hand lenses. Record the type and numbers of species present.
4. Using a bottom dredger or a shovel, carefully collect a sample from the streambed (Figure 1). Place the sample in another white dishpan and examine the species. Record the type and number of species present.

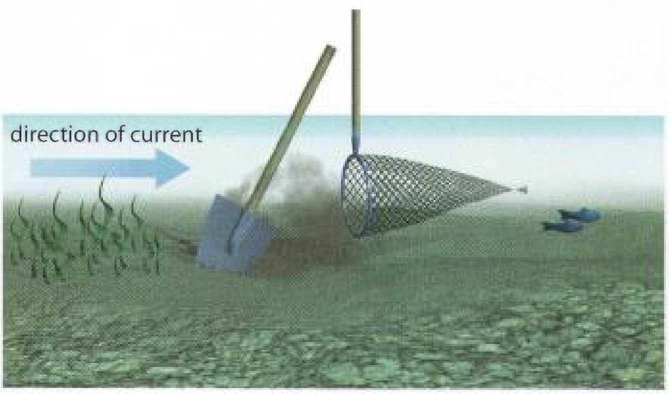


Figure 1

5. Use the plankton net or screen to collect a sample from the stream. Hold the net or screen across the stream to collect specimens from the flow of the stream. Pick up and rub any nearby rocks in front of the screen. Rinse the screen off into another white dishpan. Examine the sample with hand lenses. Record the type and numbers of species present.
6. Use the bucket to collect a water sample from the stream. Use a dissolved oxygen kit or an electronic dissolved oxygen probe to measure the amount of oxygen in the water.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) What was the most abundant species collected from your stream?

(b) Compare the dissolved oxygen levels with the species collected. Do they fit with the data in Table 1?

(c) What parts of this investigation could have caused experimental error?

(d) How could you do the investigation differently to reduce that experimental error?

Evaluation

(e) Based on your collected samples, the measured level of dissolved oxygen, and Table 1, predict if this stream is polluted.

(f) Write a hypothesis to test your prediction.

Synthesis

(g) Make a food web using the organisms you found.

(h) Predict what other organisms might be collected in another season.

(i) Identify potential sources of pollution to this ecosystem.

CHAPTER 5

Review

Changing the Balance in Ecosystems

Key Ideas

Natural phenomena impact the equilibrium in ecosystems.

- Weather-related events, including drought, fire, flooding, storms, and infestations can harm or enhance ecosystems.
- Geologic events such as volcanic eruptions, earthquakes, and landslides cause changes to ecosystems.

Pollutants affect the growth and survival of organisms.

- Pollutants can be grouped according to the part of the environment they affect.
- Human populations are producing more pollution than can be degraded in the biosphere.
- Many pollutants bioaccumulate in organisms.
- Biomagnification can occur in organisms at the top of food chains or food webs.

Vocabulary

sapwood, p. 108

pollutant, p. 113

acid precipitation, p. 114

pH scale, p. 114

bioaccumulation, p. 120

biomagnification, p. 120

pesticide, p. 121

DDT, p. 121

parts per million (ppm), p. 121

heavy metal, p. 123

endocrine-disrupting compound (EDC), p. 124

soil degradation, p. 127

deforestation, p. 128

Human activities affect ecosystems.

- Human industries such as agriculture and forestry often impact ecosystems in negative ways.
- Traditional ecological knowledge and wisdom (TEKW) allows for sustainable use of the environment.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. For each of the following descriptions, identify the natural event that most likely occurred or might occur.
   (a) liquefaction, landslides
   (b) gases released, mudslides
   (c) mild winters, fire suppression
   (d) develops over tropical oceans, flooding
   (e) high temperatures, hard-packed soil, vegetation dies
2. What is the cause of the "bluestain" wood that results after a mountain pine beetle infestation?
3. K Which of the following are sources of water pollution?

I	particulate matter
II	incomplete combustion
III	motor vehicles
IV	farm animals

   A. I and II only
   B. II and III only
   C. III and IV only
   D. I and IV only
4. K Which of the following groups contains only inorganic pollutants?
   A. lead, DDT, sulfur dioxide, pollen
   B. PCB, sulfur dioxide, mercury, spores
   C. carbon dioxide, DDT, PCB, carbon monoxide
   D. carbon monoxide, sulfur dioxide, carbon dioxide, ozone
5. What does the pH scale measure?
6. Rain is normally acidic. Explain how this occurs.
7. Acid precipitation is sometimes called acid rain. Why is acid rain not an accurate term?
8. List four types of organic pollutants and their sources. Use a table to display your answer.
9. K The buildup of chemical substances within the tissues of organisms over time is called
   A. bioremediation.
   B. biodegradation.
   C. bioaccumulation.
   D. biomagnification.
10. Bioaccumulation can impact reproduction in organisms. Give two examples of this.
11. Describe one way that TEKW is used to sustain the environment.
12. K Which of the following contain only air pollutants?
   A. PCB, DDT, PBDE, NO
   B. nitrogen dioxide, DDT, oil, heavy metals
   C. nitrogen monoxide, ozone, detergents, bacteria
   D. carbon monoxide, nitrogen dioxide, propane, ozone

Use What You've Learned

13. U Why does thermal pollution have a negative effect on aquatic environments?
   A. It reduces the oxygen in the water.
   B. It increases the oxygen in the water.
   C. It increases the rate of photosynthesis.
   D. It contains other damaging pollutants.
14. Select an ecosystem from the list below. Choose two natural events and describe how the ecosystem might change after each event.
   freshwater ecosystem
   marine ecosystem
   forest ecosystem
   grassland ecosystem
   tundra ecosystem
15. Some pollutants are considered natural. Explain what this means. Give two examples and their sources.
16. U Which of the following types of disasters are weather-related only?
   A. blizzards, avalanches, fires
   B. floods, liquefaction, landslides
   C. landslides, droughts, tornadoes
   D. droughts, hurricanes, infestations

17. Nitrogen and phosphorus are both nutrients. Explain how they can cause problems in ecosystems when they are applied as fertilizers.
18. Sketch a diagram of a food chain showing the processes of bioaccumulation and biomagnification of a pollutant.
19. Many heavy metals cause damage to the respiratory system of animals. What does this indicate about the source of the pollutants and how exposure occurs?
20. Explain what the impact of EDCs (endocrine-disrupting compounds) on gender determination of reptiles might have on populations of reptiles.

U 21. Which of these events could be an indication of biomagnification?
   A. increased global temperatures
   B. reduced numbers of phytoplankton
   C. increased pH in an aquatic ecosystem
   D. reduced population of tertiary consumers

Think Critically

22. Some farmers and foresters use biological pest control instead of chemical pesticides. For example, ladybugs are introduced that eat aphids, a common plant pest (Figure 1). Explain the benefits as well as any problems that might arise.

Figure 1

23. Monocultures are fields that have only one species of crop growing. Explain the possible consequences to the crop if an insect pest adapted to the pesticides being used.
24. Copy Table 1 in your notebook. Make a list of four agricultural technologies and how each has allowed humans to produce more food using Table 1.

Table 1

Technology	How it has allowed for more food production

25. Acid precipitation often affects ecosystems far from the source of release of the pollutants. Suggest an explanation for this. What possible solutions could prevent this?
26. Natural occurring and genetically engineered bacteria and fungi can be used to either destroy pollutants or convert them to harmless substances. The process, called bioremediation, mimics nature by using decomposers to recycle matter. Research how bioremediation is used to clean up various pollutants, and report on your findings.

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Reflect on Your Learning

27. Use the Internet to define the term "integrated pest management." Why do you think not all farmers and foresters use this method?

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28. Describe three concerns surrounding mass agricultural food production.
29. Food gathering methods that use TEKW are based on sustainable use of resources. Research two currently harvested organisms that use TEKW. Do you think sustainable use of resources should be the accepted practice? Explain your answer.

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UNIT A

Review

Sustainability of Ecosystems

Unit Summary

In this Unit, you have learned about ecosystems and the processes that occur within them. You have learned about the interaction of biotic and abiotic factors within an ecosystem, including the cycling of matter through ecosystems. You have assessed the potential impacts of bioaccumulation and identified contaminants that can bioaccumulate. You have also learned the various ways in which natural populations are altered or kept in equilibrium.

Create a concept map that relates these ideas. You may use pictures, sketches, and text to show how the ideas relate to each other. Check the key ideas and vocabulary at the end of each chapter to make sure that you have included all of the major concepts in your concept map.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Which of the following biomes is characterized by low annual precipitation, small plants, and a permafrost layer?
  A. tundra
  B. boreal forest
  C. temperate grassland
  D. temperate deciduous forest

K 2. Which of the following scenarios describes an ecosystem?
  A. all of the flowers in a garden
  B. all of the honeybees in a hive
  C. all of the living things in a pond
  D. all of the living and non-living things in a meadow

K 3. Skunks eat bird eggs, worms, and fruit. Which type of consumer is a skunk?
  A. omnivore
  B. carnivore
  C. herbivore
  D. scavenger

K 4. *E. coli* bacteria normally exist in the intestine of healthy humans where they feed on some of the contents of the digestive system. In return they synthesize vitamins for use by humans. Which of the following types of interactions is represented by this example?
  A. predation
  B. parasitism
  C. mutualism
  D. commensalism

K 5. Which of the following terms refers to organisms that are able to break down organic matter into simpler substances?
  A. scavengers
  B. autotrophs
  C. heterotrophs
  D. decomposers

K 6. Which of the following representations best illustrates the energy available in an ecosystem?
  A. food web
  B. food chain
  C. climatogram
  D. ecological pyramid

K 7. Which of the following characteristics affect climate?

I	latitude
II	elevation
III	annual precipitation

A. III only
B. I and II only
C. II and III only
D. I, II, and III

K 8. Which pair of elements is always found in organic compounds?
A. carbon and oxygen
B. carbon and nitrogen
C. oxygen and hydrogen
D. hydrogen and carbon

K 9. The process of nitrogen fixation occurs when
A. ammonia is converted into nitrates.
B. nitrates are broken down into nitrogen and oxygen.
C. ammonia and nitrates are converted to nitrogen gas.
D. nitrogen gas combines with hydrogen to form ammonia.

K 10. Which of the following groups is composed of substances that all contain phosphorus?
A. cell membranes, nucleic acids, bones
B. nucleic acids, proteins, carbohydrates
C. proteins, cell membranes, carbohydrates
D. proteins, carbohydrates, organic compounds

K 11. Which nutrient cycle does not have an atmospheric stage?
A. the carbon cycle
B. the oxygen cycle
C. the nitrogen cycle
D. the phosphorus cycle

K 12. Which of the following substances bioaccumulate?
A. PCB, lead, mercury
B. carbon, lead, nitrogen
C. phosphorus, nitrogen, carbon
D. EDCs (endocrine-disrupting compounds), potassium, calcium

13. Explain the difference between mutualism and commensalism using specific examples.

14. Name and describe the three zones that make up the biosphere.

K 15. Which of the following can result from deforestation?
A. increased soil erosion
B. fossil fuel production
C. increased oxygen levels
D. increased water pollution

K 16. Sewage is to biodegradation as PCBs are to ____________.
A. biodiversity
B. biotechnology
C. bioremediation
D. bioaccumulation

Use What You Have Learned

U 17. Natural disasters, such as volcanic eruptions or forest fires, can result in
A. succession.
B. parasitism.
C. commensalism.
D. bioaccumulation.

U 18. Burning fossil fuels may cause all of the following *except*
A. deforestation.
B. global warming.
C. acid precipitation.
D. excess atmospheric carbon dioxide.

19. Use your own labelled examples to represent each level of organization within the biosphere, from the smallest level to the largest.

20. For each of the following adaptations, indicate the stage of succession (pioneer community, mid-succession, climax community) in which they are likely to exist:
(a) shade tolerant
(b) rapidly growing
(c) require rich soil
(d) can grow without soil
(e) tolerate temperature extremes
(f) can grow in thin soil
(g) can grow in the heat of full sunlight
(h) drought and wind resistant

21. Create a graphic organizer to define the different types of symbiosis.

22. What is indicated by the direction of the arrows in a food chain or food web?

23. In your own words, define "top carnivore." Illustrate your definition by using a labelled food chain for an ecosystem.

24. (a) Give two examples of biomes with high biodiversity. What factors contribute to high biodiversity in these areas?
(b) Give two examples of biomes with low biodiversity. What factors contribute to low biodiversity in these areas?

25. Contrast the following terms:
(a) producer, consumer, and decomposer
(b) food chain and food web
(c) decomposer and producer

26. Copy and complete the energy pyramid in Figure 1. Place the amount of energy available and an example of an organism that would occupy each trophic level. Assume a standard transfer of 10 % to each level.

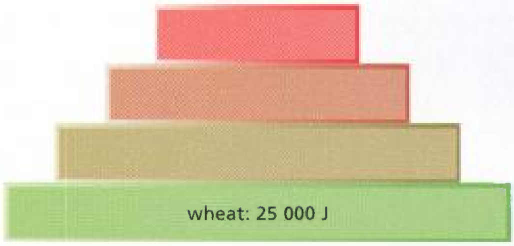

Figure 1

27. What two abiotic factors determine whether a specific region of Earth will be tundra or tropical rainforest?

28. What factors are responsible for creating variation between different locations within a single biome?

U 29. Which of the following processes are part of the carbon cycle?

I	photosynthesis
II	weathering
III	formation of fossil fuels

A. I and II
B. I and III
C. II and III
D. I, II, and III

30. How are the movements of energy and the movement of nutrients through ecosystems different?

31. Students in an earlier grade are learning about photosynthesis and cellular respiration. You have been asked to make a visual study guide for them in the form of a table or an illustration. Make sure to include the raw materials and products for each process, as well as the types of organism involved and what is needed for the processes to occur.

32. Explain why farmers might want to use pesticides that are soluble in water and also remain active for an extended period of time.

U 33. Which of the following practices illustrates the use of TEKW?
A. using drift nets to catch fish
B. using aerial sightings to locate animals to hunt
C. using depth sounders to locate schools of fish before dropping nets
D. using the location of breathing holes in Arctic ice to hunt ringed seals

Think Critically

34. What is the benefit of using models like food webs, food pyramids, and ecological pyramids? What are the limitations of these models?

35. Some plant species are pollinated by a single species. Explain how this relationship can be an advantage and a disadvantage to the plant.

36. What types of adaptations would be useful to a plant in an area in the early stages of succession?

37. Bromothymol blue turns from blue to yellow in the presence of acids. Carbon dioxide gas reacts with water and forms carbonic acid. In the experiment in Figure 2 bromothymol blue was added to each of the four test tubes.

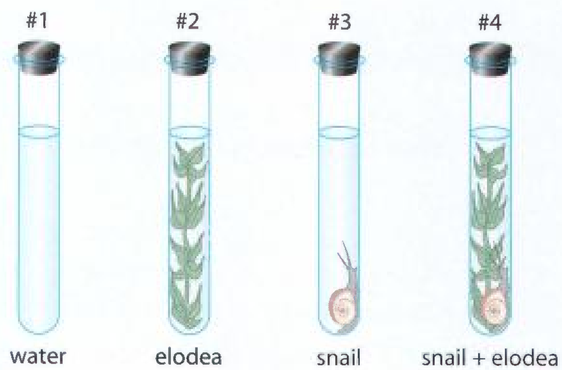

Figure 2

The test tubes were then kept at the same temperature and placed near a window. Table 1 shows the observations at the beginning of the experiment and after two weeks.

Table 1

Test tube	Initial colour of water plus indicator	Final colour of water plus indicator
1	Dark blue	Dark blue
2	Dark blue	Dark blue
3	Dark blue	Yellow
4	Dark blue	Light blue

(a) Using your knowledge of the carbon cycle, explain why test tube #3 changed colour but test tube #2 did not change.
(b) Why is there little change in test tube #4?
(c) Predict what the results might be if the test tubes were kept in a dark cupboard. Give reasons for your predictions.

38. When a nutrient is in short supply it can slow down or stop the growth of organisms in certain ecosystems. The nutrient is called a limiting factor. Explain how a nutrient can be a limiting factor in certain ecosystems.

39. Why are coastal areas usually more polluted than other parts of the ocean?

HMP **40.** The 1989 *Exxon Valdez* oil spill in ocean water off Alaska killed an estimated 250 000 seabirds. Approximately 250 bald eagles also died as a result of the oil spill. Which of the following explain why bald eagles were also killed?

I	Bald eagles prey on seabirds.
II	Bald eagles swam in the oil-covered ocean.
III	Bald eagles ate fish from the ocean.
IV	Bald eagle eggshells were weakened by the oil.

A. I only
B. I and II only
C. I and III only
D. I, II, III, and IV

Reflect on Your Learning

41. Different cultures often look at the relationships among living organisms and their ecosystems differently. Use the Internet to research the following:
(a) Using the extinction of the B.C. sea otter population as an example, explain how the views of First Nations people and early European explorers were different.
(b) What evidence is there that the attitudes of modern Canadians toward ecosystems differ from those of the early settlers?
(c) Have your own views toward ecosystems and the environment changed after this unit? If yes, describe the changes. If no, explain why.

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UNIT

B

ELEMENTS, COMPOUNDS, AND REACTIONS

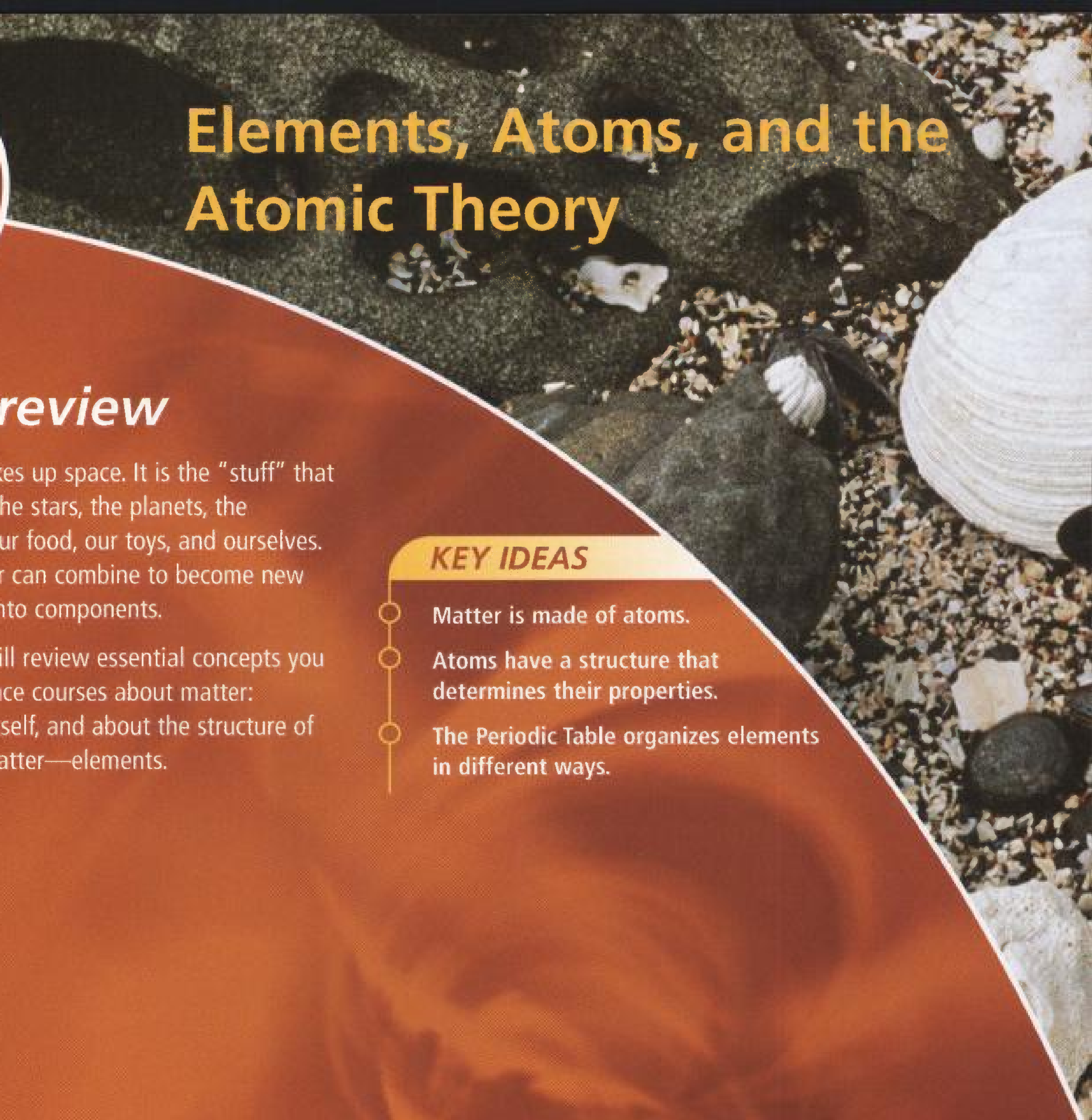
Unit Preview

Chemistry is the study of matter. What is matter? What is matter made of? What are some of the behaviours of matter? Can matter be put together and taken apart? To answer questions like these, you need to understand the structure of matter, and how the structure affects its behaviour.

As you investigate the structure of matter, you will review elements and atoms, review how atoms join together to form ionic compounds, and learn how molecular compounds are formed. You will also learn how to classify compounds based on their properties and structure, and finally, investigate chemical reactions.

CHAPTER 6

Elements, Atoms, and the Atomic Theory



Chapter Preview

Matter has mass and takes up space. It is the "stuff" that makes up the universe: the stars, the planets, the atmosphere, the rocks, our food, our toys, and ourselves. Different forms of matter can combine to become new forms, or be broken up into components.

In this chapter, you will review essential concepts you learned in previous science courses about matter: concepts about matter itself, and about the structure of the building blocks of matter—elements.

KEY IDEAS

- **Matter is made of atoms.**
- **Atoms have a structure that determines their properties.**
- **The Periodic Table organizes elements in different ways.**

TRY THIS: Modelling Matter

Skills Focus: creating models, estimating, analyzing

Elements are made from atoms. Given only a few building blocks that represent atoms of different elements, how many different kinds of matter can you create by combining atoms?

Materials: per group: 4 interlocking building blocks in 4 different colours

1. Combine the blocks together in as many different ways as possible. Draw a sketch of each combination and indicate the colour of each block.
2. Compare the combinations that you created with another group's.

A. How many different combinations could you create with the four blocks?

B. How many combinations would be possible with five blocks?

C. Did another group have a similar combination that only differed by its shape? Would this be another "unique" combination? Explain why or why not.

D. Do you think each of your combinations could represent matter found in the universe? Explain why or why not.

6.1 Properties Are Used to Identify Matter

You will recall from Grade 9 that a property is a characteristic of a substance. Properties are either physical or chemical. **Physical properties** can be observed without changing the chemical structure of the substance. These include colour, density, and electrical conductivity. For example, some physical properties of iron are that it conducts electricity, it is dense, and it is a dark grey colour.

Chemical properties describe a possible chemical change (for example, reacts with water, reacts with oxygen) that a substance may undergo. Chemical changes will produce a new substance with a different set of physical properties. For example, one chemical property of iron is that it will react with oxygen and water to form rust. We cannot observe the property without allowing some iron to react (Figure 1). Some physical properties of rust are that it does not conduct electricity, it has a low density, and it is a red-orange colour. GO

To review the different chemical and physical properties of substances, go to
www.science.nelson.com GO

Figure 1 Some of the iron in this ship's hull has reacted with oxygen and water to form rust.

STUDY TIP

30 % or 80 %?

If you do *not* review, you will remember 30 % of what you learned in class today. If you do review, you will remember 80 % for longer periods of time. For optimum recall, review new material within 24 h after having learned it in class.

To find out more about chemical changes, view the animation at
www.science.nelson.com

Classification of Matter by Properties

Scientists classify all matter as either a mixture or a pure substance, based on the types of atoms it contains, and how the atoms are arranged. As atoms cannot be seen directly, scientists infer the atomic makeup of a material by observing its physical and chemical properties.

LEARNING TIP

As you read about how matter is classified, clarify the meanings of words in bold by examining Figure 2.

The chart in Figure 2 shows the classification of matter that you have studied in previous science courses.

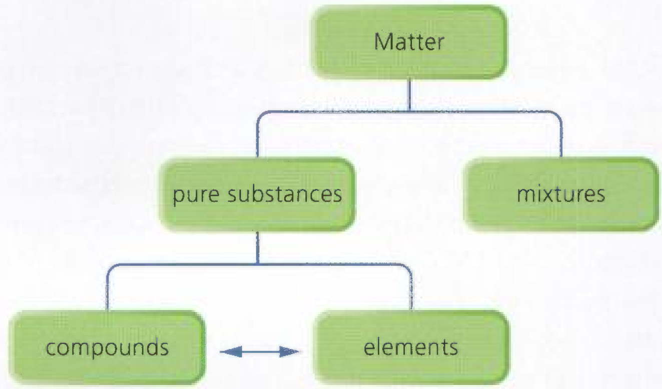


Figure 2 Classification of matter

Figure 3 Pure substances such as these piles of sucrose are always identical.

Mixtures are formed when two or more substances are put together, but are not chemically combined. The mixture will have the properties of all its component substances simultaneously. Mixtures can have variable properties for different samples.

Pure substances (often called, simply, substances) have identical properties in every sample. Samples of pure table sugar (sucrose) purchased in different cities will be identical in their properties (Figure 3).

Substances are further classified as either elements or compounds. **Elements** are substances that cannot be broken down into simpler materials. The smallest particles of elements that can exist by themselves are called **atoms**. Every element has its own unique type of atom. **Compounds** are substances, formed from two or more elements, in which the elements are always combined in the same fixed proportions. Hydrogen and oxygen are elements, and water is the compound formed from 2 parts hydrogen and 1 part oxygen. Hydrogen peroxide is formed from 2 parts hydrogen to 2 parts water—a different proportion of elements than water. Therefore, hydrogen peroxide is a different compound than water (Figure 4). You will study compounds in more detail in Chapter 7. 6A *Investigation*

6A *Investigation*

Elements and Compounds

To perform this investigation, turn to page 162.

In this investigation, you will release an element from a compound, and form another compound with the element.

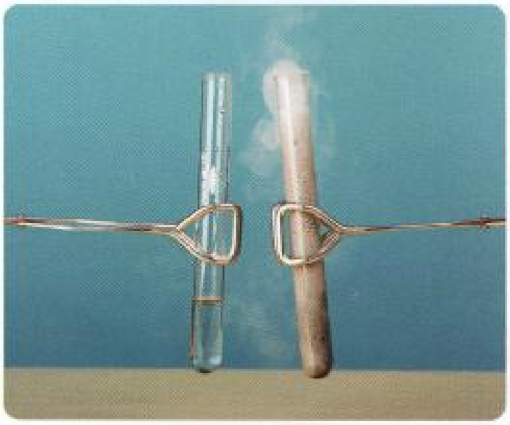


Figure 4 Water and hydrogen peroxide have different ratios of hydrogen atoms to oxygen atoms, and are therefore, different compounds. This is seen in their different properties, as the hydrogen peroxide in the right tube is reacting in the presence of the solid compound MnO_2, and the water in the left tube is not.

Formulas for the Elements

Elements are identified by names and chemical symbols. The chemical symbols are abbreviations usually based on either the Latin name or the English name of the element. Chemical symbols consist of one or two letters. The first letter is always capitalized and the second (if used) is always lower case. If one letter is used for an element, then other symbols for elements beginning with that letter must have a second letter. Therefore, carbon has the symbol C, and cobalt has the symbol Co. Nitrogen has the symbol N, and sodium has the symbol Na (from the Latin *natrium*). Figure 5 shows a few elements in their elemental form. A complete list of chemical symbols for the elements can be found in Appendix C1.

(a)

(b)

(c)

Figure 5 Samples of elements: (a) copper, Cu; (b) potassium, K; (c) calcium, Ca.

The symbols for the elements are used to write chemical formulas. For most elements, the formula of the element will simply be the chemical symbol of the element: Fe is the formula for iron, and Mg is the formula for magnesium. Some of the elements, however, are never found as single atoms in nature. They will always be bound with a certain number of atoms of the same element. An example is oxygen: in its pure elemental form, every atom of oxygen will be bound to another oxygen atom, so the formula for oxygen is written as O_2. Hydrogen is another example of an element whose atoms are found in pairs, so its formula is written as H_2. Table 1 below lists the chemical formulas for the seven elements that are found as paired atoms. Also included in the table are phosphorous and sulfur, which are commonly found in groups of 4 and 8 atoms, respectively.

Did You KNOW?

The IUPAC

The International Union of Pure and Applied Chemistry (IUPAC) is an international body that determines many standards for the science of chemistry, such as chemical names and symbols, units, definitions of terms, and methods of writing formulas.

Table 1 Elements Not Found as Single Atoms

Element	Formula	Element	Formula
hydrogen	H_2	oxygen	O_2
nitrogen	N_2	fluorine	F_2
chlorine	Cl_2	bromine	Br_2
iodine	I_2	sulfur	S_8
phosphorous	P_4		

6.1

CHECK YOUR Understanding

1. When aluminum is exposed to the air for a long time, a greyish-white coating forms on it. Is this an example of a physical or chemical property? Explain.
2. Explain why you would classify the following materials as either a pure substance or as a mixture:
   (a) sugar
   (b) nitrogen gas
   (c) beach sand
   (d) milk
   (e) distilled water
3. A material to be classified is divided up into three equal mass samples. The density of sample A is 2.34 kg/L, the density of sample B is 2.65 kg/L, and the density of sample C is 2.76 kg/L. Based on this evidence, classify the original material as either a substance or a mixture. Explain.
4. When electricity is passed through water, hydrogen gas and oxygen gas will be formed, and always in the ratio 2:1. Explain how this demonstrates that water is a compound.
5. When electricity is passed through liquid mercury, there is no evidence of a chemical change. Explain why this supports classifying mercury as an element.
6. Three samples of a material to be classified are decomposed into their component elements. Sample A contains 5 g of hydrogen, 40 g of carbon, and 16 g of oxygen. Sample B contains 10 g of hydrogen, 80 g of carbon, and 32 g of oxygen. Sample C contains 2.5 g of hydrogen, 20 g of carbon, and 8 g of oxygen. Is this material a compound or a mixture? Considering the definition of a compound, explain your answer.
7. Aluminum oxide is the compound formed from the chemical combination of aluminum and oxygen. One sample of aluminum oxide was formed from 54 g of aluminum and 48 g of oxygen. If a second sample were formed using 108 g of aluminum, how many grams of oxygen would be in the compound?
8. Which of the following best explains why ammonia is classified as a compound?
   A. It has the formula NH_3.
   B. It is a very reactive substance.
   C. All chemicals with a specific name are either elements or compounds.
   D. When decomposed, the ratio of nitrogen to hydrogen is always the same.
9. Give the chemical symbols for the following elements:
   (a) strontium
   (b) tin
   (c) nitrogen
   (d) antimony
   (e) chlorine
   (f) scandium
   (g) samarium
   (h) sulfur
   (i) hydrogen
   (j) neon
   (k) selenium
   (l) iodine
10. Write the chemical formula for the following elements:
    (a) helium
    (b) oxygen
    (c) potassium
    (d) fluorine
11. Suppose that a new element was discovered and named Victorium, after the city in which it was discovered. What symbol could be used for this new element? Explain why your choice is appropriate.

6.2 Atomic Theory

Around 1800, John Dalton revived the ancient Greek concept of atoms as the smallest pieces of matter. He used this idea to explain the chemical behaviour of elements. Dalton's theory worked very well to explain the behaviours of chemical substances, as they were known during the 1800s. Over time, further discoveries led to a refinement of the atomic theory, particularly with regard to the structure of the atom itself. In 1898, J.J. Thomson discovered the electron, a tiny negatively charged particle much smaller than the atom it was a part of. This established that the atom must have an internal structure. Shortly afterward, Ernest Rutherford showed that the atom had a nucleus, a very small space in the centre of the atom that contained almost all of the mass of the atom, and all of the positive charge. Niels Bohr proposed the concept of electron shells, to explain the emission spectra of elements.

LEARNING TIP

Active readers ask questions to check their understanding. Ask yourself, "Can I tell the meaning of the words in this section from the sentences in which they are found?"

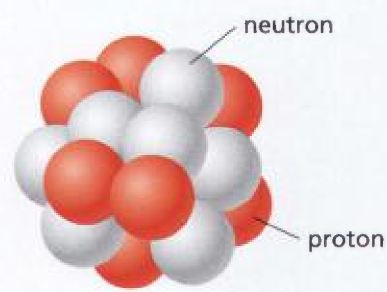


Figure 1 The structure of the nucleus of an atom according to Bohr's theory of the atom

Atomic Structure

Although new developments have since continued to refine and advance the atomic theory, we will use Bohr's version in our studies. According to Bohr's theory of the atom, every atom is composed of three types of **subatomic particles**: protons, neutrons, and electrons. The dense centre of the atom is called the **nucleus**, which contains the positively charged **protons** and the uncharged **neutrons** (Figure 1). Protons and neutrons have approximately the same mass. Each element has a unique number of protons in its nucleus, and this is called the **atomic number** of the element. Hydrogen atoms have only 1 proton, so the atomic number of hydrogen is 1. Oxygen atoms have 8 protons, so the atomic number of oxygen is 8.

Although every atom of any one element will have the same number of protons, the atoms might have a different number of neutrons. The **mass number** of an atom is the total number of protons and neutrons in the nucleus. The mass number of an element is written after the element name. For example, oxygen-18 is oxygen with a mass number of 18. Different mass numbers will not affect the physical and chemical properties of the element.

The **atomic mass** of an element is the average mass of the atoms of the element. It reflects the abundance of the different mass numbers of the element (Figure 2). It is this average that is given for each element in the Periodic Table. For example, the most common atoms of bromine are bromine-79 (50.7 % of naturally occurring bromine) and bromine-81 (49.3 %), so the atomic mass of bromine is 79.90 *u*.

Atomic mass is measured in units called atomic mass units, with the symbol *u* (or *amu*). One atomic mass unit is defined as $\frac{1}{12}$ the mass of the carbon-12 atom. You will learn more about atomic mass in the next unit.

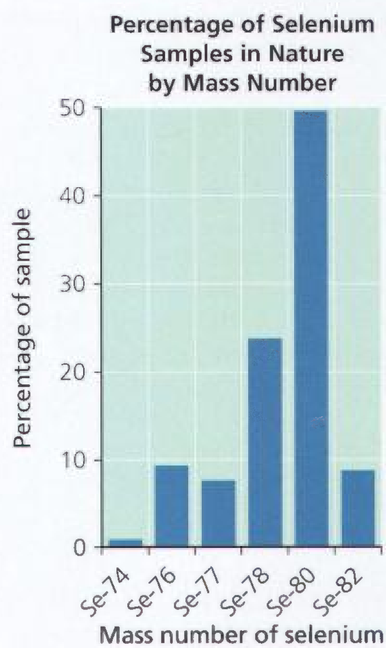


Figure 2 The relative abundance of selenium atoms found in nature. The atomic mass of selenium is 78.96 *u*.

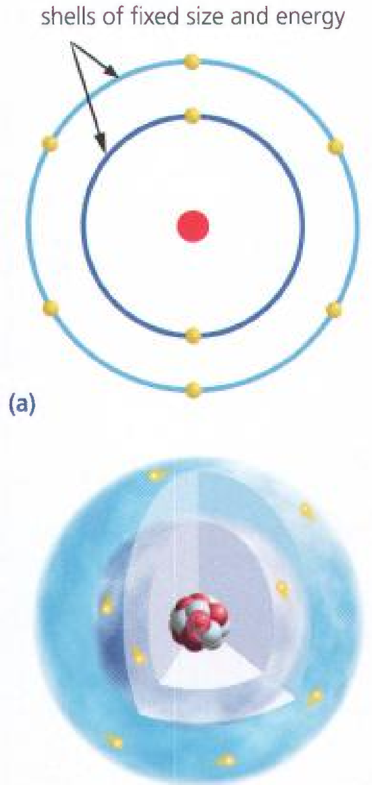


Figure 3 The structure of an atom according to Bohr's theory of the atom: (a) a 2-D drawing and (b) a 3-D drawing.

Electrons and the Bohr Theory

Outside the nucleus are found the negatively charged **electrons**, which are approximately $\frac{1}{1800}$ the mass of a proton, but have a negative charge of the same size (strength) as the positive charge on the proton. An atom has the same number of electrons as protons. (Recall that if an atom has more or fewer electrons than protons, it will have a net electric charge, and is then called an *ion*.) The electrons are arranged around the nucleus in specific regions or **electron shells** (Figure 3). Electron shells are sometimes referred to as "orbitals" or "energy levels."

Electrons can only exist in electron shells, with only a particular number in each shell. The shell closest to the nucleus (first shell) can contain a maximum of 2 electrons. The second shell can contain a maximum of 8 electrons. For the first 20 elements, the third shell can contain a maximum of 8 electrons. Potassium and calcium, the 19th and 20th elements, have 1 and 2 electrons respectively, in their fourth shells. You will learn about the arrangement of electrons for the rest of the elements in senior chemistry courses.

Bohr Diagrams

It is useful to visualize the arrangement of electrons in an atom using a Bohr diagram. A Bohr diagram shows the number of electrons that are found in each electron shell. There are many ways to write Bohr diagrams as shown in Figure 4. You may see these different styles on worksheets, exams, and in other texts. In this text, the Bohr diagrams you see will be similar to (c).

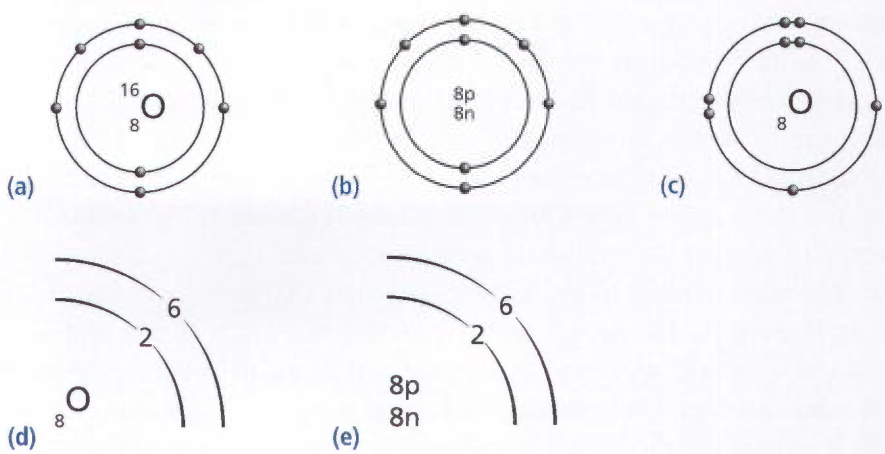


Figure 4 Some possible Bohr diagrams for oxygen: (a) The atomic number (number of protons) and mass number is shown in the centre; (b) Only the number of protons and neutrons is listed; (c) Only the atomic number is indicated in the centre with the element symbol. Electrons are paired when possible; (d) and (e) show variations that use numbers for the electrons in each shell to save space.

When drawing Bohr diagrams, a maximum of only 2 electrons can occupy the first shell, with a maximum of 8 electrons for the second and third shells. It is convenient to place electrons as a pair in the first shell. In the second and third rings, place the first 4 electrons equally around the shell, then pair up the remaining electrons. Always fill an inner shell completely before placing electrons in the next shell. Single electrons in shells are called **unpaired electrons,** and 2 electrons together are called **paired electrons.** GO

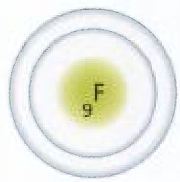
To learn more about drawing Bohr diagrams, go to **www.science.nelson.com** GO

Figure 5 shows the steps to follow to draw Bohr diagrams for the first 20 elements. Depending on the element, you might stop the process before completing all steps, or continue past Step 5.

1. Label the centre of the diagram with the atomic number and symbol for the element.

Figure 5 Drawing a Bohr diagram for the element fluorine. These steps can be used for the first 20 elements.

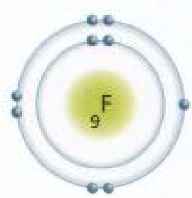
2. Determine the number of shells needed.



3. Fill the first shell with 1 set of paired electrons.

4. Place the next 4 electrons equally around the second shell.

5. Pair up remaining electrons. Do not go past a total of 8 electrons in the second shell.



STUDY TIP

It is helpful to know how you can be tested on an exam. Some context-dependent questions can be based on information such as the diagrams in Figures 3–6. To carefully read a graphic in your text or on an exam try the **4-S** system: **S**tudy the graphic. **S**ay the purpose of the graphic. **S**earch out the information in the graphic. **S**ummarize the information.

Figure 6 shows completed Bohr diagrams for 4 other elements.

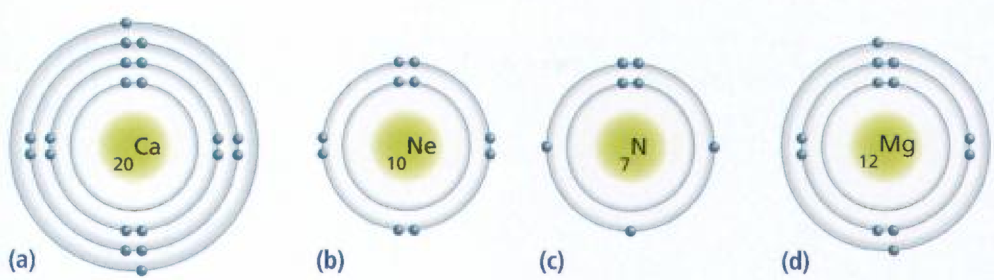


Figure 6 Bohr diagrams for (a) calcium, (b) neon, (c) nitrogen, and (d) magnesium.

6.2 CHECK YOUR Understanding

1. Copy Table 1 and use the Bohr theory of the atom to complete it.

Table 1

Subatomic particle	Mass, compared to a proton (larger, smaller, the same)	Charge (+ or −)	Location in the atom
proton	1 *u*		
		−1	
			in the nucleus

2. Copy Table 2 and complete it.

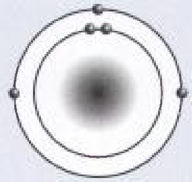
Table 2

Atom	Number of protons	Number of neutrons	Number of electrons
nitrogen-14			
bromine-79			
lithium-7			
phosphorous-31			

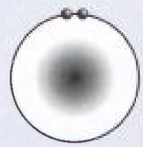
3. Draw the Bohr diagrams for atoms of
   (a) carbon
   (b) boron
   (c) argon
   (d) sodium
   (e) sulfur
   (f) aluminum
   (g) beryllium
   (h) phosphorous

4. Which element does each of the following Bohr diagrams of neutral atoms represent?

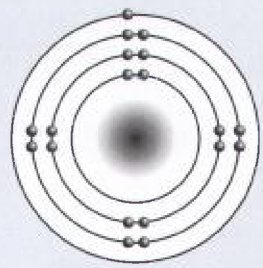
(a)



(b)



(c)



5. How many electrons are in an atom of the element with atomic number 24?

6. Consider a neutral atom that has 17 electrons.
   (a) How many protons does it have?
   (b) What is its atomic number?
   (c) Which element is it?

7. List the following for an atom with 33 protons and 42 neutrons:
   (a) the name of the element
   (b) the atomic number
   (c) the number of electrons
   (d) the mass number

6.3 Classifying Elements with the Periodic Table

The Periodic Table was developed by scientists to organize elements in such a way as to make sense of the growing information about their properties. The first periodic table listed the known elements in order of their atomic mass. In doing so, similar chemical and physical properties repeated over and over again. When an element did not fit the pattern based on its properties, a gap was left in the table. As more and more elements were identified, the periodic table was adapted to include the new discoveries.

Once the atomic numbers of the elements were determined, elements were ranked in the order of increasing atomic number, and the fit with properties was improved. Today, all of the elements through number 111 have been identified, and are shown in the Periodic Table on the inside back cover of this text.

STUDY TIP

Making study notes is important for learning and remembering. As you read this section, look at the headings and subheadings. Turn each subheading into a question, and then read to answer it. Record you answers in point form.

To learn about the discovery of new elements to fill the Periodic Table, watch the video clip at **www.science.nelson.com**

Classifying Elements Using Properties

Elements can be classified or grouped in many different ways using physical and chemical properties. For example, physical properties allow elements to be classified as metals, non-metals, or metalloids. Metals have lustre, are generally malleable and ductile, and conduct heat and electricity. Non-metals are not lustrous, are brittle, and do not conduct heat and electricity well. Metalloids have properties of both metals and non-metals (see Table 1).

Table 1 Some Metals, Non-Metals, and Metalloids

Metals	Non-Metals	Metalloids
iron	carbon	boron
aluminum	oxygen	silicon
sodium	sulfur	germanium
gold	neon	arsenic
copper	chlorine	antimony
zinc	phosphorous	tellurium

LEARNING TIP

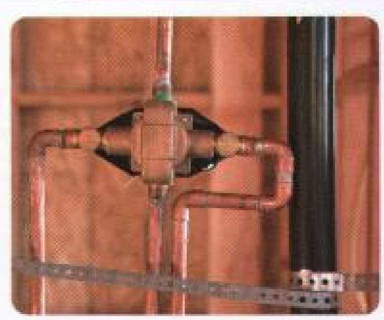
Check your understanding. Explain to a partner, using the examples in Table 1, how metals, non-metals, and metalloids are alike and how they are different.

Chemical Families

Some groups of elements have characteristic sets of common physical and chemical properties, and are called **chemical families**. For example, sodium and potassium are members of the alkali metals family. They are both soft metals with very low density that react with water to form hydrogen. In addition, the compounds formed from elements within a family are very similar in their physical properties. Therefore, sodium chloride and potassium chloride will be similar. Other chemical families include alkaline earth metals, halogens, transition metals, and noble gases. The members of these families and some of their properties are summarized in Table 2. GO

To learn more about the different chemical families, go to **www.science.nelson.com** GO

Table 2 Chemical Families and Some of Their Properties

Chemical family	Elements	Properties
Alkali metals	lithium (Li), sodium (Na), potassium (K), rubidium (Rb), cesium (Cs), francium (Fr)	• soft metals with very low density • react with water to form hydrogen • form compounds with oxygen that are very basic (alkaline) in solution • lose one electron to form an ion e.g., potassium reacting with water 
Alkaline earth metals	beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), radium (Ra)	• low-density, hard metals • react with water but not as vigorously as the alkali metals • compounds with oxygen are commonly found in rock minerals • lose two electrons to form an ion e.g., pencil sharpener made of magnesium 
Halogens	fluorine (F), chlorine (Cl), bromine (Br), iodine (I), astatine (At)	• highly reactive, toxic non-metals • bright colours as gases • gain one electron to form an ion e.g., iodine subliming to a gas 
Noble gases	helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), radon (Rn)	• very unreactive • colourless, odourless gases • do not readily form ions e.g., helium-filled balloons 
Transition metals	most of the metals in the middle of the Periodic Table	• properties of this group vary significantly • various numbers of electrons lost to form ions e.g., copper pipes 

The Periodic Table Shows Element Groups

The modern Periodic Table provides an excellent way to display the cyclic nature of the elements' properties. Each row is one period or cycle while each column is a group or family with similar properties. The Periodic Table also accommodates the classifications of elements as described earlier. Metals are found on the left side of the table, non-metals on the right side, and metalloids form a zigzag line between the two other classes (Figure 1). Each column is given a group number (Figure 2).

Other periodic table formats may be better suited to illustrate different aspects of the properties of elements. To see alternative periodic tables, go to

www.science.nelson.com

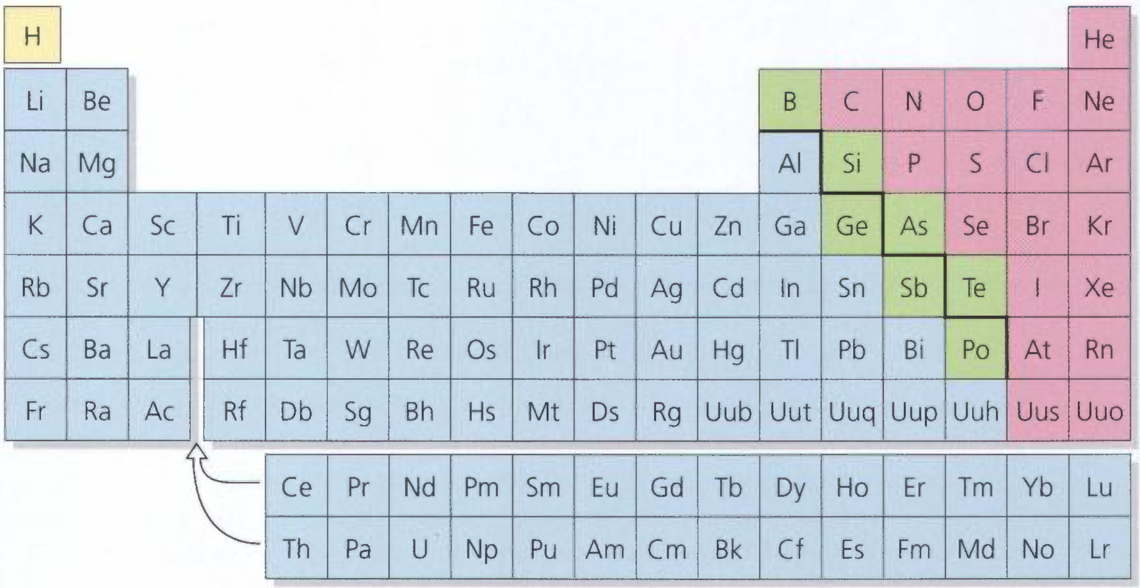


Figure 1 Periodic Table showing metal (blue), non-metal (pink), and metalloid (green) elements

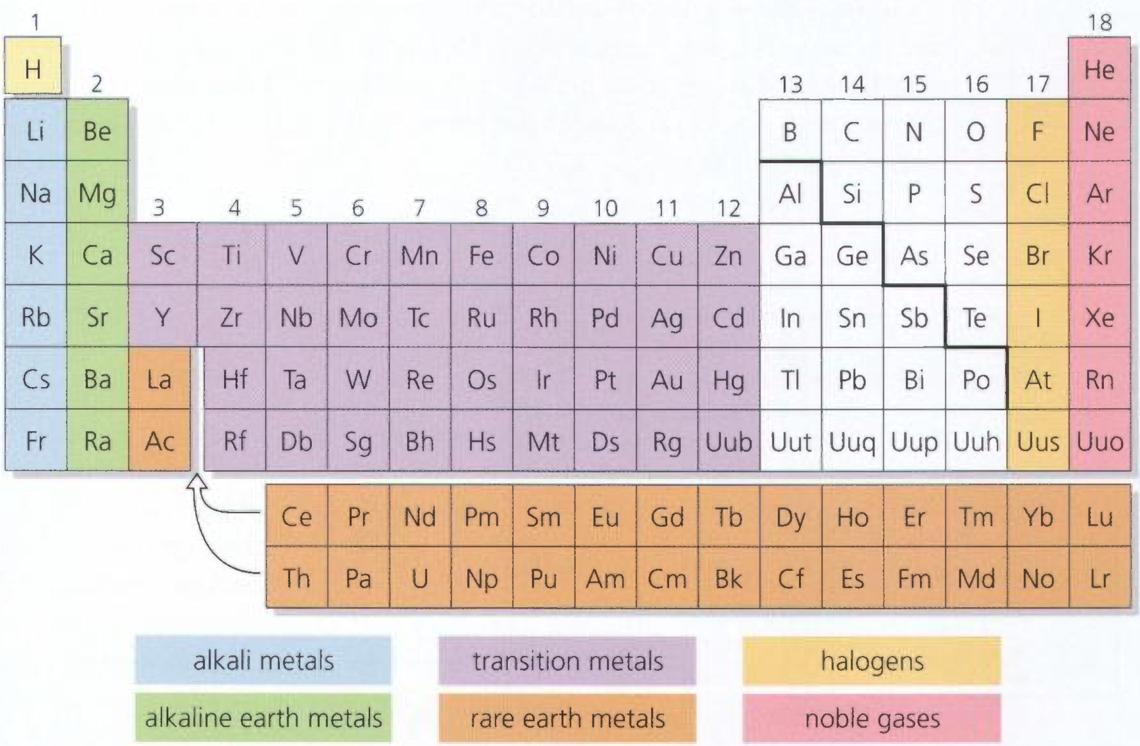


Figure 2 Periodic Table showing major families of elements and group numbers. Not all elements share properties with several other elements, and thus are not easily classified as a chemical family. These elements are indicated in white.

TRY THIS: *Bohr Diagrams and the Periodic Table*

Skills Focus: creating models, interpreting data

The properties of atoms are correlated to the arrangements of their electrons. In this activity, you will look for the relationship between the outermost shell of atoms and their chemical families.

1. Review the instructions on page 155 for drawing Bohr diagrams.
2. Draw Bohr diagrams for the first 20 elements.

A. Note which elements have only 1 electron in their outer shell. To which chemical family do they belong?

B. Note which elements have 2, 7, or 8 electrons in their outer shell. To which chemical families do they belong?

C. Should oxygen and sulfur be members of the same chemical family? Explain why or why not.

The Periodic Table Shows Electron Configuration

Consider the Bohr models for the first 20 elements. In their outermost shell, all of the elements in Group 1, the first column of the Periodic Table, have 1 electron; all of the elements in Group 2 have 2 electrons, and all of the elements in Group 13 have 3. The pattern continues: in their outermost shell, Group 14 has 4 electrons, Group 15 has 5 electrons, and so on, until Group 18 with 8 electrons. It is the number of electrons in the outermost shell of their atoms that largely determines the properties of the elements. This is understandable, as only these electrons will be in a position to interact with the electrons of another atom. Electrons in the inner shells are shielded from interaction. As you will learn in later chapters, chemical behaviour is determined by this interaction of electrons between atoms.

Compare the number of electron shells needed for an element with its row (or period) in the Periodic Table. Hydrogen and helium need only one shell. Lithium through neon need 2 shells, and so on. The number of shells needed for an element is equal to the row of the Periodic Table in which the element is listed.

To test your knowledge of the Periodic Table, go to **www.science.nelson.com**

The Periodic Table Displays Data about Elements

The Periodic Table can be used to display data about the properties of the elements. Besides the atomic number, chemical symbol, name, and atomic mass, the Periodic Table may also include the charges of the common ions (related to the number of electrons gained or lost to form ions), the density, the boiling point and melting point, the electron configuration, or any of the properties of the elements (Figure 3). Exactly which information is included depends on the intended use of the table.

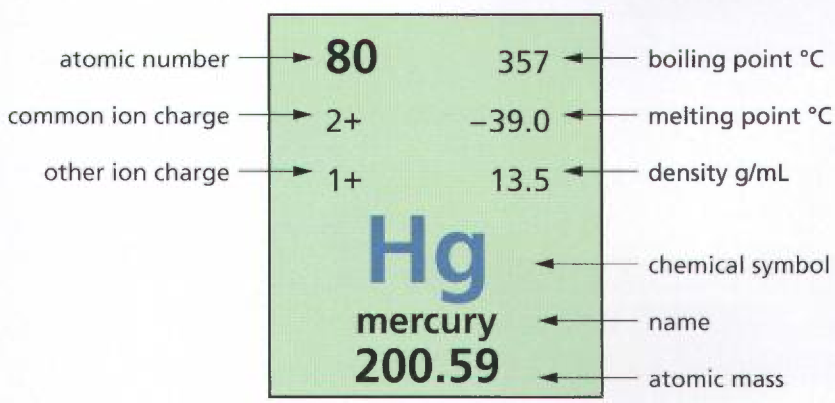


Figure 3 The entry for mercury in the Periodic Table provides several pieces of information.

6.3 CHECK YOUR Understanding

1. What criteria are used to order the elements in the modern Periodic Table?
2. Draw a sketch of the Periodic Table and indicate the location of the following groups of elements:
   (a) metals
   (b) non-metals
   (c) metalloids
   (d) halogens
   (e) alkali metals
   (f) noble gases
3. What properties differ between the elements in the alkali metals and the elements in the alkaline earth metals?
4. Explain the difference between a group and a period in the Periodic Table.
5. Hydrogen is placed above the alkali metals on the Periodic Table, yet is not a member of that chemical family. Explain why it should not be in terms of its electron configuration. Compare the Bohr diagram for hydrogen to that of lithium and fluorine.
6. Copper and gold are metals that are among the very best conductors of electricity. Consider the location of copper and gold in the Periodic Table and find one more metal that is also among the best conductors of electricity.
7. Consider the following information before answering the question below: oxygen reacts 1:2 with sodium and is a colourless gas; chlorine reacts 1:1 with sodium and is a yellow gas; neon does not react with sodium and is a colourless gas. Suppose that a new element, Pretendium, has been discovered, and it is noted that this element reacts 1:1 with sodium, and is bright green as a gas.
   (a) Which chemical family would it belong to?
   (b) How many electrons would it have in its outermost shell?
8. Consider the 7 elements that are found as paired atoms. What property (or properties) do these elements have in common?
9. The Group number is indicated at the top of each column of the Periodic Table, from Group 1 at the left to Group 18 at the right. How many electrons are there in the outermost shell of the elements in each of the following group numbers?
   (a) 1
   (b) 2
   (c) 13
   (d) 14
   (e) 17
   (f) 18
10. The outermost shell of the Bohr diagram for an element is shown in Figure 4. In which numbered group of the Periodic Table will the element be found?

Figure 4

11. There are two instances on the Periodic Table in which the order of increasing atomic mass does not agree with the order of increasing atomic number. Which two pairs of elements are not in order of increasing atomic mass?
12. Explain why all periodic tables do not include information about all the properties of each element.

6A **Investigation**

Elements and Compounds

Can an element be separated from a compound? Can an element form a compound? In this investigation, you will attempt to prove that an element (hydrogen) can be separated from a compound (hydrochloric acid), and that element will form another compound (water).

To verify what is happening in your investigation, you will perform tests. The presence of hydrogen gas can be tested by placing a small sample into an inverted test tube, and bringing a burning wood splint up to the mouth of the tube. Hydrogen gas will ignite, and a popping noise will be heard. The presence of water can be tested by using cobalt(II) chloride test paper. When in contact with water, the blue test strips will turn purple.

Questions

Can an element be separated from a compound? Can an element form a compound?

Prediction

Write a prediction based on the questions.

Experimental Design

In this investigation, you will react hydrochloric acid with zinc metal and test for the presence of hydrogen. You will also conduct a further test for the presence of water.

Materials

- safety goggles
- 2 medium test tubes
- test tube stand
- dilute hydrochloric acid in a dropper bottle
- laboratory scoop
- zinc granules (or mossy zinc)
- wood splint
- Bunsen burner or lighter
- cobalt(II) chloride test strips

INQUIRY SKILLS

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

Acids can cause chemical burns. Always wear eye protection when working with acids. If any solution splashes on skin or in eyes, flush immediately with plenty of cold water and inform your teacher. Assume all substances are poisonous. Handle test strips with care.
Avoid close contact with any gases produced in chemical reactions. There is a potential hazard to your eyes.

Procedure

1. Read through the procedure and make a table to record your observations.
2. Put on your safety goggles, and then place the test tubes in the stand.
3. Carefully fill the bottom of one test tube with 2 cm of dilute hydrochloric acid.
4. Pour one small scoop (about the size of a fingernail) of zinc granules into the test tube. Quickly invert the second test tube over the top of the first (Figure 1).

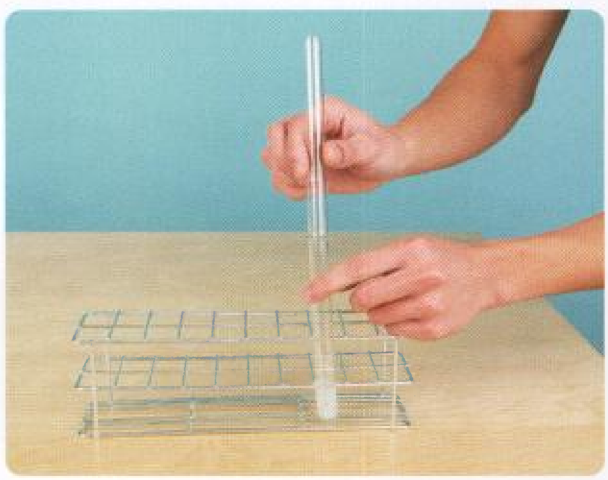


Figure 1

5. Record your observations of the reaction. What evidence of a chemical change is there?
6. After about 30 s, remove the top test tube and cover the end with your thumb (keeping it upside down).
7. Ignite the wood splint and, holding the gas-filled test tube down at a slight angle, remove your thumb and carefully slide the burning splint into the mouth of the test tube. Hold on tight, so as not to drop the tube (Figure 2).

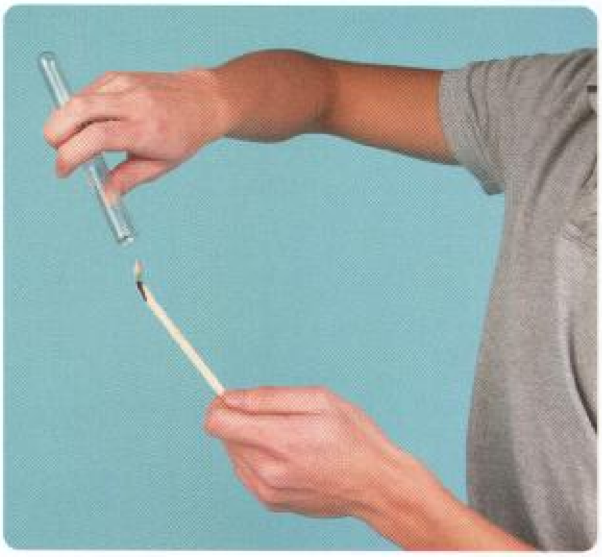


Figure 2

8. Record your observations of the reaction. What evidence shows the presence of an element?
9. If a liquid forms inside the tube, test it with the cobalt(II) chloride test strips. Record the results of this test.
10. Clean up your workstation and dispose of the materials as directed by your teacher.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

(a) What evidence is there that the gas bubbles formed in the first part of the investigation were hydrogen gas?

(b) The reaction of zinc metal and hydrochloric acid creates hydrogen gas, an element. What property of this element requires you to keep the second tube upside down?

(c) What evidence is there that the compound formed in the second test tube is water?

(d) Water has the chemical formula H_2O. Where did the hydrogen (H) and oxygen (O) atoms required to form the water molecules come from?

Evaluation

(e) Did the investigation verify your prediction? Explain.

(f) Did the investigation provide an answer to the questions? Explain.

Synthesis

(g) What other substances could be tested for, using the techniques of this investigation?

(h) Explain why it might be possible to have a successful test for hydrogen, but no water detected in the test tube.

CHAPTER 6

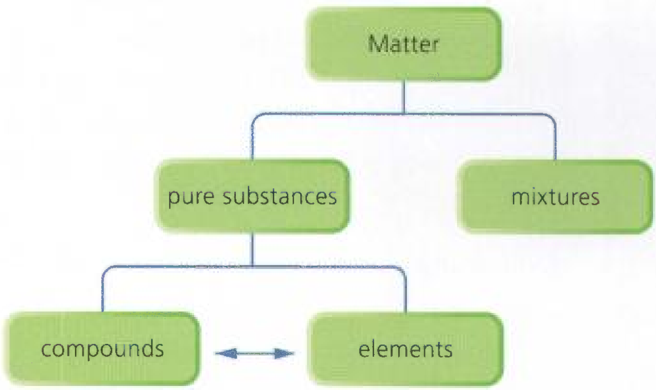
Review

Elements, Atoms, and the Atomic Theory

Key Ideas

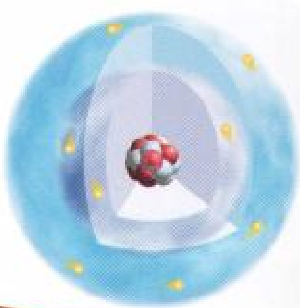
Matter is made of atoms.

- Atoms are the smallest particles of each element.
- Elements combine to form compounds.
- Mixtures are made from two or more substances that are not chemically combined.
- Elements, compounds, and mixtures together constitute all matter.
- Elements can be represented by symbols.
- Some elements are found as paired atoms.



Atoms have a structure that determines their properties.

- Atoms have component particles called subatomic particles: protons, neutrons, and electrons.
- Positive protons and neutral neutrons are found in the nucleus, and negative electrons are arranged in shells around the nucleus.
- In an atom, the number of electrons is equal to the number of protons. When the number of electrons differs from the number of protons, it is called an ion.
- The number of electrons in the outer shell of an element's atoms determines the properties of the element.

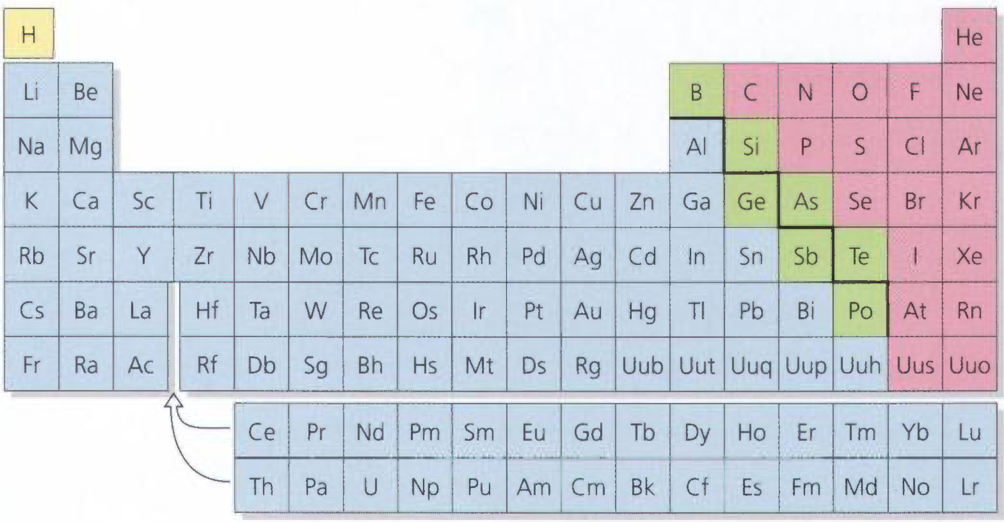


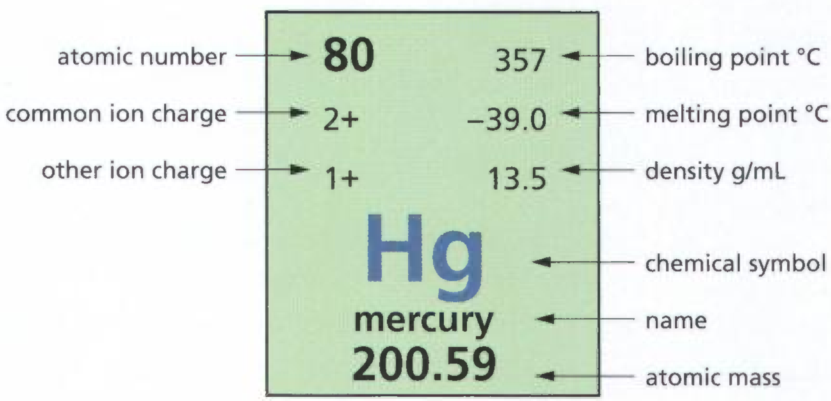
Vocabulary

physical property, p. 149
chemical property, p. 149
mixture, p. 150
pure substance, p. 150
element, p. 150
atom, p. 150
compound, p. 150
subatomic particles, p. 153
nucleus, p. 153
proton, p. 153
neutron, p. 153
atomic number, p. 153
mass number, p. 153
atomic mass, p. 153
electron, p. 154
electron shell, p. 154
unpaired electrons, p. 154
paired electrons, p. 154
chemical families, p. 157

The Periodic Table organizes elements in different ways.

- Metals are found on the left side, non-metals on the right, and metalloids in between.
- Chemical families are arranged in vertical groups.
- Periodic tables can indicate the chemical symbol, atomic number, atomic mass, ion charge, density, and other information about each element.





Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

K **1.** Which of the following does *not* describe a chemical change?
A. Sugar melts when heated to 190 °C.
B. A smoldering wood splint ignites in oxygen.
C. Iron turns red when exposed to water and air.
D. Bubbles of gas form when hydrogen peroxide solution is placed over an open cut in your skin.

K **2.** Which of the following best describes the properties of an electron?

	Mass relative to a proton	Location
A.	larger	inside the nucleus
B.	smaller	inside the nucleus
C.	similar	outside the nucleus
D.	smaller	outside the nucleus

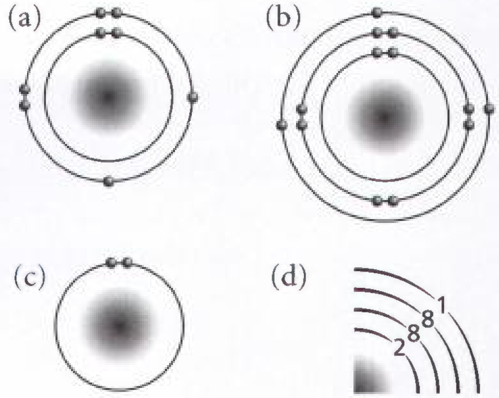
K **3.** Which of the following describes the mass number of an element?
A. It is the mass in kilograms.
B. It is the number of neutrons in the nucleus.
C. It is equal to the total number of protons and neutrons.
D. It is the average mass of all of the atoms of a sample of the element.

4. Explain the differences between metals, metalloids, and non-metals.

5. Sketch a Periodic Table and indicate where you would find a non-metal.

6. Write the formulas for the following elements:
(a) hydrogen (b) helium
(c) sodium (d) boron
(e) nitrogen (f) sulfur
(g) oxygen

7. Each of the Bohr diagrams below shows an atom of a different element. Identify each element.



8. Describe three characteristic properties of the following chemical families:
(a) halogens
(b) noble gases
(c) alkaline earth metals
(d) alkali metals

K **9.** How many electrons are there in the outer shell of an alkali metal atom?
A. 1
B. 2
C. 3
D. 7

10. Explain how to determine the number of electrons, protons, and neutrons in an atom, given the mass number and the atomic number.

Use What You've Learned

11. Draw Bohr diagrams for one element out of each column of the Periodic Table (select from the first 20 elements only).

U **12.** Which of the following statements are correct for all alkaline earth metals?

I	They readily form ions.
II	They have a full outer electron shell.
III	They are less reactive than the noble gases.
IV	They have two electrons in their outer shell.

A. I and II only
B. I and IV only
C. II and IV only
D. I, III, and IV only

13. For each of the Bohr diagrams in Figures 1–3, determine
   (a) the atomic number
   (b) the element name
   (c) the number of electrons
   (d) the number of neutrons
   (e) the number of protons
   (f) the mass number

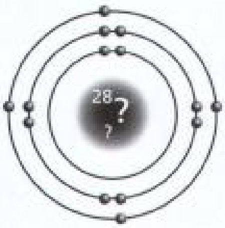


Figure 1

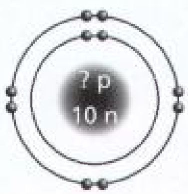


Figure 2

Figure 3

14. An element has 7 protons and 6 neutrons. Draw the Bohr diagram for an atom of this element.

15. The compound magnesium chloride is a white crystal that is highly soluble in water. Predict the properties of magnesium fluoride.

U 16. The compound hydroxyapatite is the main mineral that makes up bone. It is a complex compound formed from calcium, phosphorous, oxygen, and hydrogen. Considering the locations of calcium and strontium in the Periodic Table, which of the following explains why radioactive strontium is deposited in bone when a person ingests it?
   A. All ingested minerals are deposited in bone.
   B. The higher atomic number of strontium makes it bond more strongly to phosphorous atoms.
   C. Strontium is more reactive than calcium, and is therefore more likely to be used by a person's body to make bone.
   D. A person's body will use strontium in the same way as it uses calcium because the elements have similar chemical properties.

Think Critically

17. You have been given a sample of a clear, colourless liquid. Conduct research and find methods to determine if the substance is an element or a compound. Write a paragraph to summarize your findings.

   www.science.nelson.com GO

HMP 18. An element is observed to have the following physical and chemical properties: it is reactive with water, has a low density, and conducts electricity. Select the best response to the following statement:

   The element must be a member of the alkali metal family.
   A. The statement is supported by the observed properties.
   B. The statement is refuted by the observed properties.
   C. The statement is neither supported nor refuted by the observed properties.

Reflect on Your Learning

19. In a two-column table, list in point form new concepts or facts you have learned in this chapter. In the second column, write down questions that you feel are as yet unanswered, or are extensions of concepts in the first column. Use print and electronic resources to investigate one of those questions and summarize your findings.

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www.science.nelson.com GO

CHAPTER 7

Compounds, Ions, and Molecules

Chapter Preview

If elements are the "building blocks of matter," then what kinds of things do they build? The answer is found in the world within and around you. Elements combine to make compounds. For example, copper and sulfur combine to form a compound called copper(II) sulfide. This compound is found in copper ore. Mining companies dig up the ore, and after many stages of processing, end up with the element copper.

In this chapter, we will review some fundamental ideas about compounds and introduce some new ideas. You will learn how different types of compounds form, and how they are described in the language of chemistry.

KEY IDEAS

- **Compounds result when elements bond together in fixed proportions.**
- **Bohr diagrams can illustrate how ions form.**
- **Bonding can involve electron transfer (ionic) or electron sharing (covalent).**
- **Rules for writing chemical formulas and for naming ionic compounds are based on ion charge balances.**
- **Rules for writing chemical formulas and for naming molecular compounds are based on a prefix system.**

TRY THIS: Elements and Compounds Around You

Skills Focus: interpreting data

Pure substances are everywhere in your daily life. In this activity, you will consider a list of a few pure substances—elements and compounds—commonly found in your kitchen. Remember that pure substances contain only one kind of particle.

Table 1 Some Pure Substances in the Kitchen

oxygen (in air)	aluminum (aluminum foil)
nitrogen (in air)	sodium chloride (table salt)
carbon dioxide (in air)	sucrose (table sugar)
ammonia (in spray cleaner)	water (from the tap)
tungsten (in light bulbs)	methane (natural gas for a gas stove)
sodium bicarbonate (baking soda)	polyethylene (plastic bags)

1. Make one list of the elements in Table 1 and another list of the compounds.

A. How did you determine which of the pure substances were elements? How did you determine which of the pure substances were compounds?

B. Compare your lists with other students in the class.

C. If you examined all of the pure substances in a kitchen, which list do you think would be longer? Why do you think that list would be longer?

D. Suggest one other example of an element and one of a compound commonly found in a kitchen.

7.1 Compounds, Atoms, and Ions

In your previous chemistry studies, you have learned about elements and compounds. More than 100 elements have been identified so far, and about 90 of these occur in nature. When elements are joined together, they can build an unimaginable number of compounds (Figure 1). Compounds are everywhere in our world. They are present in the land, sea, and air, and in all living things.

STUDY TIP

A weekly study schedule will help you plan ahead. Block off times that you can commit to studying. First thing each morning, check to see what's ahead for the day. You can revise your schedule as needed.

Figure 1 Nearly everything you use or wear on a daily basis is possible because of compounds.

When atoms of one element join with atoms of another to form compounds, these substances are quite different from either element. For example, table sugar, or sucrose, is made up of carbon, the material in coal, along with two gases, hydrogen and oxygen. None of these is sweet, yet when they are brought together in just the right proportion, they make the compound that sweetens everything from soft drinks to desserts.

To see how different proportions of elements produce different properties, view the animation at **www.science.nelson.com**

Since compounds are made by chemically combining two or more elements in fixed proportions, it follows then that compounds must be made of two or more kinds of atoms. Table salt or sodium chloride is a compound made from the elements sodium and chlorine. Here, these elements exist in a one-to-one proportion: that is, for every atom of sodium there is an atom of chlorine. This information can be summarized by writing the chemical formula, NaCl.

Another common compound, water, is composed of the elements hydrogen and oxygen. For every two atoms of hydrogen, there is one atom of oxygen, so water is described by chemists with the chemical formula, H_2O.

LEARNING TIP

Information that elaborates on an important concept is often introduced by the phrase, "for example." As you read pages 170 and 171, take note of these examples as they will help you understand the material better.

What sets NaCl and H_2O apart as compounds is the way in which the atoms are joined. But how do atoms join together in different ways? What forces in nature cause atoms to join in the first place? As this is an introductory study of chemistry, we will focus on the basic ideas of chemistry, and therefore, we will restrict our studies to the first 20 elements of the Periodic Table and how they join.

The Formation of Ions

Recall that a Bohr diagram allows you to visualize a model of the atom, and can include protons, neutrons, and electrons. Modern atomic theory suggests that the tendency of atoms to join together or **bond** is based on the arrangement of their electrons, and that the protons and neutrons are not involved. Therefore, the Bohr diagrams we will use to study bonding will not include the details of the nucleus. They will show only the atomic number and the element symbol in the middle of the diagram.

For example, the element fluorine has an atomic number of 9 and is written in simple standard atomic notation as $_9F$. Recall that atoms are neutral in charge, so a fluorine atom will have an equal number of protons and electrons (9) with a resulting atomic charge of zero. The Bohr diagram for a neutral fluorine atom shows how the electrons are configured (Figure 2).

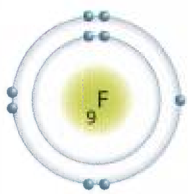


Figure 2 This Bohr diagram focuses on electrons.

How Some Atoms Form Compounds

What is it that drives elements to react and form compounds? Ironically, the answer lies within the elements that do not react. The noble gas family of elements rarely forms compounds. Helium, for example, is a lighter-than-air gas and is very unreactive with other elements, such as oxygen. GO

To learn more about noble gases and their uses, go to **www.science.nelson.com** GO

One theory of bonding is that there exists an underlying tendency for elements to acquire an outermost electron shell similar to that of its nearest noble gas. The outermost shell is called the **valence shell**, and the electrons in this shell are called **valence electrons**. In the noble gases, the valence shell holds the maximum number of electrons it can. Therefore, the valence shell is complete. The first three noble gases in the Periodic Table are helium, neon, and argon with valence shells containing 2, 8, and 8 electrons respectively (Figure 3).

Did You KNOW?

Valence

The term "valence" has been carried forward through chemistry's history. It originated as an idea about bonding that has since been disproved. Nevertheless, the word has survived in its new meaning as "outer shell."

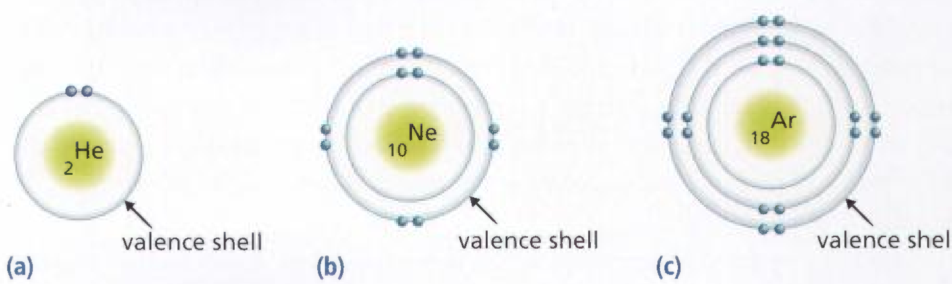


Figure 3 (a) Helium, (b) neon, and (c) argon are noble gases and, therefore, have complete valence shells.

Neon is the nearest noble gas to fluorine and sodium. As a result, a fluorine atom has a tendency to gain 1 electron and achieve a complete valence shell of 8 electrons like that of neon. Similarly, by losing 1 electron, a sodium atom's valence shell becomes complete with 8 electrons, again just like neon (Figure 4). When an atom completes its valence shell, it becomes charged since it no longer has the same number of electrons as protons. A charged atom is called an **ion**.

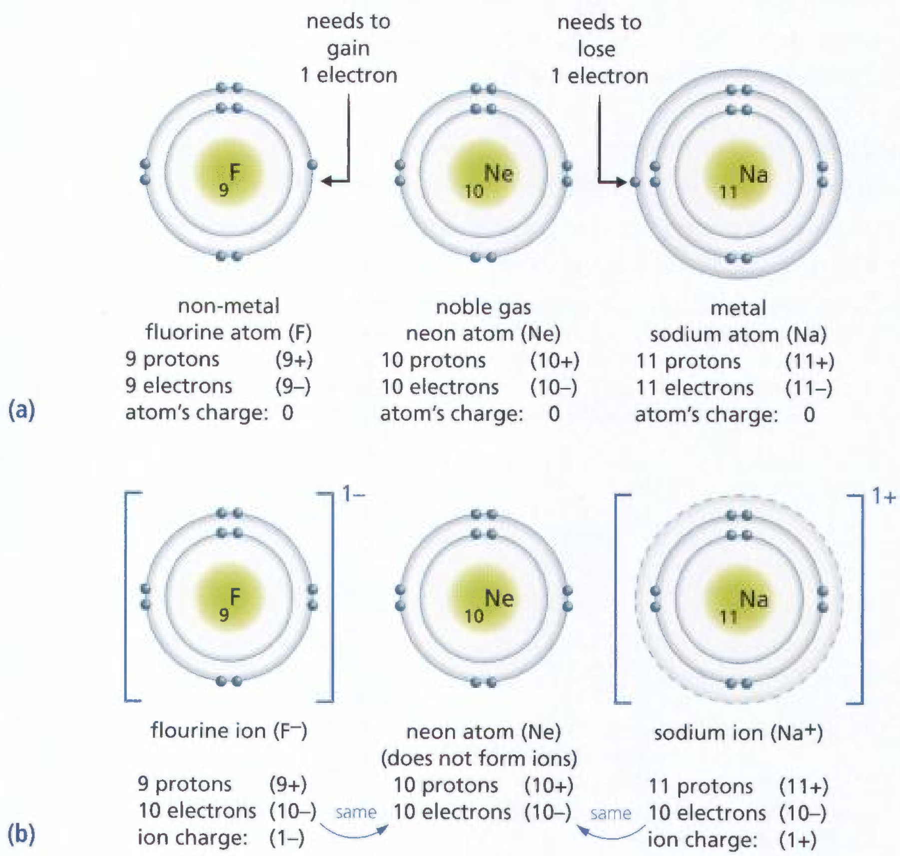


Figure 4 These Bohr diagrams illustrate how fluorine and sodium atoms' valence shells compare to that of neon. (a) By losing or gaining an electron, they become complete and have the same number of valence electrons as neon. (b) As a result, the neutral atoms become charged ions.

Did You KNOW?

Ions

Around 1830, Michael Faraday (England) first suggested ions to describe the particles that travel to positive and negative electrical contacts with which he experimented. However, it was not until 1884 that Svante Arrhenius (Sweden) described the mechanism by which this was achieved. Faraday's theory was not accepted initially, but his work eventually won the Nobel Prize in Chemistry in 1903. The word "ion" comes from a Greek word meaning "goer."

Symbols for Ions

Even though an ion may differ from an atom by only 1 or 2 electrons, it possesses entirely different properties. When representing ions, it is very important to include the ion's charge with the symbol for the element (Figure 5).

(a)

(b)

Figure 5 (a) The penny is made of copper atoms (written as Cu). (b) The solution in the beaker is blue because it contains copper(II) ions (written as Cu^{2+}).

Sometimes there is a difference in how a word is used in everyday language and its meaning in chemistry. One example is the word "sodium." In chemistry, the word "sodium" refers to sodium, the element. Elemental sodium is a metal that reacts vigorously with water producing hydrogen gas and heat, which in turn can result in an explosion. Doctors sometimes advise their patients to cut back on their sodium intake. Here, they are referring to sodium ions, perhaps from sodium chloride (table salt). For this reason, chemists take great care to distinguish between sodium atoms (Na) and sodium ions (Na^+). The ion symbol is always written as the element's symbol with the ion charge superscripted (raised). GO

To learn more about sodium (sodium ions) in foods, go to www.science.nelson.com GO

Transferring Electrons

Every atom is much more stable, or less reactive, with a complete valence shell. One way of achieving this is for an atom of one element to transfer electrons to, or receive electrons from, an atom of another element. As a result, both atoms become oppositely charged ions (Figure 6).

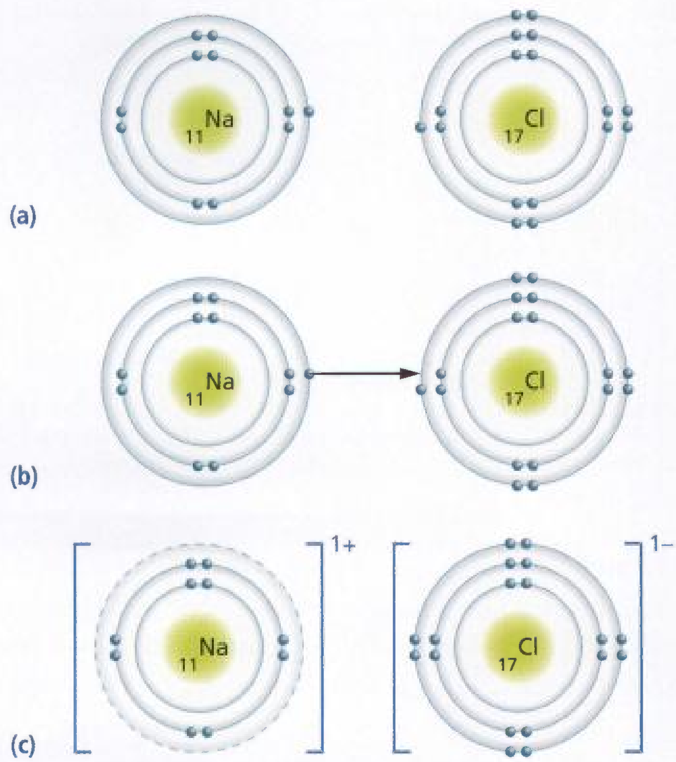


Figure 6 (a) A sodium atom and chlorine atom with incomplete valence shells. (b) The sodium atom transfers an electron to a chlorine atom. (c) The result is two oppositely charged ions; both ions now have complete valence shells.

Did You KNOW?

The Marvel of Salt

The formation of salt is a marvel of chemistry. Sodium metal is extremely reactive with water (can result in an explosion) and chlorine gas is highly toxic. Yet when these two elements are combined, we end up with sodium chloride (table salt), a common everyday food additive and a source of essential chemicals in the body.

An atom cannot just lose an electron on its own to become stable. It must come in contact with another atom that needs to gain an electron. The ion charges you have been using in your studies of chemistry result from two or more elements getting together and transferring enough electrons to complete each of their valence shells.

By gaining or losing electrons, the atoms become negatively charged ions or positively charged ions. The ion charge simply depends on the relative numbers of electrons compared to protons. Remember, only valence electrons are lost or gained by atoms—the particles in the nucleus (neutrons and protons) are not changed.

To understand the ion charges that are listed in the Periodic Table, you simply have to examine an element's total electrons and compare that with the nearest noble gas. Table 1 shows some examples of the differences in charges between ions and atoms.

Table 1 Ion Charges

Particle	Number of protons and electrons	Net charge	Symbol
sodium atom	11p | 11e 11+ | 11−	net charge = 0	Na
sodium ion	11p | 10e 11+ | 10− (10e to match Ne)	net charge = 1+	Na^+
sulfur atom	16p | 16e 16+ | 16−	net charge = 0	S
sulfur ion	16p | 18e 16+ | 18− (18e to match Ar)	net charge = 2−	S^{2-}
beryllium atom	4p | 4e 4+ | 4−	net charge = 0	Be
beryllium ion	4p | 2e 4+ | 2− (2e to match He)	net charge = 2+	Be^{2+}
aluminum atom	13p | 13e 13+ | 13−	net charge = 0	Al
aluminum ion	13p | 10e 13+ | 10− (10e to match Ne)	net charge = 3+	Al^{3+}

(p = protons, e = electrons)

LEARNING TIP

Check your understanding. Use Table 1 to explain to a partner the differences in charges between ions and atoms. To read the table carefully, use the **4-S** system: **S**tudy the table. **S**tate the purpose of the table. **S**earch out the information in the table. **S**ummarize the information.

Inspecting the ion charges in the Periodic Table, some general patterns emerge. Metals form positive ions and non-metals form negative ions. Furthermore, Group 1 ions have a 1+ ion charge, Group 2 ions a 2+ charge, and Group 17 ions a 1− charge. Hydrogen, always an exception as a "family of one," is able to lose one electron and become H^+ or gain one electron and become H^-.

To test your skills at predicting ion charges, go to **www.science.nelson.com**

7.1

CHECK YOUR Understanding

1. What is the main difference between an element and a compound?
   A. Elements are more numerous than compounds.
   B. Elements exist in nature, whereas compounds are made by scientists.
   C. A compound can be broken down into simpler substances, whereas an element cannot.
   D. An element can be broken down into simpler substances, whereas a compound cannot.
2. How are compounds related to elements?
   A. Compounds are made up of elements chemically combined.
   B. Elements are made up of compounds chemically combined.
   C. Compounds are made up of elements physically combined.
   D. Elements are made up of compounds physically combined.
3. Write a definition of a compound. Include three points in your definition.
4. How does a compound's properties compare to those of its component elements? Provide an example.
5. Air contains the elements oxygen and nitrogen. Is air a compound? Why or why not?
6. Table sugar or sucrose is a compound that has the chemical formula $C_{12}H_{22}O_{11}$.
   (a) How many different elements make up sucrose?
   (b) Name these elements and their proportions.
   (c) State some common properties of these elements.
   (d) Would another chemical made of the same elements still be considered to be sucrose? Why or why not?
7. What do we mean when we say that atoms bond?
8. What particles in an atom are responsible for bonding?
9. What is a valence electron?
   A. an electron with a combining capacity of 1−
   B. an electron in the outermost shell of an atom
   C. an electron in the innermost shell of an atom
   D. an electron that is attracted to other electrons
10. Draw Bohr diagrams to show how electrons are transferred between an atom of calcium and an atom of fluorine to form ions.
11. Draw Bohr diagrams of the following:
    (a) O and O^{2-}
    (b) Mg and Mg^{2+}
    (c) Be and Be^{2+}
    (d) N and N^{3-}
12. Copy Table 2. Consult the Periodic Table to complete the table by filling in the blanks.

Table 2 Ion Charges

Particle	Number of protons and electrons	Net charge	Symbol
fluorine atom	9p | __e __+ | __−	net charge = 0	______
fluorine ion	9p | __e __+ | __−	net charge = __	______
phosphorus atom	__p | __e __+ | __−	net charge = __	______
phosphorus ion	__p | __e __+ | __−	net charge = __	______
______ atom	20p | __e __+ | __−	net charge = __	______
______ ion	20p | __e __+ | __−	net charge = __	______

THE REAL WORLD OF C.S.I.— FROM FINGERPRINTING TO FIREARMS

Every crime scene whispers a story. The key is knowing how to interpret the clues. This is where the world of forensic chemistry plays a large role.

Forensic chemistry involves objectively analyzing the physical evidence in order to reconstruct the sequence of events surrounding a crime. In this process, forensic chemists run the evidence through a series of tests, analyze and interpret the results, and sometimes provide expert testimony based on their findings. Evidence may come in the form of fingerprints, DNA samples, and gunshot residue to name a few. Elements and the compounds they form are essential to forensic chemistry.

Fingerprinting

Fingerprint identification is one of the oldest tools used in forensics. Today, however, it is much more dependent on chemistry. Your fingers have a unique pattern of ridges and valleys spotted with tiny oil-releasing pores. When your hand comes into contact with an object, some oil transfers the ridge detail to the surface of the object (Figure 1).

These latent or invisible fingerprints may be revealed by dusting the surface with fine powders. However, different surfaces may require enhancement or development using chemical procedures first. For instance, silver nitrate is a compound that fluoresces in UV or bright light so that fingerprints can be seen. The compound cyanoacrylate (what we know as superglue) is used to bring out fingerprints on smooth surfaces like glass. When the compound is warmed, its fumes react with the invisible fingerprint residue to make them visible.

Figure 1 This fingerprint was made visible through forensic techniques.

DNA "Fingerprinting"

Just as we can be identified by the pattern of our unique fingerprints, we can also be identified by our DNA "fingerprints." Scientifically, DNA fingerprinting is known as DNA typing, DNA profiling, or genetic fingerprinting. DNA samples can come from various body cells—from hair roots to body fluids—since DNA is in our cells. This process involves chemically isolating the DNA from the cell or tissue sample, purifying it, and then replicating it. It is then analyzed by electrically separating the bands of DNA to create a unique DNA fingerprint (Figure 2). The DNA fingerprint can then be compared with a DNA profile from a suspect or matched with profiles stored on various databases.

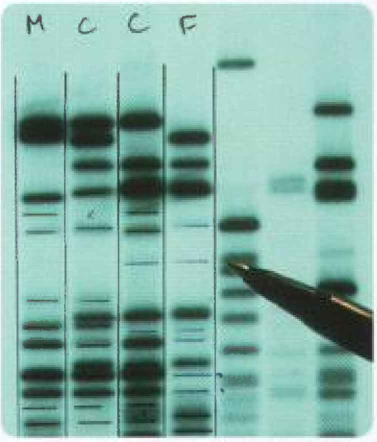


Figure 2 A DNA "fingerprint"

Firearm Evidence

Forensic chemistry also deals with the chemical analysis of a variety of types of physical evidence involving firearms. When a firearm discharges, the combustion of the primer (barium, antimony, and lead) and gunpowder (carbon, sulfur, and a compound such as sodium nitrate) in the cartridge generates gases. These gases propel the bullet out of the barrel. Residue can be left over from the combustion products, or the primer, or the gunpowder components. Residue can also come from the cartridge case, bullet, or bullet jacket. The gunshot residue may spray onto the clothing of a victim or on the hands of the shooter. In the lab, a Scanning Electron Microscope (SEM) connected to a spectrometer can be used to examine tape lifts taken from skin or clothes. This test can show the presence of small residue particles and analyze their elemental composition.

7.2 Chemical Bonding

The physical forces that join or connect atoms together are called **chemical bonds**. As previously stated, this bonding is associated with electron interactions between atoms. This has led to a theory of two general types of bonding: ionic and covalent.

Ionic Bonding—Electron Transfer between a Metal and Non-Metal

Oppositely charged ions (metals and non-metals) have a strong attraction for one another and, as a result, are held tightly together. This is known as ionic bonding and serves to build atoms into compounds called **ionic compounds**.

In the previous section, you learned that ions form when a transfer of valence electrons takes place between atoms. See Figure 6 in Section 7.1, page 172, to see a model of sodium and chlorine ion formation. After these ions are formed, they are strongly attracted by their opposite charges and NaCl results. Therefore, in **ionic bonding**, a *transfer* of valence electrons occurs.

Another example of an ionic compound is calcium fluoride (CaF_2), a substance that is added to toothpaste to strengthen tooth enamel and prevent decay. Calcium atoms transfer electrons to fluorine atoms to form oppositely charged ions. These ions are then attracted to one another to form CaF_2. So, in the compound calcium fluoride, one calcium ion combines with two fluorine ions (Figure 1).

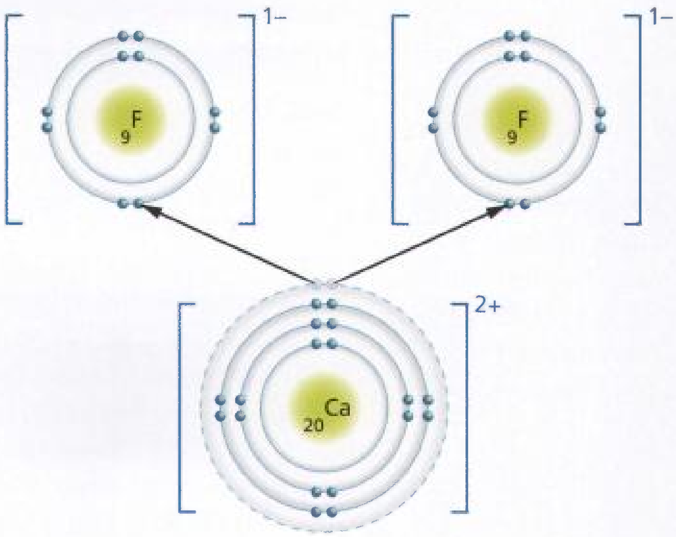


Figure 1 When calcium and fluorine combine, the calcium atom transfers 1 electron to each of 2 fluorine atoms to complete all of their valence shells. The Ca^{2+} ion now has a valence shell similar to Ar (8 electrons in its valence shell). Each F^- ion now has a valence shell similar to Ne (8 electrons in its valence shell).

Some Properties of Ionic Compounds

Ionic bonds are strong as a result of the electrical attraction of opposite charges. Also, the ions in ionic compounds have the tendency to line up in crystalline block patterns (Figure 2). These features of ionic bonding are evident in some of the common properties of ionic compounds.

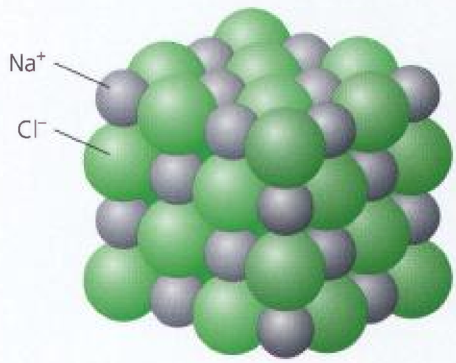


Figure 2 Na^+ and Cl^- ions form a crystal arrangement in which all of the adjacent, oppositely charged ions are equally attracted to one another. The smallest grouping that exists in the crystal is one NaCl pair.

Ionic Compounds Form Crystals

Usually, ionic compounds form crystals large enough to be seen. If you look closely at a crystal of table salt, NaCl, you can see that it looks like a little cube. This is due to the crystal arrangement of the ions of Na^+ and Cl^-. Even if it appears to be a powder, the crystal will appear under a microscope. Ionic compounds are typically solids at room temperature. GO

To view photos of ionic crystals in mineral specimens, go to **www.science.nelson.com** GO

Ionic Compounds Have High Melting Points

A tremendous amount of energy (heat) is required to separate the tightly bound ions in solid ionic compounds (better known as melting). For example, in order to melt a crystal of table salt, a temperature of 800 °C is needed—a temperature that is difficult to reach in a normal lab situation.

Ionic Compounds Are Very Hard and Brittle

Again, because of their tight crystal structures, ionic compounds do not bend very well. The ions are unable to slide around one another, and the crystals will break rather than bend when subjected to strong external forces.

Ionic Compounds Conduct Electricity When Dissolved in Water

As you know, table salt dissolves easily in water. One of the properties of water is its ability to pull apart the ions in compounds such as table salt. The separated Na^+ and Cl^- ions are now free to move about, and as a result, the solution acts as a good electrical conductor. An electrical conductivity test is a strong indication of whether a compound in solution is ionic.

Covalent Bonding—Electron Sharing between Non-Metals

Another type of bonding occurs when non-metals share their valence electrons with other non-metals to complete their valence shells. This bonding is called covalent bonding and builds atoms into **covalent** or **molecular compounds**. Therefore, in **covalent bonding**, a *sharing* of valence electrons occurs.

LEARNING TIP

Covalent

The prefix "co" in covalent, means "together," as in cooperate (working together). The term "covalent" suggests that atoms achieve complete valence shells by working together and sharing.

An example of covalent bonding is found in the everyday gas known as carbon dioxide, CO_2. The Bohr diagram in Figure 3 describes a model in which the electrons are shared between the three atoms.

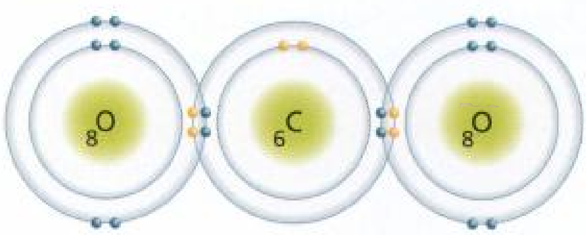


Figure 3 When carbon and oxygen combine to form carbon dioxide, the valence shells overlap. They share valence electrons so that each atom can have 8 valence electrons and become stable. Each atom's outer shell is then similar to Ne (8 electrons in the valence shell).

Another Bohr model of covalent bonding can help us understand the reason that certain elements consist of paired atoms. Recall from Chapter 6 that some elements, such as oxygen (O_2), exist in their elemental forms as paired atoms. Figure 4 shows how the 2 atoms of oxygen share their valence electrons to become stable.

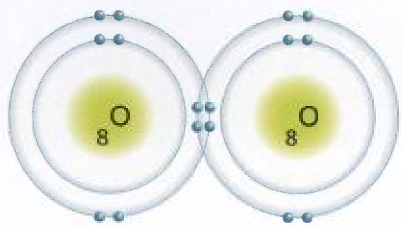


Figure 4 A Bohr diagram explains the formation of paired atoms such as O_2. Notice the sharing of valence electrons to achieve complete outer shells of 8 electrons each.

In covalent bonding, the atoms are held together by the attraction of the shared negative electrons to the positive nucleus of each atom. This is illustrated in the Bohr diagram of hydrogen gas, H_2 (Figure 5).

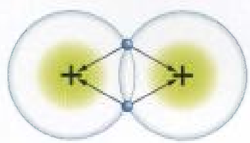


Figure 5 Two hydrogen atoms share a pair of electrons to complete their valence shells similar to He (2 electrons). The shared negative electrons are attracted to each positive nucleus. This attraction bonds the atoms together.

Atoms, Ions, and Molecules

We know that an element is the simplest form of matter and that the smallest particle of an element is an atom. Why is the atom the basic unit of matter if atoms are composed of still smaller particles? None of an atom's parts (subatomic particles) can constitute matter on its own. This is similar to a living cell. A cell is the basic unit of life even though cells are made up of smaller parts because none of a cell's parts can constitute life on its own.

Compounds are made from two or more elements that are chemically joined in fixed proportions. Different types of compounds (ionic and covalent or molecular) exist depending on how the elements are joined. You have learned that the smallest particle or basic unit of an ionic compound is an ion. The smallest particle or basic unit of a covalently bonded compound is called a molecule. A **molecule** is a neutral particle that consists of two or more atoms that are covalently bonded together, as shown in Figure 6(a). Additionally, you have learned that a few free elements like oxygen exist as paired atoms (O_2). Paired atoms are called **diatomic molecules**, as shown in Figure 6(b).

As you have seen in Figure 2 on page 177, ionic compounds form crystal arrays of alternating positive and negative ions. There is not a distinct pair of ions that exists as a unit (molecule). This is why ionically bonded compounds are not made up of molecules; they are made up of ions. Therefore, the smallest particles of matter are atoms, ions, and molecules.

Did You KNOW?

Molecules

The word "molecule" comes from the Greek word *molos* meaning small unit of mass.

(a) (b)

Figure 6 (a) A water molecule is composed of 2 hydrogen atoms covalently bonded to 1 oxygen atom. (b) 2 atoms of oxygen are covalently bonded to form a diatomic molecule.

Figure 7 illustrates the two types of compounds: ionic compounds and molecular (covalent) compounds. The terms "molecular compound" and "covalent compound" are interchangeable. The first term simply describes the nature of the particles (molecules), whereas the second describes the nature of the bonding (covalent).

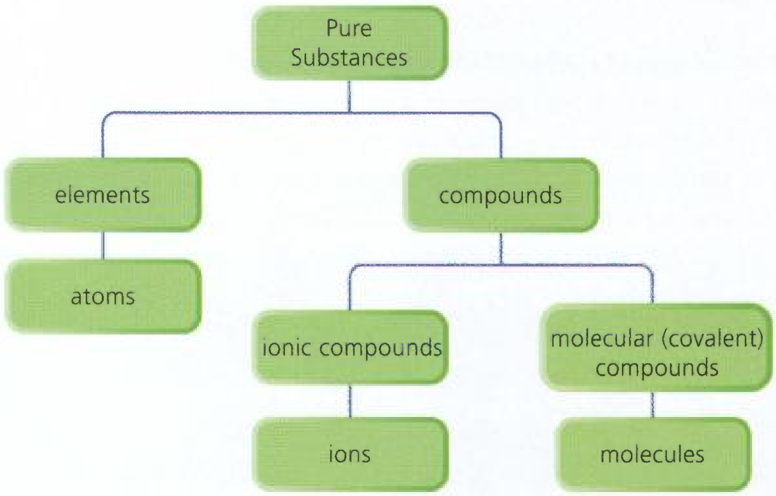


Figure 7 The smallest particles of matter are atoms, ions, and molecules.

TRY THIS: *Atoms and Molecules*

Skills Focus: creating models

The common sense of chemistry is often lost in its vocabulary. Words like "atoms" and "molecules" confuse people when they are not used in their everyday language. In this activity, you will use simple models to reinforce your understanding of atoms and molecules.

Materials: assortment of interlocking building blocks

1. Select 12 separated blocks so that you have four identical blocks of three different colours, for example, four same-sized reds, four same-sized blues, and four same-sized whites. Sizes of blocks can differ among colours.
2. Arrange the blocks on a piece of paper in groups of the same colour. Imagine that each colour represents a different element and each coloured block represents an atom of that element.
3. Designate any one of your colours as H atoms and another colour as O atoms and keep these as their representative colours throughout this activity. Build a molecule of the compound, water (H_2O). Any shape will do for this activity. Make a labelled sketch of your molecule.
4. Start again and construct a molecule of the element, oxygen (O_2), and make a labelled sketch.

A. How many different elements do you have in Step 2? How many atoms of each element? How many total atoms?

B. Predict how many water (H_2O) molecules you can build from your atoms. Test your prediction.

C. How many atoms are in each molecule of oxygen (O_2)? Predict how many more of these same molecules you can build. Test your prediction.

D. Now build a molecule of the compound, ammonia (NH_3). Make a labelled sketch. How many different colours did you use? Why? Which colours did you choose for nitrogen and hydrogen? Why?

E. Could you build a methane gas (CH_4) molecule? Why or why not?

LEARNING TIP

Connect to prior knowledge. Before reading the section on Some Properties of Molecular Compounds, ask yourself, "What are some of the things I already know molecular compounds? What are some of the things I think I will learn about?"

Some Properties of Molecular Compounds

Covalent bonds are strong within the molecule, but the molecule has no overall electric charge. Consequently, covalent molecules are not held as tightly together as are their ionic counterparts. These features of covalent bonding are evident in some of the common properties of molecular compounds.

Molecular Compounds Form Crystals

Molecular compounds will form crystals, but the molecules can be moved out of position producing varying crystal shapes. An example of this is evident in snowflakes. Water molecules can array themselves in a huge variety of solid hexagonal (six-sided) snowflake crystals (Figure 8).

Figure 8 H_2O is a molecular compound that, as a solid, forms a variety of crystal shapes.

Molecular Compounds Have Low Melting and Boiling Points

Since the attractive forces between covalent molecules (not within) are relatively weak, it makes sense that they would be easy to separate. This is evident in their lower melting points and boiling points. Table 1 lists some common molecular compounds at room temperature. Notice how these compounds are easily separated into their higher **phases** or **states** (gas, liquid, or solid). In fact, many molecular compounds are liquids or gases at room temperature and standard pressure.

Table 1 States of Common Molecular Compounds at Room Temperature

Molecular compound	Chemical	Phase/State
H_2O	water	liquid
H_2O	water vapour (in air)	gas
NH_3	ammonia (from smelling salts)	gas
CH_4	natural gas (for furnaces)	gas
CO_2	carbon dioxide (in air)	gas
$C_{12}H_{22}O_{11}$	sucrose (table sugar)	solid

STUDY TIP

Summarizing is a helpful review tool. After reading Section 7.2, write the key points you have learned about chemical bonding on a study card. Compare your summary card with a friend. Is there anything important that should be added? You can use this study card later to prepare for the chapter exam.

Molecular Compounds Are Poor Conductors of Electricity When Dissolved in Water

Many molecular compounds such as sucrose (table sugar) will dissolve in water, but unlike ionic compounds, molecular compounds do not separate to form ions. The molecules are separated from each other but each individual molecule stays intact with a neutral charge. As a result, molecular compounds are poor conductors of electricity when dissolved in water. Figure 9 gives a graphical description of the difference between an ionic compound (salt, NaCl) and a molecular compound (sucrose, $C_{12}H_{22}O_{11}$) dissolving in water. GO

To learn more about the differences between molecular and ionic compounds, go to www.science.nelson.com GO

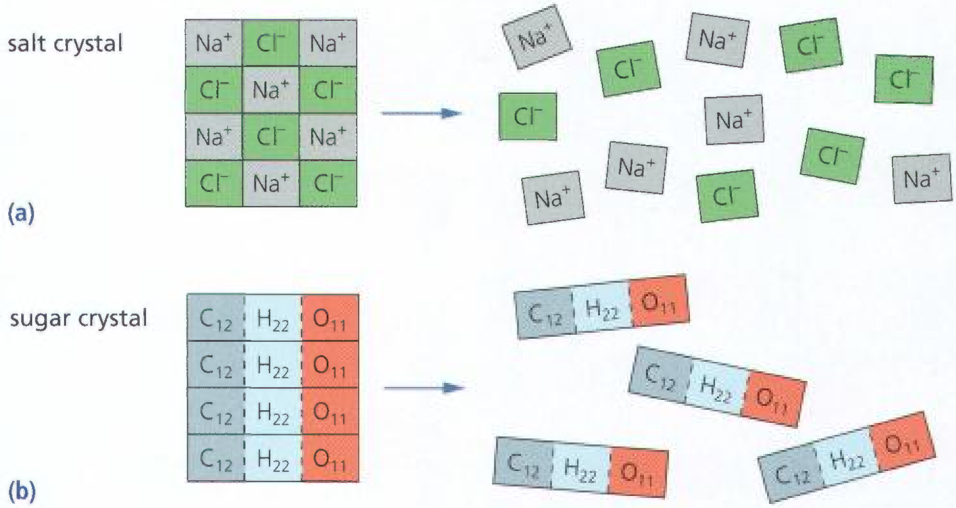


Figure 9 This model shows a major difference between ionic and molecular compounds when dissolving in water. (a) The NaCl separates and breaks apart into ions. (b) The $C_{12}H_{22}O_{11}$ separates but does not break apart into atoms or ions.

TRY THIS: *Electrical Conductivity Tests—Ionic or Molecular?*

Skills Focus: interpreting data

Ionic compounds dissolve in water and separate into their component ions. An ionic compound can also be melted (at high temperature) and separated into its ions. These separated ions will allow current to flow if a simple electrical conductivity tester is used. Molecular compounds do not separate into their components, do not form ions, and do not conduct electricity.

1. An investigation was done on the conductivity of certain substances by using an electrical conductivity tester (Figure 10). The results are shown in Table 2.

Table 2

Compound tested	Light bulb
molten salt	bright
molten sugar	off
salt water solution	bright
sugar water solution	off

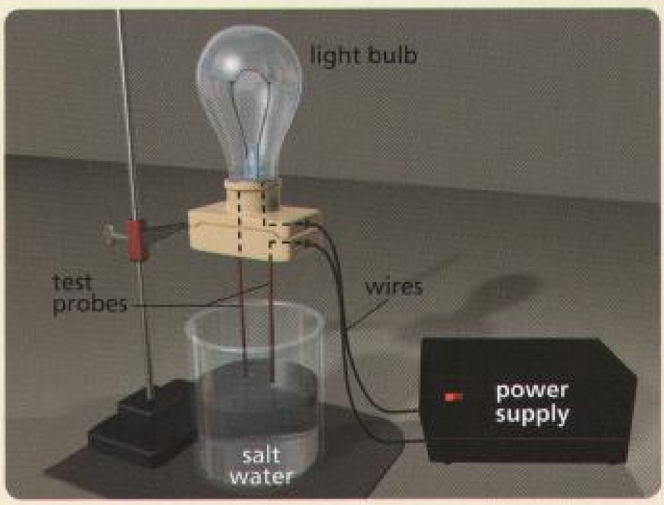


Figure 10

A. Based on the results of the conductivity tests, classify salt and sugar as ionic or molecular compounds. Explain your classifications.

B. Here are two melting temperatures: 800 °C and 185 °C. Match these temperatures with salt and sugar, and explain your choices.

7.2 CHECK YOUR Understanding

1. What do we call a physical force that holds atoms together?
   A. physical bond
   B. chemical bond
   C. physical attraction
   D. chemical attraction
2. Explain the difference between an ionic bond and a covalent bond.
3. Draw Bohr diagrams of a magnesium atom bonding with fluorine atoms. Draw atoms, then electron transfer, and finally the ions that form. What type of bonding occurs?
4. Draw Bohr diagrams of two hydrogen atoms bonding with an oxygen atom by sharing electrons to form a water molecule. What type of bonding occurs?
5. Explain why the melting points of ionic compounds and molecular compounds differ.
6. Explain why an ionic compound is hard and brittle.
7. (a) What laboratory procedure allows you to test if a compound is ionic or molecular?
   (b) What results would you expect?
8. (a) What do we call the smallest particle of an element?
   (b) What do we call the smallest particle in a compound with ionic bonds?
   (c) What do we call the smallest particle of a covalently bonded compound?
9. State the relationship between atoms and molecules.
10. Examine the drawings in Figure 11. What types of particles are modelled in each drawing?

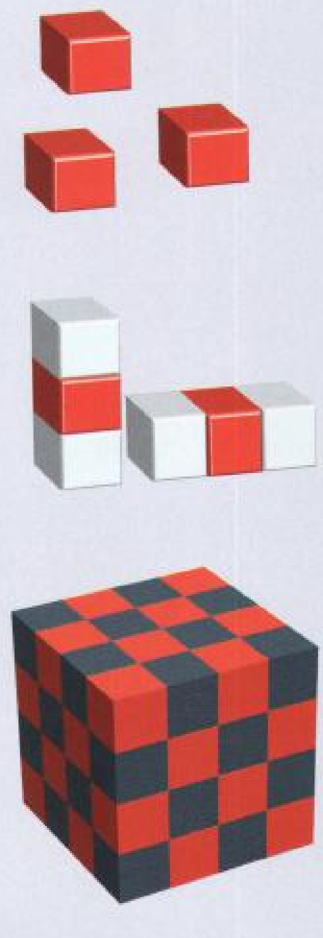


Figure 11

11. For each of the following, what type of smallest particle would exist? Explain your reasoning.
    (a) strontium
    (b) $CaCl_2$
    (c) CCl_4
    (d) SO_2
    (e) helium
    (f) bromine
    (g) MgO

7.3 Ionic Compounds: Chemical Formulas and Naming

Tens of thousands of different ionic compounds can be formed from various combinations of the over 100 elements in the Periodic Table. A standard system was needed that would allow chemists all over the world to describe these compounds in a manner that is understandable to all. In 1919, the International Union of Pure and Applied Chemistry (IUPAC) was formed. One of its primary goals was to establish conventions and standards for the "language of chemistry." The lessons that follow adhere to IUPAC standards. GO

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

In your previous studies of chemistry, you learned how to write chemical formulas for ionic compounds and how to name them. A **chemical formula** describes the proportions of the component elements. For example, the compound potassium oxide can be represented with the formula K_2O. From this, you know that there will be two atoms of the element potassium for every one atom of the element oxygen in the compound. Ionic compounds can be divided into three types for the purpose of reviewing formula and naming rules: binary ionic compounds, ionic compounds with multivalent elements, and ionic compounds with polyatomic ions.

STUDY TIP
Previewing is a helpful critical reading strategy. Preview Section 7.3 before it is discussed in class. Doing this will help you better understand the material as it is presented in class.

When determining the chemical formulas of ionic compounds, remember that chemical compounds are electrically neutral; therefore, *the fundamental rule for determining the chemical formula for any ionic compound is that the total ion charge for the compound is 0.* In other words, the total positive ion charge must be equal to or cancel the total negative ion charge. This is known as an **ion charge balance**.

You can find ion charges and chemical symbols of elements that you will need to know to write formulas and ionic compound names in the Periodic Table at the back of this book or in Appendix C1.

Binary Ionic Compounds

Ionic compounds are formed from a combination of positive and negative ions. The simplest ionic compounds contain only two types of monatomic ions (ions that have only one charged atom). These are referred to as binary ionic compounds. Some examples of these are listed in Table 1 below.

Table 1 Formula and Names of Binary Ionic Compounds

Positive ion	Negative ion	Chemical formula	Chemical name
Na^+	O^{2-}	Na_2O	sodium oxide
Ca^{2+}	F^-	CaF_2	calcium fluoride
Al^{3+}	S^{2-}	Al_2S_3	aluminum sulfide

LEARNING TIP

If you find working with sample problems difficult, try self-explanations. Go through the problem line by line and talk it out. Pay attention to visual prompts, such as the steps written in bold and the arrows that keep you on track. Note where your understanding is clear and where there are gaps. Sometimes it is helpful to reread the problem and to draw a quick sketch.

The following sample problems show the steps to follow to determine the chemical formulas for binary ionic compounds.

SAMPLE PROBLEM 1

Determine Chemical Formula

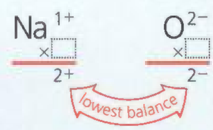
What is the chemical formula for the ionic compound formed from the elements sodium and oxygen?

Solution

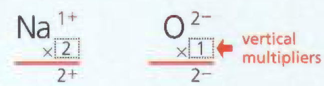
Step 1: Look up the elements' symbols and their ion charges. Always write the positive charge first. Use 1+ rather than just + when balancing charges.

$$Na^{1+} \qquad O^{2-}$$

Step 2: Use a visual approach to balancing the charges. Use vertical multiplication to obtain a balanced ion charge. Vertical multiplication just means to multiply numbers in a vertical column.



Step 3: Fill in the required multipliers.



Step 4: The multipliers become the subscripts (small numbers that represent atoms) in the chemical formula: Na_2O_1. When there is only one of a particular type of atom, the number "1" does not need to be written as a subscript, so the final formula is Na_2O. The above charge balance that led to the formula Na_2O can also be represented by the model shown:

Practice

What is the chemical formula for the ionic compound formed from the elements beryllium and chlorine?

SAMPLE PROBLEM 2

Determine Chemical Formula

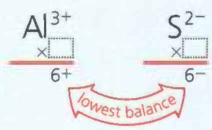
What is the chemical formula for the ionic compound formed from aluminum and sulfur?

Solution

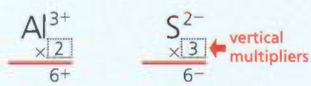
Step 1: Look up the symbols and their ion charges. Write the positive ion first.

$$Al^{3+} \quad S^{2-}$$

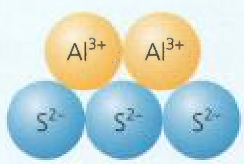
Step 2: Use vertical multiplication to set up a balanced ion charge.



Step 3: Fill in the required multipliers.



Step 4: The multipliers become the subscripts in the chemical formula. The chemical formula is Al_2S_3. The charge balance that led to Al_2S_3 can be imagined as the model shown:



Practice

What is the chemical formula for the ionic compound formed from the elements calcium and nitrogen?

Remember that it is important to understand that the main idea is to obtain a charge balance for chemical formulas for ionic compounds. But you may have noticed a shortcut that allows you to obtain the formula's subscripts rather quickly.

This shortcut is called the criss-cross method. To do this, you bring the number above the metal element down to be the subscript of the non-metal, and the number above the non-metal element down to be the subscript of the metal. If there is a common factor in the subscripts generated, you must reduce the subscripts as a final step. Examples of the criss-cross method are shown on the next page.

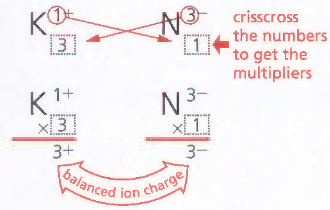
LEARNING TIP

People learn in different ways. Some people like to think in words. When forming ionic compounds, try "talking it out":

1. Write the metal element in its ion form.
2. Write non-metal element in its ion form.
3. Crisscross (swap) charges as subscripts.
4. Reduce subscripts if necessary.

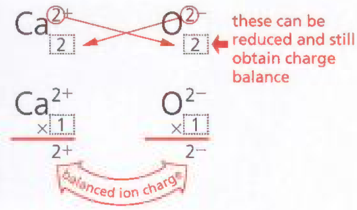
Crisscross Method

Example 1: What is the chemical formula for the ionic compound formed from potassium and nitrogen?



The chemical formula is K_3N.

Example 2: What is the chemical formula for the ionic compound formed from calcium and oxygen?



The chemical formula is CaO.

Naming Binary Ionic Compounds

For binary ionic compounds, the positive ion's name (the metal element) is written first. The negative ion's name (the non-metal element) is written second, but this element's name is changed to end in "ide" (Table 2). So for the formula Na_2O, the chemical name is sodium oxide. Note that chemical names do not use capital letters, and the multiplier (subscript) "2" in the formula is part of the ion charge balance and has no bearing on the chemical name.

Other examples of chemical names for binary ionic compounds are aluminum sulfide (Al_2S_3) and calcium nitride (Ca_3N_2).

Table 2 Some "ide" Endings for Negative Ions

Non-Metal element	Negative ion	Negative ion name
nitrogen (N)	N^{3-}	nitride
phosphorous (P)	P^{3-}	phosphide
oxygen (O)	O^{2-}	oxide
sulfur (S)	S^{2-}	sulfide
fluorine (F)	F^{-}	fluoride
chlorine (Cl)	Cl^{-}	chloride
bromine (Br)	Br^{-}	bromide
iodine (I)	I^{-}	iodide

Ionic Compounds with Multivalent Elements

Many of the metal elements (after atomic number 20) have more than one ion charge. They are said to be **multivalent**. Ionic compounds with multivalent elements contain a metal that is multivalent.

The Stock System is used for naming multivalent metals. This system uses a Roman numeral to represent the positive ion charge when more than one charge is possible. For example, the notation for naming the Cu^{2+} ion is copper(II) and it is read as "copper two." Similarly, the Cu^{+} ion is named copper(I) and is read as "copper one." The Roman numeral is always in parentheses and there is no space before the first parenthesis. Table 3 lists several multivalent metals and their ion names.

Table 3 Multivalent Metals and Their Ion Names

Metal	Ion	Ion name	Metal	Ion	Ion name
chromium	Cr^{2+}	chromium(II)	manganese	Mn^{2+}	manganese(II)
	Cr^{3+}	chromium(III)		Mn^{3+}	manganese(III)
cobalt	Co^{2+}	cobalt(II)	tin	Sn^{2+}	tin(II)
	Co^{3+}	cobalt(III)		Sn^{4+}	tin(IV)
copper	Cu^{+}	copper(I)	lead	Pb^{2+}	lead(II)
	Cu^{2+}	copper(II)		Pb^{4+}	lead(IV)
iron	Fe^{2+}	iron(II)			
	Fe^{3+}	iron(III)			

The following sample problems show the steps to follow to determine the chemical formulas for ionic compounds with multivalent elements.

SAMPLE PROBLEM 3

Determine Chemical Formula

What is the chemical formula for copper(I) oxide?

Solution

Step 1: Look up the ion charge for the non-metal. You do not have to look up the ion charge for copper because the number in the parentheses tells you this. The ions in the compound are Cu^{+} and O^{2-}.

Step 2: Fill in the required multipliers. The multipliers become the subscripts in the chemical formula.

$$\begin{array}{cc} Cu^{1+} & O^{2-} \\ \times 2 & \times 1 \\ \hline 2+ & 2- \end{array}$$

The chemical formula for copper(I) oxide is Cu_2O.

Practice

What is the chemical formula for copper(II) chloride?

STUDY TIP

Remember to do the practice problems, as this helps you learn the material. It also helps you to see if you need to study more.

SAMPLE PROBLEM 4

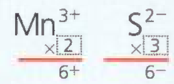
Determine Chemical Formula

What is the chemical formula for manganese(III) sulfide?

Solution

Step 1: Look up the ion charge for the non-metal. The ions are Mn^{3+} and S^{2-}.

Step 2: Fill in the required multipliers.



The chemical formula for manganese(III) sulfide is Mn_2S_3.

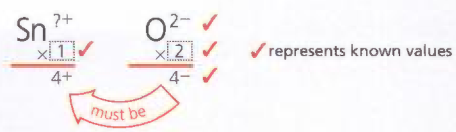
Practice

What is the chemical formula for chromium(III) sulfide?

Naming Ionic Compounds with Multivalent Elements

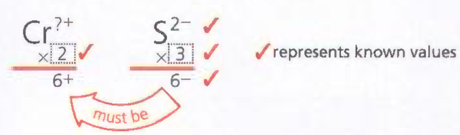
When naming ionic compounds with multivalent elements, you have to pay careful attention to the ions you are naming. For example, SnO_2 cannot be named tin oxide as in binary ionic compounds since there are two common types of tin ions, Sn^{2+} and Sn^{4+}. To correctly name SnO_2, you must first determine (with a little arithmetic) which Sn ion is in the compound. The ion charge on O is known (O^{2-}), which allows us to obtain the ion charge on Sn. (Hint: Always look up the ion charge for both the positive and negative ions. That way, you will know if the metal ion is multivalent, and that the multivalent naming system [Roman numerals] must be used.)

In this example, the ion charge for Sn must be 4+ for the formula to be charge balanced. The metal ion here is Sn^{4+}, tin(IV). So, the name will be the names for both ions—SnO_2 is tin(IV) oxide.



Let's look at another example: What is the chemical name for Cr_2S_3? First, check the Periodic Table to find out if one of the ions is multivalent. Notice that Cr or chromium is. The ions are $Cr^?$ (multivalent) and S^{2-}. Do your arithmetic to find out which chromium ion is in the compound.

The ion charge on Cr must be 3+ to have ion charge balance. Since Cr^{3+} is chromium(III), the chemical name for Cr_2S_3 is chromium(III) sulfide.



Ionic Compounds with Polyatomic Ions

Recall that certain groups of atoms are capable of first bonding together, and then acting as though they were a single ion. Such groups are called **polyatomic ions**. Ionic compounds with polyatomic ions contain at least one ion that is polyatomic. The sulfate ion is one example of a polyatomic ion. Its formula is traditionally written as SO_4^{2-}, but for our purposes, it is a good idea to visualize the formula as a cluster such as $(SO_4)^{2-}$ in order to isolate the ion charge from the cluster. This will aid you in formula writing. Table 4 lists several of the more common polyatomic ions. You will notice that only one polyatomic ion has a positive ion charge, NH_4^+; all of the rest have negative charges. A more complete list is found in Appendix C2.

Table 4 Some Common Polyatomic Ions

Polyatomic ion	Visualize	Name
NH_4^+	$(NH_4)^+$	ammonium
CO_3^{2-}	$(CO_3)^{2-}$	carbonate
ClO_3^-	$(ClO_3)^-$	chlorate
OH^-	$(OH)^-$	hydroxide
NO_3^-	$(NO_3)^-$	nitrate
PO_4^{3-}	$(PO_4)^{3-}$	phosphate
SO_4^{2-}	$(SO_4)^{2-}$	sulfate

To write chemical formulas for ionic compounds with polyatomic ions and to name them, the same rules apply as for binary ionic compounds. Once again, the fundamental principle for formula writing is total ion charge balance.

To practise naming ionic compounds and ionic compound formulas, go to **www.science.nelson.com**

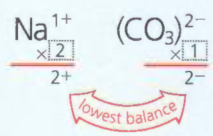
SAMPLE PROBLEM 5

Determine Chemical Formula

What is the chemical formula for sodium carbonate?

Solution

Look up the formulas for the two ions: sodium ion and carbonate ion. For the polyatomic ion, write its formula in visualized form. The ions are Na^+ and $(CO_3)^{2-}$.



The chemical formula becomes $Na_2(CO_3)$ or simply Na_2CO_3. When *only one* polyatomic ion appears in a chemical formula, it is conventional to leave out the parentheses.

Practice

What is the chemical formula for magnesium sulfate?

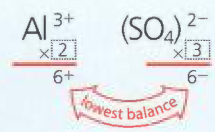
SAMPLE PROBLEM 6

Determine Chemical Formula

What is the chemical formula for aluminum sulfate?

Solution

Look up the formulas for the two ions: aluminum ion and sulfate ion. For the polyatomic ion, write its formula in visualized form. The ions are Al^{3+} and $(SO_4)^{2-}$.



The chemical formula is $Al_2(SO_4)_3$. In this case, the parentheses for the SO_4 group must be used. Otherwise, the formula would suggest Al_2SO_{43}.

Practice

What is the chemical formula for ammonium sulfide?

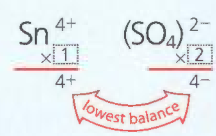
SAMPLE PROBLEM 7

Determine Chemical Formula

What is the chemical formula for tin(IV) sulfate?

Solution

Look up the formulas for the two ions: tin(IV) ion and sulfate ion.



The chemical formula is $Sn(SO_4)_2$

Practice

What is the chemical formula for manganese(II) sulfite?

Naming Ionic Compounds with Polyatomic Ions

Naming ionic compounds with polyatomic ions is straightforward—just use the ion names. Look up the names for the two ions in the compound. For example, in $(NH_4)_2CO_3$, both ions are polyatomic: ammonium ion, NH_4^+ and carbonate ion, CO_3^{2-}. Thus, the chemical name is ammonium carbonate. Remember that the name of the polyatomic ion does *not* end in "ide," except for "hydroxide."

Table 5 lists some examples of ionic compounds with polyatomic ions that are commonly used, along with their chemical formulas and names.

Table 5 Some Common Ionic Compounds with Polyatomic Ions

Chemical formula	Chemical name	Common name	Everyday use
$NaOH$	sodium hydroxide	caustic soda	oven cleaner
$NaHCO_3$	sodium bicarbonate	baking soda	cooking, cleaning
$MgSO_4$	magnesium sulfate	Epsom salt	soothing bath salt
$CaSO_4$	calcium sulfate	gypsum	drywall board
Na_2CO_3	sodium carbonate	washing soda	clothes washing
$CuSO_4$	copper(II) sulfate	bluestone	garden fungicide
$Ca(OH)_2$	calcium hydroxide	garden lime	lawn (soil) treatment

7.3 CHECK YOUR Understanding

1. (a) Show how vertical multiplication can be used to do a charge balance if Zn^{2+} combines with Cl^{-}.
   (b) Write the chemical formula and name for the compound that would be formed.
2. Write either the chemical formula or chemical name for these binary ionic compounds:
   (a) strontium sulfide
   (b) $CaCl_2$
   (c) lithium bromide
   (d) K_2O
   (e) beryllium oxide
   (f) Li_2Se
   (g) potassium phosphide
   (h) Ca_3N_2
   (i) calcium arsenide
   (j) MgF_2
   (k) scandium oxide
   (l) Na_2S
   (m) magnesium oxide
   (n) $ZnCl_2$
   (o) sodium nitride
3. Write either the chemical formula or chemical name for these ionic compounds with multivalent elements:
   (a) molybdenum(III) sulfide
   (b) $PbCl_2$
   (c) rhodium(IV) bromide
   (d) Cu_2O
   (e) mercury(II) oxide
   (f) Tl_2Se
   (g) bismuth(V) phosphide
   (h) PbF_4
   (i) rhenium(VII) arsenide
   (j) CoF_2
   (k) copper(I) telluride
   (l) Fe_2S_3
   (m) niobium(V) iodide
   (n) $PtBr_4$
   (o) titanium(IV) nitride
4. Write either the chemical formula or chemical name for these ionic compounds with polyatomic ions:
   (a) sodium acetate
   (b) $PbCrO_4$
   (c) barium acetate
   (d) $CaSO_4$
   (e) mercury(II) chlorite
   (f) Li_3PO_4
   (g) bismuth(V) phosphate
   (h) $(NH_4)_2HPO_4$
   (i) rhenium(VII) permanganate
   (j) $Co(ClO_4)_2$
   (k) copper(II) hydrogen oxalate
   (l) $Fe_2(SO_4)_3$
   (m) chromium(II) hydrogen sulfide
   (n) $Ba(ClO)_2$
   (o) titanium(IV) nitrite
5. First classify each of the following ionic compounds as binary, multivalent, or polyatomic (combinations can exist). Then write either the chemical formula or chemical name.
   (a) potassium acetate
   (b) PbF_2
   (c) calcium acetate
   (d) Li_2O
   (e) copper(II) chlorite
   (f) Na_3PO_4
   (g) lithium phosphide
   (h) $(NH_4)_2SO_4$
   (i) rhenium(VII) nitride
   (j) $CaCl_2$
   (k) lead(II) hydrogen oxalate
   (l) Cr_2S_3
   (m) iron(II) hydrogen sulfide
   (n) $PbBr_4$
   (o) tin(IV) nitride

7.4 Molecular Compounds: Chemical Formulas and Naming

Molecular compounds result when atoms of non-metals bond by sharing electrons. Since sharing electrons can take many forms, the chemical formulas for molecular compounds cannot be predicted from the valence electrons involved. For this reason, ion charges are not referred to in this section.

For example, carbon atoms and oxygen atoms can share electrons in different ways and form compounds of CO and CO_2. Nitrogen–oxygen compounds are so numerous that they often are called NO_x compounds, with formulas such as NO, N_2O, NO_2, and N_2O_4. As it is not possible to predict how non-metals might join with other non-metals, you must know either the chemical formula or the chemical name to write the other.

Writing Chemical Names for Molecular Compounds from Formulas

LEARNING TIP

As you study Table 1, make connections to your prior knowledge. Ask yourself, "How does this relate to what I have learned in math class?"

A prefix system is used for naming molecular compounds that consist of only 2 non-metals. Table 1 lists the first 10 prefixes, which represent the numbers 1 through 10. These prefixes are used to describe the number of atoms of each non-metal element in the compound.

Table 1 Prefixes Used in Naming Molecular Compounds

Prefix	Number	Prefix	Number
mono	1	hexa	6
di	2	hepta	7
tri	3	octa	8
tetra	4	nona	9
penta	5	deca	10

Look at the following examples for writing chemical names from formulas:

Example 1: Write the chemical name for N_2Cl_4.
Step 1: Recognize from the Periodic Table that both elements, N and Cl, are non-metals.
Step 2: Consider the number and name of each atom (element): 2 nitrogen atoms, 4 chlorine atoms.
Step 3: Use prefixes, and end the last element with "ide". The chemical name for N_2Cl_4 is *di*nitrogen *tetra*chlor*ide*.

Example 2: Write the chemical name for CO_2.
Step 1: Recognize from the Periodic Table that both elements, C and O, are non-metals.
Step 2: Consider the number and name of each atom (element): 1 carbon atom, 2 oxygen atoms.
Step 3: Use prefixes, and the last element ends in "ide". The chemical name for CO_2 is *mono*carbon *di*ox*ide.*

If the first element has only 1 atom, the "mono" is understood, but only on the first atom. Therefore, CO_2 is carbon *di*oxide, but CO is carbon *mono*xide. Monoxide is just easier to say than mono-oxide (monoxide), but both are acceptable according to IUPAC standards. Otherwise, abbreviations are not used, as shown by triiodide, decaoxide, and tetraoxide.

Several molecular compounds that you may recognize have common names that are still used in modern chemistry. These common names can be replaced by chemical names as shown in Table 2.

To test your skills at naming non-ionic compounds, go to **www.science.nelson.com**

Table 2 Some Common Molecular Compounds

Chemical formula	Common name	Chemical name
H_2O	water	dihydrogen monoxide*
NH_3	ammonia	nitrogen trihydride*
N_2O	laughing gas; nitrous or nitrous oxide	dinitrogen monoxide

* seldom, if ever, used

Writing Formulas for Molecular Compounds from Chemical Names

Writing the chemical formula is just a matter of following the instructions provided by the name. First, look up the elements involved in the Periodic Table. Once you have determined that the compound is covalent (non-metal with non-metal), do not look up any ion charges; simply examine the name, as shown in Table 3.

Table 3 Writing Chemical Formulas of Molecular Compounds

Chemical name	Name describes	Chemical formula
carbon dioxide	1 C atom, 2 O atoms	CO_2
sulfur trioxide	1 S atom, 3 O atoms	SO_3
dinitrogen tetraoxide	2 N atoms, 4 O atoms	N_2O_4
dichlorine monoxide	2 Cl atoms, 1 O atom	Cl_2O

The writing of molecular formulas is much easier than writing ionic formulas since no ions are required, nor is any ion charge balance.

A summary of all chemical formula and naming conventions discussed is given in Table 4 and Table 5.

Table 4 Writing Chemical Formulas for Ionic and Molecular Compounds

Examine the name	Metal (positive ion) / Non-Metal (negative ion)?	Compound type	Perform charge balance if necessary	Chemical formula
aluminum oxide	Yes: Al^{3+} / O^{2-}	binary ionic	Al^{3+} ×2 = 6+; O^{2-} ×3 = 6−	Al_2O_3
manganese(II) oxide	Yes: Mn^{2+} / O^{2-}	ionic with multivalent element	Mn^{2+} ×1 = 2+; O^{2-} ×1 = 2−	MnO
manganese(IV) hydroxide	Yes: Mn^{4+} / OH^{-}	ionic (both binary and with multivalent elements) and polyatomic ion	Mn^{4+} ×1 = 4+; $(OH)^{1-}$ ×4 = 4−	$Mn(OH)_4$
sulfur dioxide	No: S / O non-metal/non-metal	molecular	not necessary: just use prefixes in name	SO_2

Table 5 Writing Chemical Names for Ionic and Molecular Compounds

Examine the chemical formula	Metal (positive ion) / Non-Metal (negative ion)?	Compound type	Use charge balance if necessary	Chemical name
$MgCl_2$	Yes: Mg^{2+} / Cl^{-}	binary ionic	not necessary	magnesium chloride
PbO_4	Yes: $Pb^{?+}$ / O^{2-}	ionic with multivalent element	$Pb^{?+}$ ×1 = 8+; O^{2-} ×4 = 8− (must be)	lead(IV) oxide
$Ni_2(SO_4)_3$	Yes: $Ni^{?+}$ / SO_4^{2-}	ionic (both binary and with multivalent elements) and polyatomic ion	$Ni^{?+}$ ×2 = 6+; $(SO_4)^{2-}$ ×3 = 6− (must be)	nickel(III) sulfate
P_2O_5	No P / O non-metal/non-metal	molecular	not necessary; just use prefixes	diphosphorus pentaoxide

7.4 CHECK YOUR Understanding

1. Write either the chemical formula or chemical name for these molecular compounds:
   (a) nitrogen monoxide
   (b) SiO_2
   (c) boron monoxide
   (d) P_2O_5
   (e) tellurium dibromide
   (f) CO_2
   (g) dinitrogen tetraoxide
   (h) SeF_2
   (i) carbon disulfide
   (j) $AsBr_4$
   (k) arsenic trioxide
   (l) S_2O_5
   (m) sulfur dioxide
   (n) CS_2
   (o) tetraphosphorous decaoxide
2. The bolded information in Table 6 is correct. Some of the unbolded information is incorrect. Copy Table 6 in your notebook and correct the errors.

Table 6

Given	Formula type	Name or formula
(a) barium carbide	polyatomic ionic	**$CaCO_3$**
(b) **SO_2**	covalent	sulfur trioxide
(c) copper(II) oxide	**multivalent ionic**	Cu_2O
(d) Al_2O_3	multivalent ionic	**aluminum oxide**
(e) **magnesium acetate**	binary ionic	$Mg(CH_3COO)_2$
(f) Co_2O_3	**multivalent ionic**	cobalt(II) oxide
(g) silver(I) chloride	binary ionic	**AgCl**
(h) $K_2C_2O_4$	**polyatomic ionic**	potassium(II) oxalate
(i) chromium(II) sulfide	multivalent ionic	**Cr_2S_3**
(j) **NaCl**	binary ionic	sodium monochloride
(k) **copper(II) hydroxide**	multivalent/ polyatomic ionic	Cu_2OH
(l) $CuSO_4$	**multivalent/ polyatomic ionic**	copper(I) sulfate

3. Copy Table 7 in your notebook.

Table 7

Given	Formula type	Name or formula
calcium carbonate	polyatomic ionic	$CaCO_3$
SO_3	molecular	sulfur trioxide

Complete the table using the following names or formulas in the first column:
(a) copper(II) oxide
(b) Al_2S_3
(c) barium acetate
(d) Fe_2O_3
(e) silver fluoride
(f) $Na_2C_2O_4$
(g) manganese(III) oxide
(h) LiCl
(i) copper(I) hydroxide
(j) $CuSO_3$
(k) aluminum chloride
(l) $Cr(NO_2)_2$
(m) calcium hydroxide
(n) $K_2Cr_2O_7$
(o) gold(III) sulfide
(p) AlN
(q) magnesium hypochlorite
(r) NH_4ClO_4
(s) tricarbon disulfide
(t) BeO
(u) ammonium phosphate
(v) Cu_2SO_4
(w) chromium(III) chromate
(x) K_2S
(y) lead(II) carbonate
(z) $KMnO_4$

Compounds, Ions, and Molecules

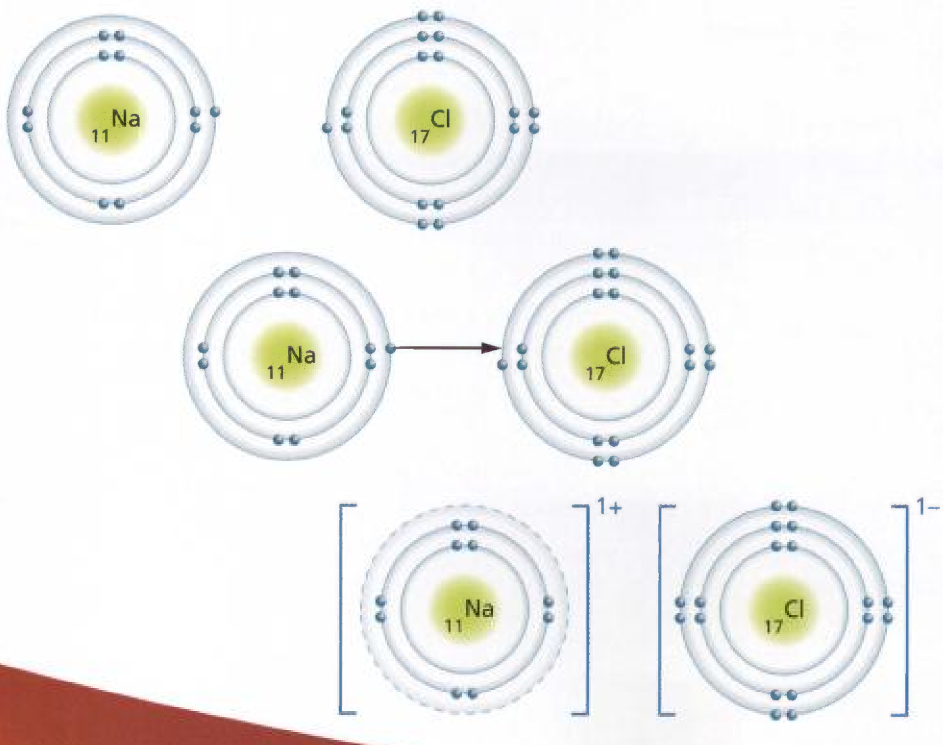
Key Ideas

Compounds result when elements bond together in fixed proportions.

- The simplest form of matter is an element. The smallest particle of an element is an atom.
- A compound is made up of two or more elements chemically bonded in fixed proportions.
- Each compound has properties that are different from the elements that they are made from.

Bohr diagrams can illustrate how ions form.

- Bohr diagrams show how electrons are arranged in shells.
- Only the valence electrons in the valence shell are involved when atoms join together.
- Atoms tend to acquire the same number of valence electrons as their nearest noble gas. Noble gases have complete valence shells.
- When atoms gain or lose electrons, they become negatively or positively charged and are called ions.
- An atom and an ion of the same element have completely different properties. The symbol for an ion includes the charge, for example, Na^{+} or O^{2-}. The symbol for an atom is written as Na or O.

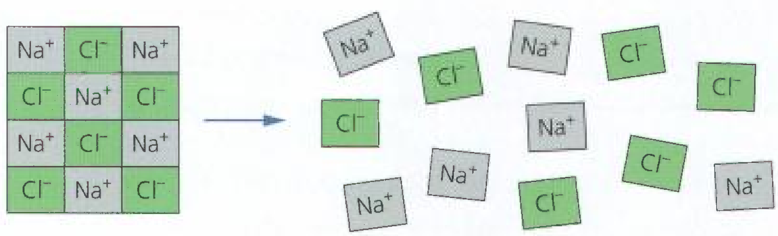


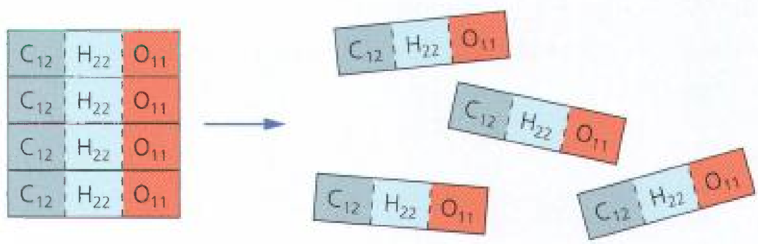
Vocabulary

bond, p. 170
valence shell, p. 170
valence electrons, p. 170
ion, p. 171
chemical bonds, p. 176
ionic compounds, p. 176
ionic bonding, p. 176
covalent or molecular compounds, p. 177
covalent bonding, p. 177
molecule, p. 178
diatomic molecule, p. 178
phase or state, p. 180
chemical formula, p. 183
ion charge balance, p. 183
multivalent, p. 187
polyatomic ion, p. 189

Bonding can involve electron transfer (ionic) or electron sharing (covalent).

- A chemical bond is a force that holds atoms together to form compounds.
- There are two general types of chemical bonds: ionic and covalent.
- Ionic bonds involve a transfer of electrons between atoms. Ionic bonding forms ionic compounds. The smallest particle of an ionic compound is an ion. Ionic compounds separate into ions when dissolved in water so they conduct electricity.
- Covalent bonds involve a sharing of electrons between atoms. Covalent bonds form molecular compounds. The smallest part of a molecular compound is a molecule. Molecular compounds do not separate into ions when dissolved in water, so they are poor conductors of electricity.





Rules for writing chemical formulas and for naming ionic compounds are based on ion charge balances.

- The chemical formulas for ionic compounds can be predicted by balancing ion charges.
- The chemical names are derived from the ion names.
- Ionic compounds can be classified into binary, ionic with multivalent elements, and ionic with polyatomic ions.

Rules for writing chemical formulas and for naming molecular compounds are based on a prefix system.

- The chemical formulas for molecular compounds are derived from their chemical names (and vice versa) based on a prefix system, for example, mono, di, and tri.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Which of the following describes compounds?
   A. They have atoms as their smallest particles.
   B. They can be easily separated by physical methods.
   C. They cannot be broken down into simpler substances.
   D. They are composed of two or more elements in fixed proportions.

K 2. Atoms form compounds through interactions of which of the following?
   A. nuclei
   B. protons
   C. neutrons
   D. electrons

K 3. What are the valence electrons in an atom?
   A. the total number of electrons
   B. the electrons in the outermost shell
   C. the electrons that always occupy the first shell
   D. the number of electrons that equal the protons

K 4. Which of the following is an example of an ion?
   A. O
   B. O^{2-}
   C. O_2
   D. 2O

K 5. Which of the following is the smallest particle of an element?
   A. ion
   B. atom
   C. molecule
   D. compound

6. What is the main difference between ionic bonding and covalent bonding?

K 7. Which of the following is the smallest particle of a covalently bonded compound?
   A. ion
   B. atom
   C. element
   D. molecule

K 8. How do ions form?

I	Atoms gain or lose protons.
II	Atoms gain or lose neutrons.
III	Atoms gain or lose electrons.

   A. I only
   B. II only
   C. III only
   D. I and III

K 9. Why is a crystal of an ionic compound held together so strongly?
   A. Ionic bonds are a result of electron transfer.
   B. Similar ions are strongly attracted to each other.
   C. Crystals have a definite shape that results from ionic bonds.
   D. Each ion is equally attracted to all adjacent oppositely charged ions.

10. Compare the melting points for ionic compounds and molecular compounds. Explain why they are different.

11. What is the concept used in determining the fixed proportions of elements in ionic compounds?

12. What are the names of the following?
   (a) Ca^{2+}
   (b) K
   (c) K^+
   (d) S^{2-}
   (e) $SO_4^{\ 2-}$
   (f) $NH_4^{\ +}$

Use What You've Learned

U 13. How do positive ions form?
   A. Atoms gain protons.
   B. Atoms lose protons.
   C. Atoms gain electrons.
   D. Atoms lose electrons.

14. Draw Bohr diagrams for atoms of lithium, beryllium, magnesium, phosphorous, fluorine, and argon.

15. Draw Bohr diagrams for the ions of sulfur, potassium, aluminum, and nitrogen.

16. Can an atom turn into an ion on its own? Explain.

17. Indicate the nearest noble gases for each of the following atoms. Secondly, state the number of electrons that each atom will gain or lose. Thirdly, write the symbol for the ion that will form.
   (a) H
   (b) N
   (c) Li
   (d) S
   (e) Al
   (f) Cl
   (g) O
   (h) Ca

U 18. What is the chemical formula for barium nitrate?
   A. Ba_3N_2
   B. $BaNO_3$
   C. $Ba(NO_3)_2$
   D. $Ba(NO_2)_2$

19. For each of the following compounds, classify it as ionic or molecular and write its chemical formula.
   (a) barium nitrate
   (b) ammonium sulfate
   (c) lead(II) chloride
   (d) aluminum sulfide
   (e) carbon disulfide

20. For each of the following compounds, classify it as ionic or molecular and write its chemical name.
   (a) KCl
   (b) $(NH_4)_3N$
   (c) P_3Br_6
   (d) Cr_2O_3
   (e) $Mg_3(PO_4)_2$

21. For each of the following compounds, classify it as ionic or molecular and write the chemical name or formula.
   (a) NaBr
   (b) magnesium sulfate
   (c) NBr_3
   (d) lead(IV) oxide
   (e) $Ca(MnO_4)_2$

Think Critically

22. Oppositely charged ions are held together by electrostatic forces. What other opposite forces in nature hold objects together?

23. At a molecular level, why is it unlikely to find a single isolated unit such as KBr? Use a sketch to support your answer.

24. Write out and number your own set of rules that explain how to correctly write chemical formulas for ionic compounds given the chemical name.

25. Write out and number your own set of rules that explain how to correctly write chemical formulas for molecular compounds given the chemical name.

HMP 26. Which of the following correctly list a compound with its formula and compound type?

	Name	Formula	Type
I	carbon dioxide	CO_2	molecular
II	lithium sulfate	$LiSO_4$	polyatomic ionic
III	potassium chloride	KCl	binary ionic
IV	manganese(II) sulfate	Mn_2SO_4	multivalent ionic

   A. I and III only
   B. II and III only
   C. III and IV only
   D. I, II, and III only

27. Suppose you are asked to predict the chemical formula for the covalent compound that results when nitrogen atoms combine with oxygen atoms. Conduct an Internet search to determine if a formula for nitrogen oxide exists and write a brief paragraph to report what you learn.

www.science.nelson.com GO

Reflect on Your Learning

28. Why do you think that chemistry is often referred to as the "central science"? Give some examples to support your reasoning.

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

CHAPTER 8

Classifying Chemical Compounds

Chapter Preview

Early chemists had determined that all chemical compounds in the world could be placed in one of two categories: chemical compounds that existed as part of living things (organisms), and those that did not. These two groups were called organic and inorganic compounds. Subsequently, chemists were able to make chemical compounds in the laboratory that were previously thought only to exist in living things. This changed their understanding of organic and inorganic compounds, although a form of this classification exists today.

In this chapter, you will learn how ionic and molecular compounds can be further classified by examining chemical formulas and molecular structures.

KEY IDEAS

- All chemical compounds are either organic or inorganic.
- Inorganic compounds can be molecular or ionic (acids, bases, or salts).
- Lewis diagrams (electron dot) can explain how molecular compounds form as a result of bonding pairs of electrons.
- Organic compounds are molecular and contain carbon and hydrogen.

TRY THIS: Classifying Compounds

Skills Focus: classifying

All compounds can be classified into one of two groups: organic or inorganic. For this activity, you will use the older, and partly correct, meaning of "organic," which states that organic compounds are present in or result from living organisms. For example, a strand of your hair would contain an organic compound. An inorganic compound is simply one that is not organic. An example of an inorganic compound is a rusted iron nail.

1. Think about the matter in the world around and within you, and consider which matter would contain organic compounds and which would contain inorganic compounds.
2. Make two lists: one with five examples of matter that contains organic compounds, and one with five examples of matter that contains inorganic compounds.

A. Which list was easier to create? Why do you think this is the case?

B. Beside each organic example, state the original living organism that contained the organic compound.

8.1 Classifying Inorganic Compounds

You know that compounds can be ionic or molecular based on how their elements are bonded. But all compounds can also be organic or inorganic, depending on the kinds of elements within. Inorganic or organic, what's the difference? An organic chemical was originally believed to come from a living organism (Figure 1). However, a significant discovery was made in the mid-1800s when "organic" compounds were synthesized in the lab from non-living compounds. Today, compounds that have a high percentage of carbon by mass are classified as **organic compounds**; otherwise they are considered to be **inorganic compounds**.

LEARNING TIP

Identifying key words helps readers determine the most important concepts in a section. To help you determine key words, look for words that are bolded, used in headings, or repeated.

Figure 1 Organic compounds were first thought to exist only in living organisms.

Almost all of the compounds you have studied so far—such as water, salt, carbon dioxide, iron(III) oxide (rust), sodium carbonate (washing soda)—are inorganic compounds. All of the compounds for which you have learned to name and write formulas are inorganic. Yes, some of these compounds contain carbon atoms, but the carbon is not considered present in a high percentage. What then is high percentage carbon? We will answer this question later in this chapter.

In Chapter 7 you learned that inorganic compounds can be ionic or molecular based on the bonds that join them together internally. In this chapter, you will delve further into the study of all compounds and learn more about their behaviours.

As you investigate the nature of these chemicals, you will realize the significance of the bonding types involved (Figure 2).

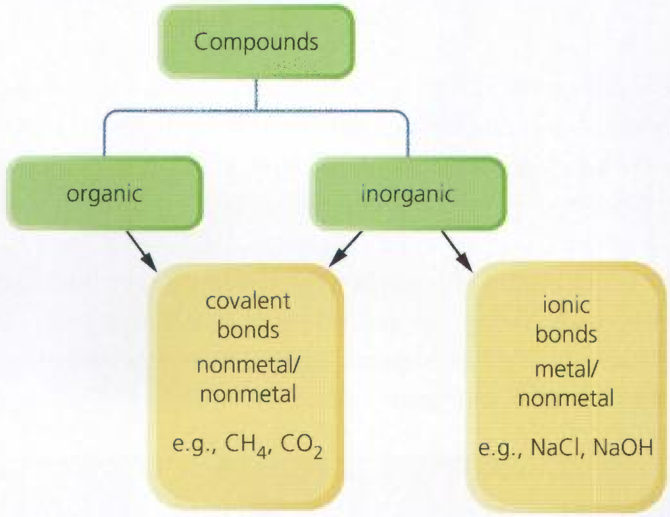


Figure 2 Bonding plays a key role in the behaviour, and therefore, in the classification of compounds. From this diagram, you can see that covalent bonds can be present in both organic and inorganic compounds, while ionic bonds are only present in inorganic compounds.

Inorganic Molecular Compounds

Compounds in this class are

- inorganic, so they contain little (at least not in a high percentage) or no carbon
- molecular, so they have a non-metal bonded to a non-metal to form molecules

There are some examples of inorganic molecular compounds that are quite common, but the number of examples is small: water (H_2O), ammonia (NH_3), carbon dioxide (CO_2, considered low percentage carbon), and laughing gas (N_2O). Can you think of some other common everyday examples that fit this classification? There are not many, are there? Most inorganic compounds are ionic.

Inorganic Ionic Compounds

The classification of inorganic ionic compounds has a long history of development. 8A Investigation

By the 1500s, early chemists (the alchemists) recognized that one group of substances shared a common property—a sour taste. These substances possessed other properties as well. They were called acids from the Latin word *acidus*, meaning sour. Another group of substances, called alkalis (or bases), was prepared from the ashes of wood. Bases had a slippery feel and were discovered to be effective cleaners.

In the 1600s, the alchemists realized that bases could react with acids and neutralize or destroy them. The resulting solution contained a new substance that tasted salty. When the water was evaporated from these solutions, a crystalline solid remained. These products were appropriately called salts.

Advances in the study of acids, bases, and salts were made when scientists started looking at the components of acids and bases to conceptually explain their classification.

8A Investigation

Classifying Solutions of Ionic Compounds

To perform this investigation, turn to page 224.

In this investigation, you will look for some fundamental similarities and differences among a number of ionic compounds.

In the 1800s, the Swedish chemist Svante Arrhenius recognized the presence of ions in solution, and their relationship to acids and bases. These studies led to what is understood as the Arrhenius definitions of acids, bases, and salts: **Acids** are substances that release H^+ ions in solution; **bases** are substances that release OH^- ions in solution; **salts** are substances that release positive ions and negative ions *other than* H^+ and OH^- in solution. These Arrhenius definitions hold true today for ionic compounds.

It is a common understanding that, unless otherwise stated, the term "solution" means that substances are dissolved in water. These water solutions often are referred to as **aqueous** (from Latin *aqua*, water) solutions and have the designation of (aq). For example, NaCl (aq) represents a solution formed when sodium chloride (table salt) is dissolved in water.

To learn more about Arrhenius and his contributions, go to www.science.nelson.com

General Properties of Acids, Bases, and Salts

As you may know from experience, acids like lemon juice taste sour, and bases like soap taste bitter (Figure 3). Salts, like table salt, do not taste anything like acids or bases. *For obvious safety reasons, when testing for acids, bases, or salts in a laboratory, you should never rely on taste tests.* Chemists instead use properties like those described in Table 1.

Figure 3 Acids and bases are common household chemicals. Generally speaking, most food products are acids and most bases make good cleansing agents.

To test your knowledge of common household acids and bases, go to www.science.nelson.com

Table 1 General Properties of the Water Solutions of Acids, Bases, and Salts

Acids	Bases	Salts
• conduct an electric current • cause chemical indicators to change colour (for example, litmus turns red) • react with certain metals to produce hydrogen gas	• conduct an electric current • cause chemical indicators to change colour (for example, litmus turns blue) • do not react with certain metals to produce hydrogen gas	• conduct an electric current • have no effect on chemical indicators (for example, litmus does not change colour) • do not react with certain metals to produce hydrogen gas

Chemical indicators are commonly used in school laboratories to test for acids and bases. Chemical indicators are molecular compounds that have a specific colour. They can change if they interact with an acid or base and turn into a slightly different compound with a different colour. Table 2 shows a list of common indicators and their colours in acids and bases. A colour chart of indicators can also be found in Appendix C6.

Table 2 Some Common Chemical Indicators and Their Colours

Chemical indicator	Colour in acid	Colour in base
methyl orange	red	yellow
methyl red	red	yellow
bromothymol blue	yellow	blue
litmus	red	blue
phenolphthalein	colourless	pink
indigo carmine	blue	yellow

Acidity

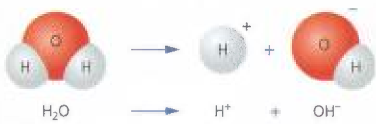


Figure 4 A few water molecules form H^+ and OH^- ions (about one in a million).

Solutions are said to be acidic, basic, or neutral based on the relative amounts of H^+ and OH^- ions that they contain. Pure water is always neutral because it always has an equal number of H^+ and OH^- ions. This happens because water is slightly ionic; a very few water molecules still have a tendency to produce a very small number of H^+ and OH^- ions, always in equal amounts. For this reason, chemists sometimes find it helpful to think of water as HOH rather than H_2O (1 HOH produces 1 H^+ ion and 1 OH^- ion) (Figure 4). Thus, a conductivity test of pure water will show a very small flow of electric current.

If an acid (H^+) is added to water, the $H^+ = OH^-$ balance in water is disrupted and we end up with more H^+ than OH^-. The resulting solution is said to be acidic. Similarly, if a base (OH^-) is added to water, we end up with more OH^- than H^+ in solution and the solution is considered to be basic. Adding salt (containing no H^+ or OH^-) does not affect the $H^+ = OH^-$ balance in water, so the solution remains neutral.

TRY THIS: *Electrical Conductivity Tests*

Skills Focus: interpreting data

You learned in Chapter 7 that solutions of ionic compounds conduct electricity, whereas molecular compounds do not. You have also learned that water (H_2O) is a molecular compound. In an investigation, conductivity tests were conducted on water as well as other compounds in solution. An ammeter was added to the test circuit to measure current flow in milliamperes (mA) (Figure 5). The light bulb used was one that required very little power to illuminate.

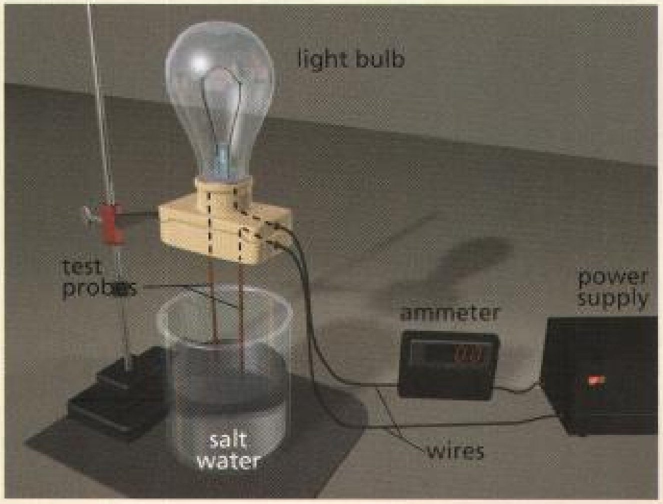


Figure 5

1. The electrical conductivity tester was used by inserting the test probes in a variety of materials. The water used was pure or distilled water (all minerals removed). The conductivity test results appear in Table 3.

Table 3

Compound tested	Light bulb	Current (mA)
table salt (NaCl) in water	very bright	400 mA
table sugar ($C_{12}H_{22}O_{11}$) in water	very dim	0.0040 mA
water	very dim	0.0040 mA
methanol (CH_4O), a liquid alcohol (no water present)	off	0 mA

A. Based on the results of the conductivity tests, which compounds would you classify as completely ionic or molecular?

B. Should pure water be classified as completely molecular? Explain.

C. How do you explain the conductivity of the sugar solution?

Table 4 summarizes the method in which solutions are classified as acidic, basic, or neutral.

Table 4 Classifying Solutions as Acidic, Basic, or Neutral

Solution classification	Relative ion count	Examples
acidic	$H^+ > OH^-$	HCl (aq) provides extra H^+
neutral	$H^+ = OH^-$	H_2O, NaCl (aq)
basic	$H^+ < OH^-$	NaOH (aq) provides extra OH^-

Acidity is described then, as a measure of the relative amounts of H^+ and OH^- in a solution. It follows that the higher the relative number of H^+ ions, the higher the acidity.

Measuring Acidity (The pH Scale)

Is hydrochloric acid a hazardous chemical? It all depends on how much hydrochloric acid is present in a given amount of water. A large amount of HCl in water (concentrated hydrochloric acid) will cause severe skin burns, and this same acid exists in your stomach for digestive purposes, but in a less concentrated form. How can we measure these differences in acidity?

Chemists have developed an acidity scale called the **pH scale.** The normal range of pH is from 0 to 14, with a pH of 7 being neutral. Solutions with a pH lower than 7 are acidic, whereas solutions with a pH greater than 7 are basic. Hydrochloric acid in the stomach has a pH of 1, while concentrated hydrochloric acid (1M) has a pH of 0. Therefore, concentrated HCl is more acidic. It is possible to have an extremely acidic solution with a pH lower than 0 (negative pH value), or an extremely basic solution with a pH greater than 14. The pH values for a variety of substances are given in Figure 6.

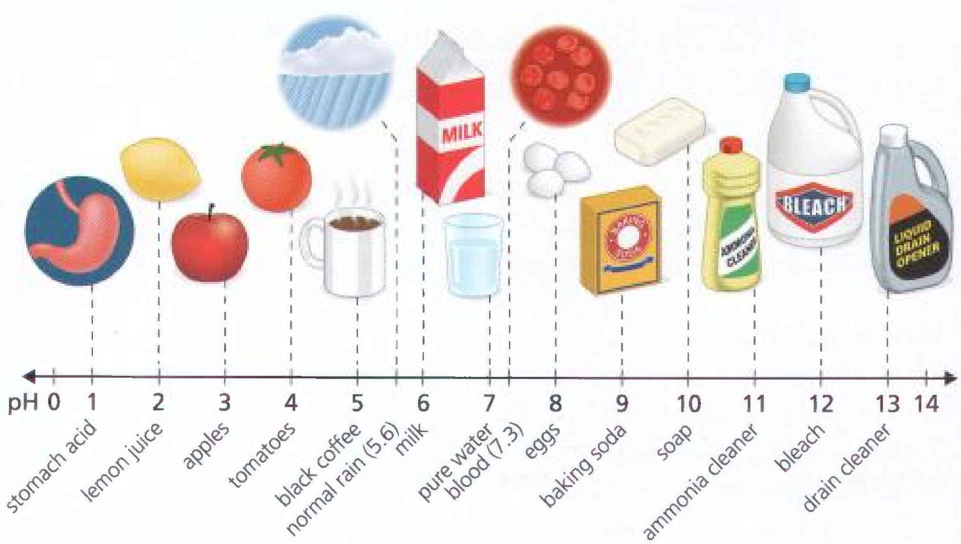


Figure 6 The pH scale allows chemists to quickly determine the acidity of solutions.

LEARNING TIP

When you are reading difficult text, it is a good habit to paraphrase (say in your own words) difficult passages. Ask yourself, "Am I making good use of the tables and figures provided, and remembering to stop and reread difficult passages?"

Did You KNOW?

Protecting the Stomach

Your stomach has mechanisms to stop it from being damaged by the high acidity of the hydrochloric acid in it. The stomach wall is protected by a fairly thick coat of mucus. The cells in this mucus secrete a bicarbonate-rich solution. Bicarbonate is a base that neutralizes the acid. If hydrochloric acid gets through to the stomach wall, a person can develop gastric ulcers.

Did You KNOW?

The pH Scale

The pH scale was developed in 1909. The symbol "pH" was chosen to represent the "power of Hydrogen," to describe the concentration of H^+ ions in solution. Think of the pH scale as a "backwards" scale—the lower the pH, the higher the number of H^+ ions, and the higher the acidity.

The pH scale for measuring acidity has mathematical similarities to the Richter scale that is used for measuring earthquakes. Both scales are based on logarithms (powers of 10) so that every 1 point move on the Richter or pH scale represents 10 times more or less shaking force or acidity, respectively. A solution with a pH of 4 has 10 times more H^+ ions (ten times more acidic) than one with a pH of 5. A solution with a pH of 3 is 100 times more acidic than a pH of 5 (Table 5).

Table 5 Acidity and pH

Substance	pH	Relative acidity (compared to water)
pure water	7	neutral
human saliva	6	10 (10^1) times more acidic than water
black coffee	5	100 (10^2) times more acidic than water
tomato juice	4	1 000 (10^3) times more acidic than water
soft drink	3	10 000 (10^4) times more acidic than water
lemon juice	2	100 000 (10^5) times more acidic than water
stomach acid	1	1 000 000 (10^6) times more acidic than water

Figure 7 A pH meter can be used to accurately measure the acidity of a solution.

A solution's pH can be directly measured with an electronic instrument called a pH meter (Figure 7), or with pH paper. The pH paper will display a certain colour when immersed in a solution. When that colour is matched to a colour chart for the pH paper, the solution's pH can be approximated (Figure 8).

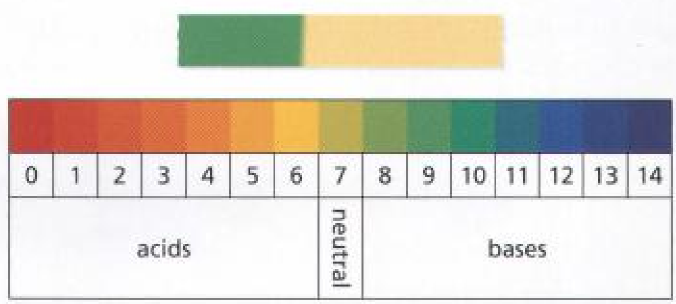


Figure 8 The left side of this strip of pH paper was immersed in a solution. The strip has turned green and indicates that the solution's pH is close to 9.

To learn how to make a pH test chemical at home, go to **www.science.nelson.com**

Naming Acids

Many of the commercial acids you encounter in the chemistry lab originate as manufactured gases. Gases are denoted by using (g) after their formulas. These particular gases readily dissolve in water and become acidic solutions. Some examples appear in Table 6.

The examples in Table 6 suggest that a system exists for naming acids. Some names include the term "hydro"; some do not. Some names end in "ic"; some end in "ous."

Table 6 Names for Some Common Acids and Their Gas Origins

Acid name	Gas	Chemical name of gas	Gas dissolved in water to form acid	Chemical name of solution
hydrochloric acid	HCl (g)	hydrogen chloride	HCl (aq)	hydrogen chloride
nitric acid	NO_2 (g)	nitrogen dioxide	HNO_3 (aq)	hydrogen nitrate
sulfurous acid	SO_2 (g)	sulfur dioxide	H_2SO_3 (aq)	hydrogen sulfite

As with all chemical compounds, the acid names are derived from the acids' chemical formulas. The rules for naming acids are summarized in the flowchart in Figure 9.

LEARNING TIP

As you read Figure 9, create a picture in your mind. Cover the figure and recall your picture. Compare your picture with the information in Figure 9. Did you leave out any important information? If so, repeat the strategy.

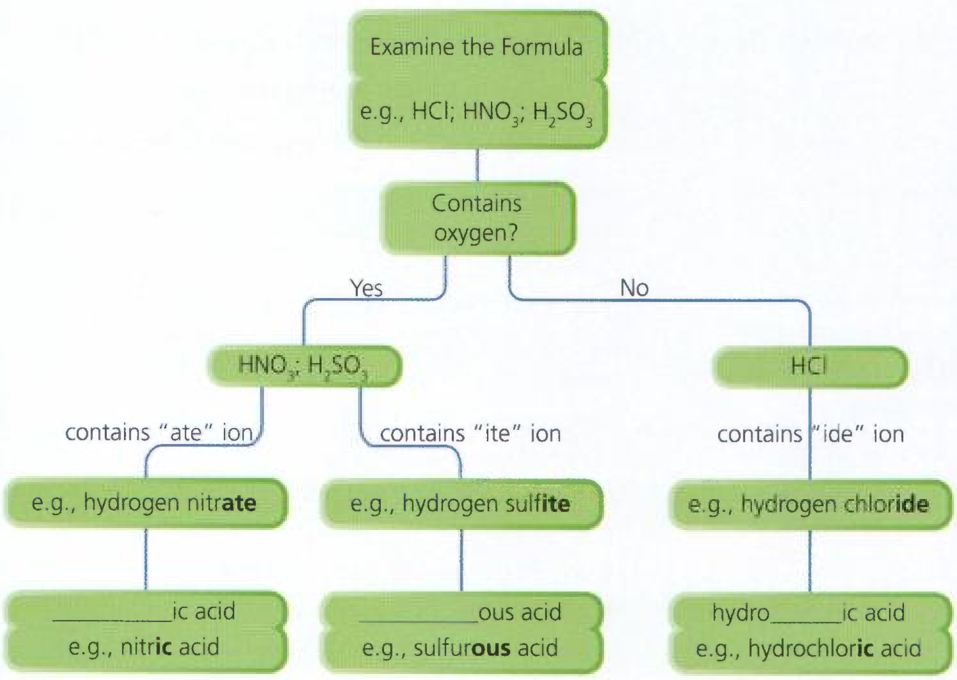


Figure 9 An acid's name is derived from the acid's chemical formula.

Notice that the negative ions in hydro ____ ic acids are "ide" ions, and these ion names become "ic" as in hydrochloric acid. There is no general rule as to how much of the ion name is retained. For example, the nitrate ion in HNO_3 leads to nitric acid, whereas the sulfite ion in H_2SO_3 leads to sulfurous acid, not sulfous acid. Furthermore, an acid such as HI is named hydriodic acid, simply because it is easier to say than hydroiodic acid. Do not be concerned with these little quirks, as long as you can follow the general rules and write the proper prefixes and suffixes for acid names.

Naming Bases and Salts

You have already learned the IUPAC rules for naming bases and salts when you learned about naming ionic compounds. Some examples appear in Table 7.

Table 7 Ionic Compound Naming Rules for Bases and Salts

Ionic compound	Classification	Chemical name
$NaNO_3$	salt	sodium nitrate
KCl	salt	potassium chloride
NaOH	base	sodium hydroxide
$Ca(OH)_2$	base	calcium hydroxide

TRY THIS: Metal and Non-Metal Oxide Solutions (A Periodic Trend)

Skills Focus: interpreting data, classifying

Oxygen is reactive with many of the elements in the Periodic Table. We observe this on a daily basis with metals such as iron and copper. Once reacted with oxygen, these metals join a class of compounds called oxides, so in these cases, iron(II) oxide and copper(II) oxide are formed. Non-metals also react both naturally and in commercial situations with oxygen to form oxide compounds such as carbon dioxide and sulfur dioxide.

Interestingly, these commonly produced oxides often are open to the environment and are then exposed to water as water vapour or rain. What happens next? Are new substances created once again? If so, do they exhibit familiar properties?

1. Tests were done on various solutions with bromothymol blue indicator solution and the results are recorded in Table 8.

Table 8

Oxide in water	Bromothymol blue test	Classification
MgO	blue	
CaO	blue	
SO_2	yellow	
NO_2	yellow	

2. Complete Table 8 by classifying each solution as acidic, basic, or neutral. (See Table 2 on page 203 for indicator colours.)

A. Examine the classifications in Table 8 and locate the elements involved in the Periodic Table. State a simplified periodic trend that appears to exist with solutions of metal and non-metal oxides.

B. Write the chemical formula for carbon dioxide. If you tested a solution of carbon dioxide with bromothymol blue, would the solution be acidic, basic, or neutral?

C. Write the chemical formula for sodium oxide. If you tested a solution of sodium oxide with bromothymol blue, would the solution be acidic, basic, or neutral?

8.1 CHECK YOUR Understanding

1. In the early years of chemistry, why were certain compounds considered to be organic?
2. Give an example of a substance that would fit the original definition of an organic chemical.
3. State a modern definition of an organic compound.
4. (a) What property do acids, bases, and salts have in common?
   (b) What is the effect of an acid on blue litmus paper?
   (c) What is the effect of a base on blue litmus paper?
   (d) What would you expect to happen if an iron nail were placed in hydrochloric acid?
5. Give the Arrhenius definitions for acids, bases, and salts.
6. Classify each of the following substances as an acid, a base, or a salt.
   (a) LiOH
   (b) KNO_3
   (c) $Sr(OH)_2$
   (d) HBr
   (e) KCl
   (f) H_2SO_4
   (g) $Ca(OH)_2$
   (h) HNO_3
7. (a) Which two ions are present in very small amounts in any sample of pure water?
   (b) What is a good alternative chemical formula for water, rather than H_2O? Why?
   (c) With respect to ion count, why is water considered to be neutral?
8. How do the number of H^+ and OH^- ions compare after
   (a) HI is added to water?
   (b) KBr is added to water?
   (c) KOH is added to water?
9. You test a solution with bromothymol blue indicator solution and the indicator turns yellow. What can you conclude about the relative H^+ and OH^- ion count?
10. Give some examples of where the term pH is used in your everyday life.
11. Make a sketch of the pH scale and label it with pH values. Show the areas that represent acidic, basic, and neutral solutions.
12. What would you expect the pH value for grapefruit juice to be? (>7, 7, <7)
13. Write the acid name for each of the following ionic compounds.
    (a) HI
    (b) H_2CO_3
    (c) HClO
    (d) HNO_2
14. Write the chemical formula for each of the following acids.
    (a) hydrocyanic acid
    (b) oxalic acid
    (c) chlorous acid
    (d) nitric acid
15. Write the acid name or chemical formula for each of the following.
    (a) HBr
    (b) sulfurous acid
    (c) $HClO_4$
    (d) phosphoric acid
16. First, classify each of the following substances as an acid, a base, or a salt. Then, write the name or chemical formula. If the substance is an acid, write the acid name.
    (a) potassium hydroxide
    (b) KNO_3
    (c) $Mg(OH)_2$
    (d) HI
    (e) sodium sulfate
    (f) $HClO_4$
    (g) aluminum hydroxide
    (h) H_2CrO_4

8.2 Another Look at Bonding—Lewis Diagrams

You have learned that bonding types (ionic and covalent) can be used to classify all compounds. Ionic compounds can be further classified as acids, bases, and salts based on their compositions. Molecular compounds can be further classified based on their atomic arrangements or structures. In order to gain an understanding of how atoms are arranged in molecules, we will investigate Lewis diagrams.

In the early 1900s, the American G.N. Lewis developed a system of arranging dots around the symbol of an element to represent an atom's valence electrons as it prepares to bond. Lewis reasoned that, for studies of bonding, there was no need to represent any of the other subatomic particles (protons, neutrons, or other electrons) as only valence electrons are involved in bonding. Looking at the atomic model proposed by Bohr and the Lewis diagram, you will notice striking similarities (Figure 1). GO

To learn more about the work of G.N. Lewis, go to **www.science.nelson.com** GO

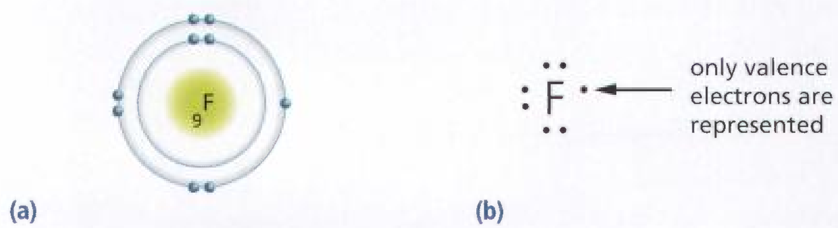


Figure 1 (a) A Bohr diagram of the fluorine atom is very similar to (b) a Lewis diagram.

LEARNING TIP

Are you able to explain the similarities and differences between Bohr's and Lewis's atomic models? If not, re-examine Figures 1 and 2. What type of bonding are Lewis diagrams useful for representing?

Lewis Diagrams and Covalent Bonds

You might consider a **Lewis diagram** as a simpler version of a Bohr diagram that has only valence electrons illustrated. However, there is a subtle (slight) difference in how the valence electrons are arranged. The Bohr model describes an atom in its natural state, whereas a Lewis model describes an atom as it prepares to bond with other atoms. The Lewis model shows that when an atom prepares to form a covalent bond, its valence electrons arrange themselves as single electrons whenever possible. A single electron is then able to pair with another single electron from another atom to form a shared pair, or **bonding pair**, of electrons. Lewis diagrams are also called **electron dot diagrams** since the valence electrons are designated by dots. However, symbols other than dots are used if they provide a better understanding of bonding between atoms.

A Lewis diagram for an oxygen atom shows the 6 valence electrons as dots surrounding the symbol for oxygen, with 2 single valence electrons (Figure 2(a)). An atom of argon (noble gas) has a complete valence shell of 8 valence electrons so it has no single valence electrons (Figure 2(b)).

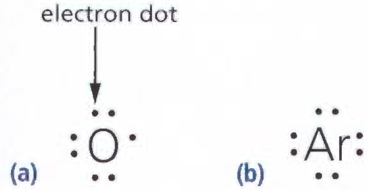


Figure 2 Lewis diagrams showing electron dots for the valence electrons of (a) oxygen and (b) argon atoms

Lewis Diagrams for Atoms

Drawing Lewis diagrams for atoms is easy by following a few steps.

Example 1: A Lewis diagram for a chlorine atom.

1. Determine the number of valence electrons. The number of valence electrons can easily be determined from the group (family) number in the Periodic Table. Since we will restrict ourselves to the first 20 elements, we can use the following method:
   (a) Elements in Groups 1 and 2 have 1 or 2 valence electrons respectively.
   (b) Elements in Groups 13 through 18 have 3 to 8 valence electrons based on the group number. For example an element such as chlorine in group 17 has 7 valence electrons.
2. Arrange the valence electrons as dots around the atom's symbol. First place 2 valence electrons together as paired electrons and then place up to 3 valence electrons as unpaired electrons equally around the valence shell. If there are more valence electrons, then begin to double up the unpaired electrons to make paired electrons (Figure 3).

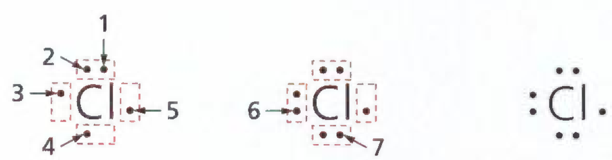


Figure 3 Placing 7 valence electrons for Cl in a Lewis diagram

Example 2: A Lewis diagram for a boron atom.

1. Boron has 3 valence electrons.
2. Place 2 valence electrons together as paired electrons and the third as an unpaired electron. This illustrates boron in its natural state. But Lewis diagrams show electrons ready to bond so wherever possible, electrons are placed singly. Therefore, one of the paired valence electrons is moved to show all 3 valence electrons as unpaired (single) electrons, ready for bonding (Figure 4). This model of "changing places" closely resembles the modern atomic theory studied in more advanced courses.

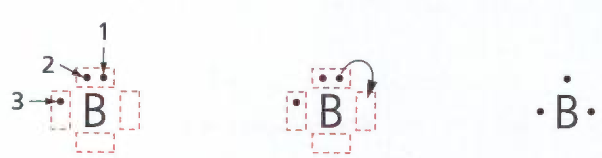


Figure 4 Placing 3 valence electrons for B in a Lewis diagram

STUDY TIP

Summarizing helps you to monitor your understanding of what you read. As you read Example 1, identify the main point in each step. Complete the statement, "This step tells me to..." Write each step in a point-form note on a study card. Include a visual on the back of your study card. You can use this study card later to help you prepare for a chapter test.

A quick method is to place electrons singly equally around the shell until 4 are placed, after which they are seated in pairs. This method works, but it is not supported by modern atomic theory.

Lewis Diagrams for Molecules

As you learned earlier, each atom has a tendency to complete its valence shell when bonding. A complete valence shell is one that matches its nearest noble gas. All noble gases have 8 valence electrons, except helium, which has 2. This is known as the **octet rule**.

To draw a Lewis diagram for a molecule, you must first be given the molecular formula. Atoms are then connected to one another by pairs of shared electrons, or bonding pairs. Consider the example for water (Figure 5). The molecular formula is H_2O. Each of the 2 hydrogen atoms has 1 valence electron. The oxygen atom has 6 valence electrons. (Note that "x" is used rather than dots for the hydrogen electrons. This is done simply to differentiate between the hydrogen and oxygen electrons.) By following the octet rule, the Lewis diagram shows how the 2 hydrogen atoms bond with the oxygen atom.

LEARNING TIP

When forming Lewis diagrams for molecules, it helps to visualize the dots arranged in pairs with the bonding pairs placed between the atoms which they connect, and the lone pairs at different sides of the atomic symbol.

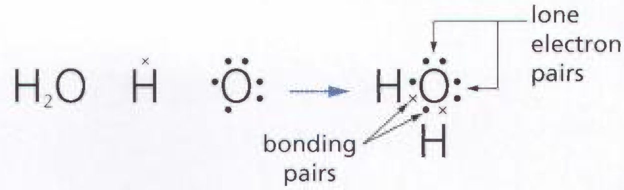


Figure 5 A Lewis diagram for water (H_2O).

The purpose of a Lewis diagram is to illustrate that the formation of these covalent molecules is possible. In Figure 5, you can see that arranging the bonding atoms in this manner leads to all atoms having complete valence shells as a result of bonding pairs of electrons. Oxygen ends up complete with 8 valence electrons (with 2 bonding pairs), and each hydrogen atom ends up complete with 2 valence electrons (with 1 bonding pair). As a result, the octet rule is satisfied for all atoms. Each bonding pair of electrons forms a **covalent chemical bond**. Note that the other pairs of electrons are not involved. These **lone electron pairs** do not form bonds.

To practice interpreting Lewis diagrams, go to **www.science.nelson.com**

Other carefully selected covalent molecules such as ammonia (NH3) can be represented by Lewis diagrams (Figure 6).

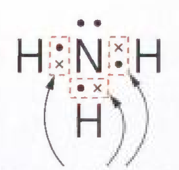


Figure 6 In the Lewis diagram for NH_3 each N atom obtains 8 valence electrons and each H atom obtains 2 valence electrons, thereby satisfying the octet rule.

For simplification, the bonding pair of electrons is often replaced by a line to represent a single covalent bond (Figure 7).

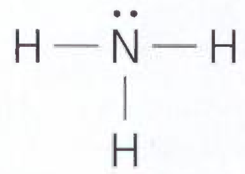


Figure 7 A simplified Lewis diagram for NH_3 shows each bonding pair of electrons as a line representing a covalent bond.

Common covalent molecules such as carbon dioxide require an introduction to double bonds, which is beyond the scope of our studies.

Lewis Diagrams for Ionic Compounds

Lewis diagrams can also be drawn for ionic compounds, but they simply mimic (imitate) the electron transfer that can be shown in a Bohr diagram (Figure 8). Since formulas for ionic compounds are predictable based on ion charge, we seldom rely on Lewis diagrams to help us understand the ionic bonds that exist. Lewis diagrams are more commonly used to explain covalently bonded compounds whose formulas cannot be predicted.

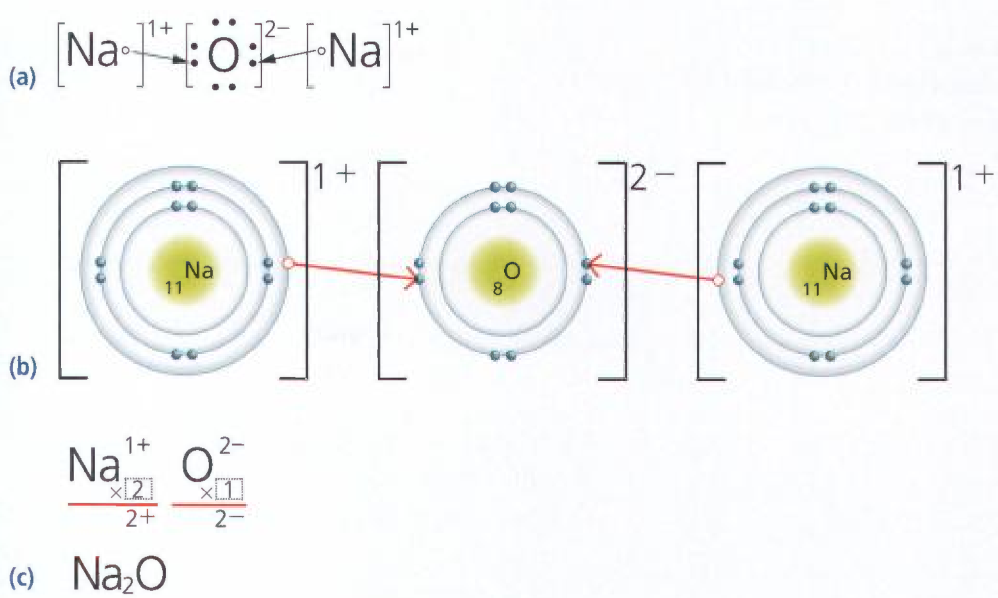


Figure 8 (a) A Lewis diagram for ionic compounds shows how the valence shells are completed by electron transfer. (b) This same transfer is shown in the Bohr diagram. (c) However, formulas for ionic compounds can be predicted from the combining ion charges.

8.2 CHECK YOUR Understanding

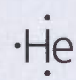
1. What type of bonding are Lewis diagrams useful for representing?
2. State the number of valence electrons for each of the following elements:
   (a) carbon (C)
   (b) argon (Ar)
   (c) lithium (Li)
   (d) magnesium (Mg)
   (e) hydrogen (H)
   (f) helium (He)
   (g) sulfur (S)
   (h) phosphorous (P)
3. Copy Table 1 in your notebook, leaving large spaces for drawing the diagrams. Complete the second and third column for all of the elements. Complete the fourth column for those elements that will form ions.

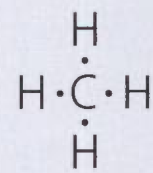
Table 1

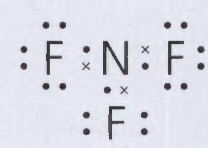
Element	Bohr diagrams for atoms	Lewis diagrams for atoms	Lewis diagrams for ions
hydrogen			
magnesium			
oxygen			
sulfur			
carbon			
boron			
beryllium			
potassium			
helium			
nitrogen			

4. Draw Lewis diagrams for each of the following molecules. Use "x" to represent electrons for the second element.
   (a) HCl
   (b) F_2
   (c) H_2O
   (d) carbon tetrachloride
   (e) sulfur difluoride
   (f) nitrogen trichloride
5. In your notebook, draw Lewis diagrams that will correct the errors in the following Lewis diagrams.

   (a) 

   (b) 

   (c) CH_4 

   (d) NF_3 

6. Why is it uncommon to draw Lewis diagrams for ionic compounds?
   A. Lewis diagrams can only illustrate covalent bonding.
   B. Ionic compounds can not be represented by Lewis diagrams.
   C. Ionic compounds involve electron transfer, not electron sharing.
   D. Formulas for ionic compounds are predictable and understandable based on ion charges.

8.3 Organic Compounds

Early chemists believed that certain chemicals were only found in living organisms. These chemicals were appropriately called organic chemicals since they came from organisms. It was later discovered that some of these "organic" chemicals could be synthesized in the lab from non-living things. Nevertheless, the name "organic" stuck.

It was the German chemist Friedrich Wöhler (Figure 1) who, in the 1800s, first converted an inorganic chemical into urea, $(NH_2)_2CO$. Urea is a compound that can be isolated from urine. Urea was recognized as organic by all chemists and was believed to be manufactured only by living organisms.

Today, the sheer number of known organic compounds is staggering! Chemists estimate that 10 million compounds have been discovered so far, and 9 million of those are organic compounds. Living things are made up of thousands of different organic compounds. After studying organic compounds from nature, chemists and engineers often attempt to duplicate these compounds in the laboratory. The result is a wide variety of synthetic chemicals that have become part of our daily lives, such as fuels, fabrics, plastics, and medicines. An estimated 250 000 new organic compounds are synthesized in research laboratories every year.

Modern **organic chemistry** is often described as the chemistry of carbon compounds. Organic compounds are molecular compounds that have carbon atoms as their basis. Organic molecules contain C, H, and sometimes O, N, and other non-metals, and they have covalent bonds. A few examples of organic compounds are listed in Table 1. Notice that carbon and hydrogen atoms are always present.

Figure 1 Friedrich Wöhler (Germany) is considered the "father" of modern organic chemistry.

Table 1 A Few Common Organic Compounds

Organic compound	Name	Use
CH_4	methane, natural gas	house heating
C_4H_{10}	butane	lighter fluid
C_8H_{18}	octane	gasoline component
CH_3OH	methanol	windshield washer antifreeze
C_2H_5OH	ethanol	alcoholic beverages, gasoline additive

Not all compounds that contain carbon are organic. Thus, carbon dioxide (CO_2) with no H, and sodium bicarbonate ($NaHCO_3$) with the metal Na, are both inorganic compounds. On the other hand, methane (CH_4) and ethanol (C_2H_5OH) are both examples of organic compounds.

Did You KNOW?

What Is Organic?

The term "organic" has different meanings depending on the context in which it is used. Today you hear phrases such as "organic fruit and vegetables." In this case the term "organic" is not used as a chemistry term. An organic apple suggests that the conditions in which the apple was grown were controlled to avoid the use of manufactured fertilizers. However, a chemist might say that all apples are organic since they contain organic compounds.

Sometimes it is sufficient to say that organic compounds have a high percentage of carbon, but there is no hard-and-fast rule as to what constitutes a high percentage. Here are some percentages for the above examples, using mass numbers:

CO_2 $\quad \frac{12}{44} \times 100\ \% = 27\ \%$ C inorganic

$NaHCO_3$ $\quad \frac{12}{84} \times 100\ \% = 14\ \%$ C inorganic

CH_4 $\quad \frac{12}{16} \times 100\ \% = 75\ \%$ C organic

C_2H_5OH $\quad \frac{24}{46} \times 100\ \% = 52\ \%$ C organic

In most cases, if you notice C and more than one H in the formula, along with no metals, you can expect the compound to be organic.

Did You KNOW?

Silicon

The only element with similar bonding abilities to carbon is the element silicon (Si). This is evident in the fact that silicon appears in the many compounds contained in dirt, soil, sand, and rocks. Notice its position in the Periodic Table in relation to carbon.

What's So Special About Carbon?

Carbon has the unique ability to form several bonds with other atoms as well as with itself. This is due to the fact that carbon has 4 valence electrons. The 4 valence electrons allow carbon atoms to form chains of various lengths, and these chains can then have all types of branches. Each unpaired valence electron in carbon is capable of pairing up with another single electron from a different atom such as hydrogen. This bonding pair of electrons forms a covalent chemical bond (Figure 2).

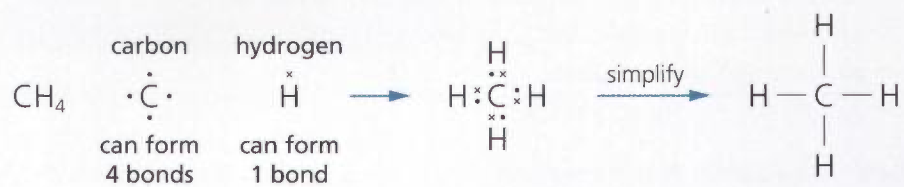


Figure 2 Valence electron dots for C and H show how these elements can be arranged and bond to form a methane molecule, CH_4. Since all bonds are shared electron pairs, it follows that all organic compounds are molecular.

Structural Formulas

Simplified Lewis diagrams, also called **structural formulas**, can be drawn to help visualize organic molecules (Figure 3). Chemists find that structural formulas are very useful for studying organic compounds. These formulas not only show the number of atoms in each organic molecule, but also the arrangement of these atoms. In many cases, the structure of the molecule helps chemists understand that particular compound's properties and behaviour.

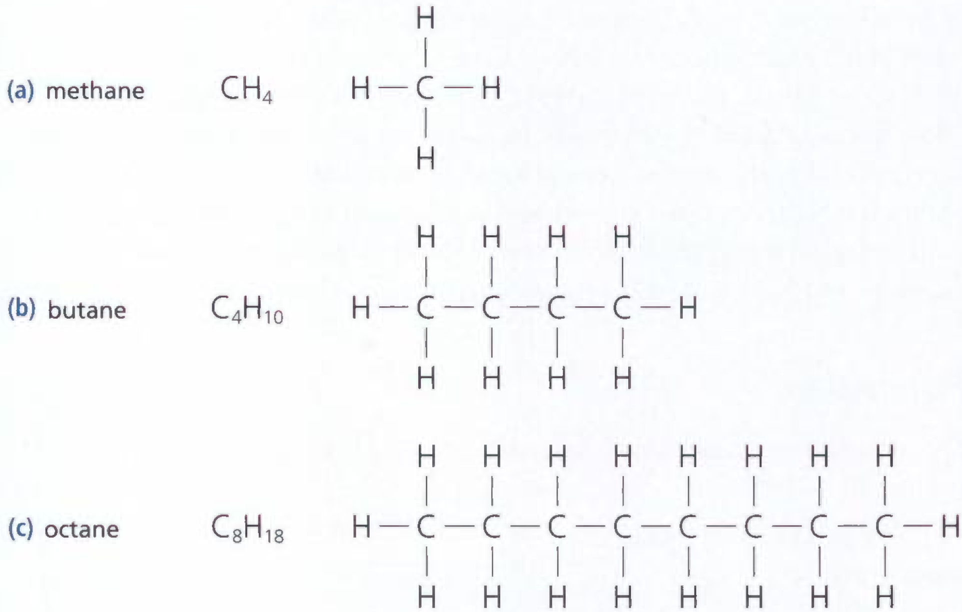


Figure 3 Structural formulas for (a) methane, (b) butane, and (c) octane

When oxygen bonds within organic molecules it requires 2 bonds (2 bonding pairs) in order to fill its valence shell. The Lewis diagrams and structural formulas for the oxygen-containing compounds methanol and ethanol are shown in Figure 4. Notice that structural formulas do not show any non-bonding electron dots such as those on O atoms. In structural formulas, it is understood that the valence shells are complete for each atom.

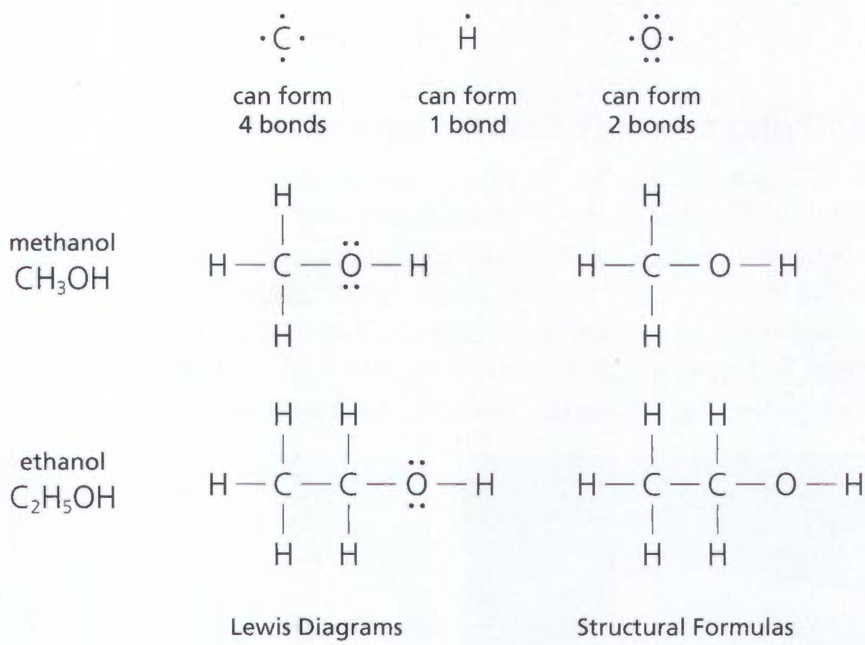


Figure 4 Structural formulas leave out the non-bonding electron dots.

LEARNING TIP

Keep in mind this set of basic rules by which you can form Lewis structures. Bonds are pairs of electrons shared between two atoms. Most covalently bonded atoms (except hydrogen) have a filled octet of balanced electrons.

To learn how the organic compound ethanol could help fuel the future, listen to the audio clip at **www.science.nelson.com**

Chemists reason that different compounds have different properties and should have different compositions. Usually the composition of a compound is described by its chemical formula. But sometimes the chemical formula does not help describe differences in organic compounds. For example, ether and ethanol both have the same chemical (molecular) formula (C_2H_6O). Ether is a highly explosive liquid, and can be used as an anesthetic. Ethanol is the alcohol found in alcoholic beverages. They are from different organic families and have quite different properties. How can they both be C_2H_6O?

TRY THIS: *Structural Formulas*

Skills Focus: creating models

Organic chemists rely on structural formulas to better describe composition and properties of organic molecules. A structural formula uses a bond line to show a bonding pair of electrons, as shown in the structural formulas for ethanol and ether in Table 2.

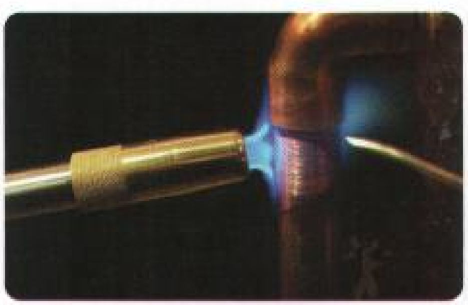
1. Sketch structural formulas for the following organic compounds. Recall that each C atom has 4 bond lines, each O atom has 2, and each H atom has 1.
   (a) C_3H_8
   (b) CH_4O
   (c) C_4H_{10} (sketch two different structures)
   (d) C_3H_8O (sketch three different structures)
   (e) $C_4H_{10}O$ (sketch seven different structures)

Table 2

Organic compound	Molecular formula	Structural formula	Organic molecular formula
ethanol	C_2H_6O	H H | | H — C — C — O — H | | H H	CH_3CH_2OH
ether	C_2H_6O	H H | | H — C — O — C — H | | H H	CH_3OCH_3

Classifying Organic Compounds

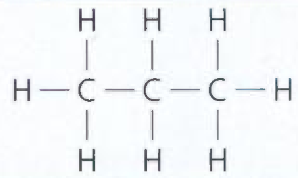
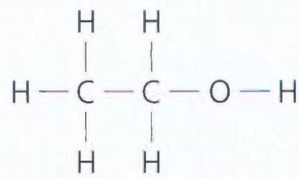
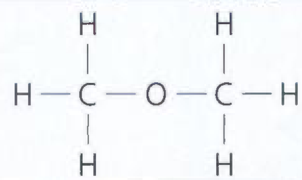
A very elaborate scheme has been developed for classifying organic compounds. The classification of these compounds into families is based on their properties and molecular structures. Only a few of these families are illustrated in Table 3. The simplest of all organic compounds are the **hydrocarbons** since, as their name suggests, they only contain the elements hydrogen and carbon. You may have heard of methane, propane, butane, and octane (Figure 5). Note the similarities in their names.


(a)

(b)

Figure 5 Some of the hydrocarbons may be familiar to you. (a) Propane torches are used when soldering pipes. (b) Octane is an important component of gasoline.

Table 3 Some Families of Organic Compounds

Family name	Sample compound name	Structural formula
hydrocarbons	propane	
alcohols	ethanol	
ethers	dimethyl ether	

Sources of Organic Compounds

Organic compounds are naturally occurring or synthetic. Many natural organic compounds are produced by plants during photosynthesis. The plants take in carbon dioxide, CO_2 (the source of the carbon for the carbon compounds) from the air. They react CO_2 with H_2O to produce organic molecules. You know these organic compounds as carbohydrates, sugars, proteins, and fats. Animals then eat the plants and manufacture more organic compounds in more chemical reactions. Humans eat both carbon-containing plants and animals and eventually return the carbon to the ground and the air. This cycle of carbon starting in the air and eventually returning to the air is called the carbon cycle.

Another major source of natural organic compounds comes from deep within Earth. Crude oil and natural gas deposits formed millions of years ago when plant and animal remains were subjected to enormous forces of heat and pressure. These natural deposits contain mixtures of organic compounds that are nowadays separated into their component parts at gas processing plants and oil refineries (Figure 6). Many of the components in these mixtures are simple hydrocarbons such as methane, propane, butane, and octane. They are primarily separated to be used as fuels, but often these simple molecules are used as building blocks by chemists to synthesize larger, more complex molecules. These small molecules are like pieces of LEGO to a chemist! GO

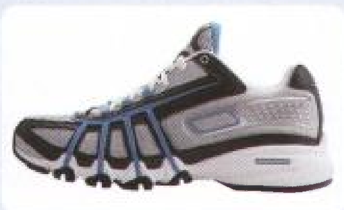
Figure 6 An oil refinery

To learn more about how oil refineries work, go to **www.science.nelson.com** GO

8.3 CHECK YOUR Understanding

1. State a modern definition of organic chemistry.
2. Why was the term "organic" originally chosen? Give an example of an original organic substance.
3. For each photo below, consider the substances that make up the object. List those substances that you think are organic and those that you think are inorganic.

(a)



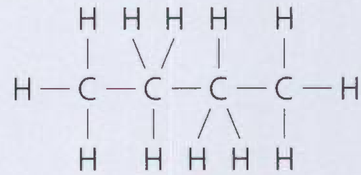
(b)

(c)

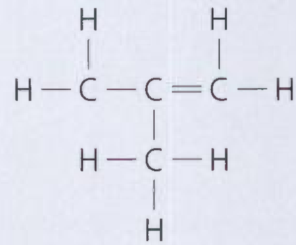
(d)

4. What two elements are always common to organic compounds?
5. Is washing soda (Na_2CO_3) considered to be organic? State two reasons why or why not.
6. Explain what makes carbon special when it bonds with other elements.
7. Draw a Lewis diagram of carbon, and a Lewis diagram of hydrogen.
8. (a) Draw a Lewis diagram to illustrate how a molecule of propane (C_3H_8) can exist.
   (b) Draw a structural formula for a molecule of propane.
9. Draw five different structural formulas for C_6H_{14}.
10. Identify the errors in the following structural formulas. In your notebook, draw the correct structural formulas.

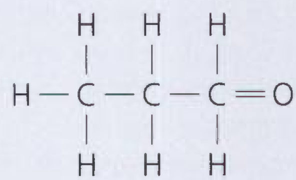
(a) C_4H_{10}



(b) C_4H_{10}



(c) C_3H_8O



11. What is a major source of organic molecules?
12. What type of industrial plant (factory) is used to separate mixtures of organic compounds?

SPIDER CHEMISTS

The world around us is made of many different materials with distinct chemical structures. Some are natural, such as starch, wool, and silk, while others are synthetic, such as plastic pop bottles, latex paint, and superglue. What they have in common is that they are all made of giant molecules!

All life is made possible because of giant molecules called polymers. A polymer consists of long chains composed of small repeating molecular units called monomers. Polymers usually consist of thousands of monomers covalently bonded together. They can be many millions of times larger than simple molecules such as water or carbon dioxide. There are three major types of biological giant molecules: proteins, carbohydrates, and nucleic acids. Proteins are long chains of amino acids, such as keratins that form our fingernails and hair. Carbohydrates are chains of sugars that form substances such as cotton, cellulose (the wood fibre of trees), or starches for storing energy. Nucleic acids are chains of nucleotides that take the form of DNA or RNA.

Scientists have also created a large variety of synthetic polymers such as nylon, plastic, and rubber. Of particular interest to chemists today, is how to produce a synthetic equivalent of spider silk. Spider silk is a fine protein polymer that is known for its strength and elasticity. It is one of the strongest natural fibres, and gram for gram, is six times stronger than steel (Figure 1).

Chemists have already created materials that are either very strong or very stretchy, but have not been able to achieve both qualities in the same material. Recently, chemists have determined that the secret behind the combined strength and flexibility of spider silk lies in the arrangement of the amino acids.

Moreover, chemists are fascinated with the spider's ability to create different types of silk that serve different functions. Spiders start a web with dragline silk that creates an incredibly strong framework. The web is then rewoven with a slightly more flexible and sticky molecular structure called capture silk. Once the prey is captured in the web, the spider produces another type of polymer to wrap around the trapped insect (Figure 2).

Spider silk may hold lots of promise for creating tear-resistant textiles and high-strength fibres needed for lightweight bulletproof gear. More interestingly, spider silk is chemically unreactive, water insoluble, and resistant to bacteria and fungi. This makes it ideal for biomedical applications, including sutures, artificial tendons and ligaments, and biomedical devices. Synthetic fibres are often used in place of natural materials, since they are strong, light, elastic, and inexpensive.

Figure 1 Individual fibres of spider silk

Figure 2 A spider uses a third type of silk to wrap its captured prey.

8.4 Explore an Issue

DECISION MAKING SKILLS

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

The Great Organic Debate: Healthier—Yes or No?

The term "organic" has different meanings even within the scientific community. An organic chemist believes that organic compounds are defined as carbon based, whereas an agricultural scientist identifies organic foods as naturally grown according to certain specifications. But even after settling on a common definition, scientists still cannot agree on the role of organic food production in modern agriculture.

The Issue: Naturally Grown Foods Are Healthier

What role do synthetic chemicals play in food production and how do these foods affect your health? The world population is constantly increasing and travel is much more accessible than in the past. As a result, scientists are not only faced with the challenge of providing an adequate food supply, but also with controlling disease. Naturally grown foods are safe to produce and consume, but are they healthier and can their rate of production meet world needs? What are the alternatives and are they safe?

Statement

People should eat only organic foods.

Background to the Issue

Organic Farming

All foods contain organic compounds, but an organic food is one that has been grown in certain soil conditions. "Organic farming" refers to crops that have been grown without using any synthetic fertilizers or pesticides (Figure 1). Organic farming is often considered the most natural way to farm in the sense that it relies solely on natural fertilizers (manure) and natural methods of controlling pests and disease. Organic farming also includes growing plants, whose fibres are used in clothing, and the growing of grapes, which are used to make organic wines.

Farmers can grow certified organic crops by meeting strict standards, including proper buffer fields between the organic field and any non-organic fields (preventing non-organic pollen from fertilizing organic crops). All crops that are to be sold as organic must be inspected and certified.

Figure 1 Produce labelled "organic" is grown using only natural fertilizers and methods.

Non-Organic Farming

According to public attitudes, organic food is the healthy option, both for people and the environment. But is organic food really as good as we think? One argument is that organic farming can lead to the risk of contamination with dangerous natural bacteria and mould toxins. Increased levels of natural pesticide found in organic produce could even be as dangerous as synthetic chemicals.

Conventional (non-organic) farming has utilized synthetic chemicals such as fertilizers and pesticides since their development (Figure 2). Fertilizers containing elemental nitrogen, phosphorus, and potassium have been manufactured for the past one hundred years. Plants depend on nitrogen for leaf and stem growth, phosphorus for root development and blooms, and potassium for roots and general vigour.

Figure 2 In conventional farming, synthetic fertilizers are sprayed on crops to help their growth.

Take a Position

1. Carefully read the statement and background information.
2. Your teacher will assign you to a group. Your group will then be divided into two subgroups: one that will support the statement and one that will oppose it.
3. With your subgroup, research the topics of organic and non-organic foods and how chemistry is involved in agriculture. Sources of information could include newspaper or journal articles, textbooks, library references, and the Internet.

   www.science.nelson.com GO

Communicate Your Position

1. Prepare a presentation that supports your position on organic versus non-organic foods. Prepare a list of pros and cons, and establish an argument for how your pros outweigh your cons. Consider, for example:
   (a) What types of chemicals are used and what are their benefits and hazards?
   (b) What effects do organic and inorganic foods have on human health?
   (c) What effects do the organic and inorganic farming practices have on human and environmental health?
   (d) How available and affordable are organic and inorganic farming practices throughout the world?
2. Present and defend your position in a group debate.

8A Investigation

Classifying Solutions of Ionic Compounds

A compound is said to be ionic if it releases positive and negative ions when dissolved in water. A simple laboratory test is to measure the electrical conductivity of the solution formed because ionic solutions are relatively good conductors. Beyond the fact that ionic solutions conduct electricity, are there other interesting properties that separate these solutions into different groups? What further tests can be used?

Questions

What tests can be used to classify solutions of ionic compounds into groups? How can these groups be defined?

Experimental Design

In this investigation, you will be given some ionic solutions of compounds to test. In Part I, you will test several unknown solutions and note some of their properties. You will use the similarity of properties to classify these solutions into three groups. Then, the identities of the compounds in the solutions will be revealed and you will write definitions that explain why each compound belongs in its particular group.

In Part II of this investigation, you will test several known household compounds. From the results you obtain and information provided, you will use your definitions from Part I to classify these compounds.

Always wear eye protection when working with any of these solutions. Some of these chemicals can be corrosive to skin, eyes, and clothing. If any solution splashes on skin or in eyes, flush immediately with plenty of cold water, and inform your teacher. Wash away any spills on any other surface with plenty of water.

Bromothymol blue can stain clothing. Use with care.

INQUIRY SKILLS

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

Materials

- safety goggles
- 6 small test tubes (10 mm × 75 mm)
- water soluble marker
- set of 6 unknown solutions (labelled A–F)
- 6 dropping pipettes
- test tube rack
- spot plate or glass square (10 cm × 10 cm)
- dropping bottles of phenolphthalein solution and bromothymol blue solution
- red litmus paper
- blue litmus paper
- magnesium ribbon
- set of 6 household solutions (vinegar, oven cleaner, table salt, colourless carbonated drink, lemon juice, milk of magnesia)

Procedure

Part I: Tests of the Unknown Solutions

1. Follow the safety instructions provided by your teacher and put on your safety goggles.
2. Label six small test tubes A to F with a water soluble marker. Obtain a sample of each of the six unknown solutions from your teacher and fill each test tube approximately half full. Place a dropping pipette in each test tube and organize these in a test tube rack.
3. Place two drops of each solution in separate labelled spots on a spot plate or a glass square. Next, add one drop of phenolphthalein solution to each spot and record your results in your copy of Table 1. If nothing happens, write "no change."

Table 1 Tests of the Unknown Solutions

Unknown solution	Phenolphthalein	Bromothymol blue	Red litmus	Blue litmus	Magnesium ribbon
A					
B					

4. Repeat Step 3 using bromothymol blue solution instead of phenolphthalein. Repeat Step 3 with a small piece of red litmus paper. Repeat Step 3 with a small piece of blue litmus paper.
5. Add a small strip of magnesium ribbon to the remaining solution in each test tube and record your results.
6. Place all solutions with solid waste such as litmus paper and magnesium ribbon in the designated waste container. Rinse all remaining chemicals from the glassware down the sink with lots of water.

Part II: Tests of Common Household Solutions

7. Repeat Part I for the household solutions. Record your results in your copy of Table 2.
8. Clean up your workstation and dispose of these materials as directed by your teacher. Wash your hands with soap and water.

Table 2 Tests of Common Household Solutions

Household solution	Phenolphthalein	Bromothymol blue	Red litmus	Blue litmus	Magnesium ribbon
vinegar					
oven cleaner					

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

(a) Examine your results in Table 1. Classify ionic solutions A to F into three groups according to the following guidelines:

Group 1: all solutions that showed a change with the magnesium ribbon

Group 2: all solutions that showed changes with phenolphthalein, bromothymol blue, and litmus

Group 3: all solutions that fit in neither Group 1 nor Group 2

(b) Use your results from Table 2 to place the household solutions into your three groups.

(c) In chemistry terms, Group 1 chemicals are called acids, Group 2 chemicals are bases, and Group 3 chemicals are salts. Your teacher will provide you with the chemical formulas for the unknown solutions. Write these formulas under the headings of acids, bases, or salts.

(d) Examine the formulas for the acids and make up a definition of an acid. Do the same for bases and salts.

(e) Your teacher will provide you with the chemical formulas for the household solutions. Use your definitions to explain why each one is an acid, base, or salt.

(f) Summarize your test results in your copy of Table 3.

Table 3 Summary of Tests on Ionic Solutions

	Phenolphthalein	Bromothymol blue	Red litmus	Blue litmus	Magnesium ribbon
acids					
bases					
salts					

Evaluation

(g) Did your evidence enable you to confidently classify all of the solutions? Explain.

Synthesis

(h) Use your copy of Table 4 to predict the results for the given solutions.

Table 4 Summary of Tests on Ionic Solutions

Solution	Phenolphthalein	Bromothymol blue	Red litmus	Blue litmus	Magnesium ribbon
KBr					
$Sr(OH)_2$					
HNO_3					

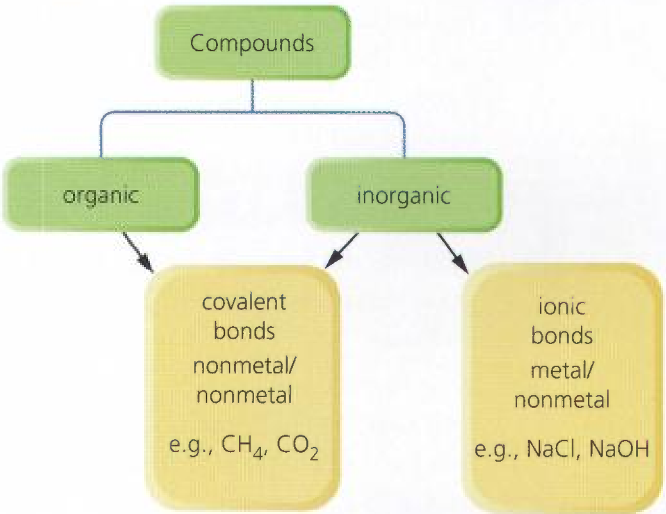
CHAPTER 8 Review

Classifying Chemical Compounds

Key Ideas

All chemical compounds are either organic or inorganic.

- Organic compounds have a high percentage (by mass) of the element carbon; inorganic compounds do not.



Inorganic compounds can be molecular or ionic (acids, bases, or salts).

- Inorganic compounds can be molecular or ionic based on the type of bonds that hold the components (elements) together.
- Inorganic molecular compounds are common but few in number.
- Inorganic ionic compounds can be classified as acids, bases, or salts depending on their properties.
- Acids can be defined as substances that release H^+ ions in solution; bases as substances that release OH^- ions in solution; and salts as substances that release positive ions and negative ions *other than* H^+ and OH^- in solution.
- Acidity is the measure of the relative amounts of H^+ and OH^- in a solution, and is often measured on a pH scale.
- Most acids can be named using a conventional system.

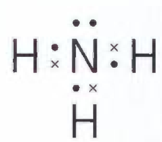
Solution classification	Relative ion count	Examples
acidic	$H^+ > OH^-$	HCl (aq) provides extra H^+
neutral	$H^+ = OH^-$	H_2O, NaCl (aq)
basic	$H^+ < OH^-$	NaOH (aq) provides extra OH^-

Vocabulary

organic compound, p. 201
inorganic compound, p. 201
acids, p. 203
bases, p. 203
salts, p. 203
aqueous, p. 203
acidity, p. 205
pH scale, p. 205
Lewis diagram, p. 210
bonding pair, p. 210
electron dot diagram, p. 210
octet rule, p. 212
covalent chemical bonds, p. 212
lone electron pairs, p. 212
organic chemistry, p. 215
structural formulas, p. 216
hydrocarbons, p. 218

Lewis diagrams (electron dot) can explain how molecular compounds form as a result of bonding pairs of electrons.

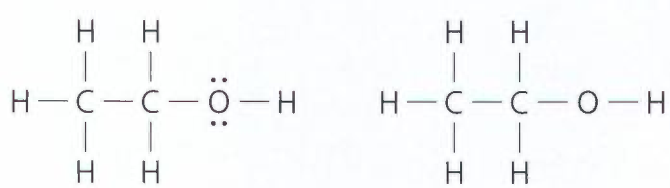
- A Lewis diagram is helpful for understanding covalent bonding in molecular compounds.
- Lewis diagrams only show valence electrons, which are typically represented by dots around an element's symbol.
- An element prepares for bonding by arranging valence electrons as single electrons whenever possible.
- Single electrons from one element pair with single electrons from other elements to form bonding pairs of electrons.
- Atoms of elements attempt to achieve complete valence shells similar to their nearest noble gas. This is known as the octet rule.



Organic compounds are molecular and contain carbon and hydrogen.

- Organic chemistry is the chemistry of carbon compounds.
- Besides carbon, organic compounds contain hydrogen, and sometimes oxygen or other non-metals.
- Organic compounds can be natural or synthetic.
- Simplified Lewis diagrams or structural formulas can be drawn to help visualize organic molecules.
- Organic compounds are so numerous that an elaborate classification scheme into families is necessary. Families include hydrocarbons, alcohols, and ethers.

C_2H_5OH



Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Which of the following did early chemists think applied to organic compounds?
   A. They were healthy to eat.
   B. They were free of pesticides.
   C. They were composed of organic matter.
   D. They were derived from living organisms.

K 2. Which of the following is found in all organic compounds?
   A. water
   B. carbon
   C. oxygen
   D. nitrogen

K 3. Which of the following is *not* a type of ionic compound?
   A. salt
   B. acid
   C. base
   D. water

K 4. Which of the following is correct in a Lewis diagram?

I	The electrons are represented by dots.
II	Only valence electrons are represented.
III	The electrons are shown in different shells.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II, and III

K 5. The octet rule generally refers to the tendency for a bonding atom to acquire
   A. 8 valence electrons.
   B. a total of 8 electrons.
   C. 2 plus 8 for a total of 10 electrons.
   D. an equal number of electrons and protons.

K 6. Which of the following statements applies to acids, bases, and salts?
   A. Their solutions conduct electricity.
   B. They react with chemical indicators.
   C. They cause litmus paper to change colour.
   D. They react with metals to produce hydrogen gas.

7. (a) What types of elements are commonly found in ionic compounds?
   (b) What types of elements are commonly found in molecular compounds?

8. (a) Use relative amounts of H^+ and OH^- to describe how a solution is classified as acidic, basic, or neutral.
   (b) Explain why water is neutral.

9. (a) What is the normal range of the pH scale?
   (b) What do the following pH values represent?
      (i) 3
      (ii) 9
      (iii) 7

10. What difference exists between the acidity of a solution with a pH of 3 and one with a pH of 2?

11. Why does carbon form such a large number of organic compounds?

K 12. Which of the following describes the number and location of the electrons in a Bohr diagram of an atom?

	Number of electrons	Location of electrons
A.	equal to the number of protons	arranged in shells around the nucleus
B.	equal to the number of protons	arranged in a single shell around the nucleus
C.	equal to the number of neutrons	arranged in shells around the nucleus
D.	equal to the number of neutrons	arranged in a single shell around the nucleus

Use What You've Learned

13. What test is commonly used to determine if a compound is ionic or covalent and what would be its results?

U 14. What is the name of the acid H_2CrO_4?
   A. chromic acid
   B. chromous acid
   C. hydrochromic acid
   D. hydrochromous acid

15. Copy Table 1, and then complete.

Table 1

Formula	Name	Litmus test result	Classification (acid, base, or salt)
KOH			
	chloric acid		
	potassium chromate		
H_2SO_3			
	lead(II) iodide		
HBr			
	calcium hydroxide		

U 16. What is the number of valence electrons for a phosphorus atom?
   A. 5
   B. 8
   C. 15
   D. 31

17. Draw Lewis diagrams for atoms of the following elements:
   (a) Ca
   (b) H
   (c) C
   (d) O
   (e) N

18. Draw Lewis diagrams for the following molecules. Then, draw structural formulas for the molecules.
   (a) PH_3
   (b) H_2O
   (c) CCl_4

19. Draw structural formulas for the following organic molecules:
   (a) C_2H_6
   (b) C_3H_8

Think Critically

HMP 20. If some acid is added to a solution with a pH of 10.0, what will always happen to the pH of the solution?
   A. The pH will increase.
   B. The pH will decrease.
   C. The pH will become 7.0.
   D. The pH will stay the same.

21. Conduct an Internet search to make a list of some common situations where pH is important.

   www.science.nelson.com GO

22. Carbon dioxide is a common gas with the well-known formula, CO_2. Attempt to draw a Lewis diagram for a molecule of CO_2 to discover why more advanced Lewis theories are necessary.

23. Do an Internet search to learn the chemical formula for an organic chemical of your choice. For ideas of an organic chemical, consider the name of a medicine, drug, household plastic, fabric, or others. Examine labels for ideas. How will you know when you discover an organic chemical formula?

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Reflect on Your Learning

24. Write a short paragraph to explain how your ideas about acids, bases, and salts have changed since studying this chapter. What did you think about these chemicals before?

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

CHAPTER 9

Investigating Chemical Reactions

Chapter Preview

What chemical reactions occur in your daily life? Riding in a car, walking, breathing, and listening to a portable music player all depend on chemical reactions. A car obtains its energy to move from the reaction of gasoline with oxygen. From the food that we eat, the body's cells use chemical reactions to produce non-stop energy that is required for normal function and movement. Portable music players rely on the electrical energy produced from chemical reactions in batteries.

In this chapter, you will investigate the world of chemical reactions and learn how chemists make sense of and describe them.

KEY IDEAS

- Chemical reactions are processes that involve chemical change and obey the Law of Conservation of Mass.
- Chemical equations are used to describe chemical reactions.
- There are six common types of chemical reactions.
- Chemists are able to predict the products of common reactions.
- The rate of a chemical reaction is affected by various factors.

TRY THIS: *Modelling Physical and Chemical Change*

Skills Focus: creating models

Chemistry is just complicated common sense! One of the challenges of learning chemistry is trying to understand things that you cannot see. You cannot see the incredibly small, and that is precisely why chemists use models.

In this activity, you will use interlocking building blocks to model and demonstrate the difference between a physical change and a chemical change. Recall that in a physical change, no new substance is formed as is evident when water boils and changes into water vapour (gas). However, when water is broken down by electrolysis into hydrogen gas and oxygen gas, a chemical change occurs.

Materials: an assortment of interlocking building blocks

1. Choose six blocks and use them to show an example of physical change.
2. Use these same blocks to demonstrate an example of a chemical change.

A. Describe your example of physical change by sketching the blocks before and after.

B. Use a word statement to represent the sketches that you just made.

C. Make up some symbols for your blocks. For example, a red block could be "R." Convert your word statement of the physical change into a statement using symbols.

D. Repeat A through C for your example of a chemical change.

9.1 Describing Chemical Reactions

You have learned that chemists use classification schemes to make sense out of vast amounts of information. For instance, in Chapters 7 and 8 you saw patterns in how chemical compounds can be classified as ionic or molecular, as organic or inorganic, as acids, bases, and salts, and as organic family compounds (Figure 1).

LEARNING TIP

The key ideas in the chapter preview provide you with the "big ideas" that you need to look for as you read Chapter 9. Ask yourself, "What do I already know about chemical reactions and what do I need to pay close attention to?"

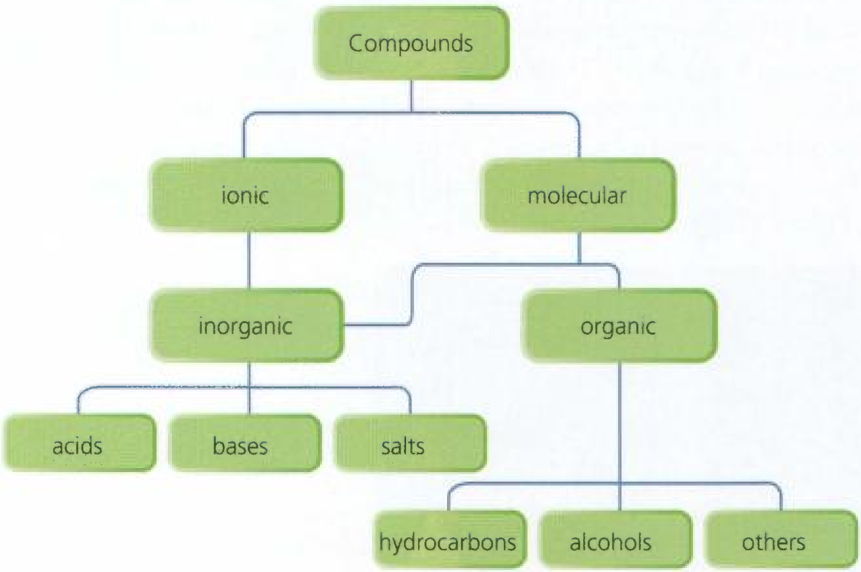


Figure 1 Many of the compounds you have studied can be produced by chemical reactions, or the compounds themselves can be used to produce other substances in chemical reactions.

Chemical reactions are used to manufacture things that we use every day. The plastics that are so common (keyboards, bottles, chair seats, TV monitors, toys), all of the metals you notice (coins, file cabinets, chair legs, car parts, structural supports), medicines, and even the fabrics in your clothing, are all examples of things that result from chemical reactions (Figure 2).

Figure 2 The nylon used in this rope is produced through a chemical reaction.

Figure 3 Rusting is a slow chemical reaction.

Chemical reactions are simply processes that involve chemical change. You may recall that a chemical change is one in which new substances are formed, whereas a physical change is one in which no new substances are formed. One everyday example of a chemical change is when iron combines with oxygen to form a new substance called rust (iron(II) oxide), as shown in Figure 3. Chemists are particularly interested in studying chemical changes and have developed a method to describe them.

A fairly common occurrence in our modern world is the launching of the space shuttle. After the shuttle has left the launching pad, the huge amount of smoke that can be seen comes from the burning of the fuel in the two solid rocket booster engines. But other engines are at work here—the three engines on the shuttle itself. They derive their power simply from the reaction of hydrogen and oxygen, which produces pure water and a tremendous amount of energy. Most of the water is produced as colourless vapour, so you cannot see it coming out of the three shuttle engines (Figure 4).

To learn more about how the space shuttle works, go to **www.science.nelson.com**

Figure 4 The three shuttle engines produce colourless water vapour during launch. The three blue cones of light coming from the engines are called blue mach diamonds. Their presence and distance from the main engines indicate a good lift-off.

To understand what happens in the space shuttle launch reaction, we need to use our imaginations at a molecular level. At this molecular level, imagine observing molecules of hydrogen (H_2) flying around and colliding with molecules of oxygen (O_2). Some of these collisions would result in breaking the bonds holding the molecules together, therefore allowing new bonds to form between the hydrogen and oxygen atoms. The result is the formation of water molecules.

One way to describe this chemical reaction is to use molecular models as in Figure 5.

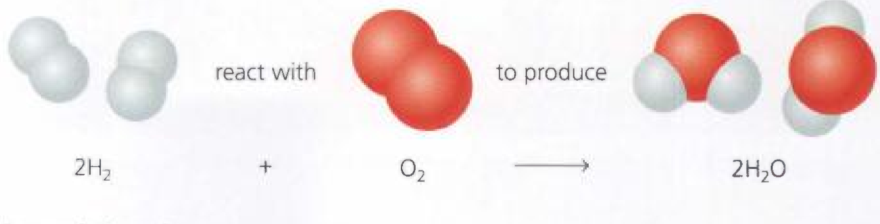


Figure 5 A chemical word equation for this reaction is: "2 molecules of hydrogen react with 1 molecule of oxygen to produce 2 molecules of water."

Another method to describe the water formation reaction from the space shuttle is to use a chemical formula equation or chemical equation. A **chemical equation** uses chemical formulas to describe the chemicals that react (the **reactants**) and those that are produced (the **products**). The chemical equation for water formation is shown like this:

$$\underset{\text{reactants}}{2H_2 + O_2} \rightarrow \underset{\text{products}}{2H_2O}$$

An arrow ($\rightarrow$) is used as a symbol to represent "changes into" or "produces." The plus sign (+) can be read as "reacts with" or "and," depending on the circumstance. Think of a chemical equation simply as a chemical sentence or statement that describes a chemical reaction. The equation above can then be read as "2 molecules of hydrogen react with 1 molecule of oxygen to produce 2 molecules of water."

Chemical equations are understood by chemists throughout the world. Although a chemist in France may not understand the words of a chemist from China, these scientists are able to communicate through the writing of chemical equations. 9A *Investigation*

9A *Investigation*

Mass and Chemical Reactions

To perform this investigation, turn to page 258.

In this investigation, you will look at what happens to the overall mass of chemicals in a chemical reaction.

Conservation of Mass and Atoms

Antoine Lavoisier was a French chemist who investigated chemical changes and discovered an important fundamental principle. He observed that as long as no material was allowed to enter into or escape from a reaction vessel (a situation known as a closed system), then the total mass of the chemicals produced was equal to the total mass of the chemicals that reacted. This is now known as the Law of Conservation of Mass. An everyday version of this law can expressed as, "What goes in, must come out!" That is, in a chemical reaction, matter is neither gained nor lost. The **Law of Conservation of Mass** for a chemical reaction states that the total mass of the reactants is equal to the total mass of the products.

In order for this to be true, the number of atoms of each element in the reactants must be equal to those in the products. For example, looking back at Figure 5, you will notice that 4 atoms of hydrogen exist in the reactants and 4 atoms of hydrogen appear in the products. Similarly, you will see 2 atoms of oxygen in both the reactants and the products.

We have been using the term "equation" on a regular basis, and the term itself suggests that something is equal. You can now answer the question, "What is equal in a chemical equation?" The answer is that the number of *atoms* of each element in the reactants is equal to those in the products. In other words, *atoms are also conserved in a chemical reaction.*

LEARNING TIP

Check your understanding. The Law of Conservation of Mass can be explained in this way: The atoms in use today have been recycled time after time. Atoms that exist today are essentially the same ones that existed thousands of years ago. Discuss with a partner.

To learn more about the Law of Conservation of Mass, view the animations at **www.science.nelson.com**

9.1 CHECK YOUR Understanding

1. What is the main difference between a physical change and a chemical change?
   A. In a physical change, no new substances are formed, whereas in a chemical change, new substances are formed.
   B. In a chemical change, no new substances are formed, whereas in a physical change, new substances are formed.
   C. A chemical change involves a transfer of electrons, whereas a physical change involves a sharing of electrons.
   D. A physical change involves a transfer of electrons, whereas a chemical change involves a sharing of electrons.
2. For each of the following, state whether it is a physical change or a chemical change. Give reasons for each answer.
   (a) freezing water to form an ice cube
   (b) burning toast
   (c) placing a nail in water and allowing it to rust
   (d) pouring concrete onto a driveway and allowing it to set
   (e) pouring molten silver into a mould to solidify and make jewellery
   (f) composting leaves by allowing them to rot and decay in a box
   (g) shredding leaves with a lawn mower
3. Hydrogen gas (burns extremely fast) and oxygen gas (supports burning) can be combined to make water, which can put out fires. Explain why water is so different from its components.
4. What is a chemical equation?
5. Use words to describe the following chemical equations.
   (a) $S + O_2 \rightarrow SO_2$
   (b) $2\ SO_2 + O_2 \rightarrow 2\ SO_3$
   (c) $N_2 + 3\ H_2 \rightarrow 2\ NH_3$
6. (a) Identify the reactants and products in the following chemical word equations:
   (i) magnesium + oxygen → magnesium oxide
   (ii) water → hydrogen + oxygen
   (iii) methanol + oxygen → carbon dioxide + water
   (iv) aluminum + copper(II) chloride → aluminum chloride + copper
   (b) Rewrite the word equations as formula equations. The formula for methanol in (iii) is CH_3OH.
7. State the Law of Conservation of Mass for a chemical reaction.
8. Use the Law of Conservation of Mass to provide the missing numbers.
   (a) calcium + chlorine → calcium chloride
   40.1 g 71.0 g ? g
   (b) ammonia → nitrogen + hydrogen
   34 g ? g 6 g
   (c) ethanol + oxygen → carbon dioxide + water
   46 g ? g 88 g 54 g
   (d) magnesium + copper(II) chloride →
   24.3 g 134.5 g
   aluminum chloride + copper
   ? g 63.5 g
9. What particles are conserved in a chemical reaction?
   A. atoms
   B. molecules
   C. simple ions
   D. polyatomic ions

9.2 Writing and Balancing Chemical Equations

Equations used in chemistry, like sentences, can be general statements with very little detail or more specific statements with more detail. A word equation is very general and can be used to describe the formation of water:

$$\text{hydrogen} + \text{oxygen} \rightarrow \text{water}$$

However, chemists usually prefer to use chemical equations because of the greater detail that they provide. Recall from Chapter 7 that certain elements like hydrogen and oxygen exist as diatomic molecules. Using the formulas for hydrogen, oxygen, and water, the chemical equation would be:

$$H_2 + O_2 \rightarrow H_2O$$

Examining the atoms though, reveals that they are not conserved in this equation. Notice the number of O atoms on each side of the equation.

H_2	+	O_2	$\rightarrow$	H_2O
2 H atoms		2 O atoms		2 H atoms, 1 O atom

This incomplete chemical equation is called a **skeleton equation**. Although the chemical formulas are correct, the atoms are not conserved. Chemists use an important process called *balancing* to correct this.

LEARNING TIP

Check your understanding. Explain to a partner why skeleton equations are sometimes called unbalanced equations.

Counting Atoms

Before you learn how to balance chemical equations, you first need to know how to count atoms. For example, "5 H_2O" represents 5 water molecules (Figure 1), so the coefficient "5" describes the number of molecules. The subscripts describe the number of atoms of the element in front of them. In Figure 1, you can easily see that there are a total of 10 H atoms and 5 O atoms.

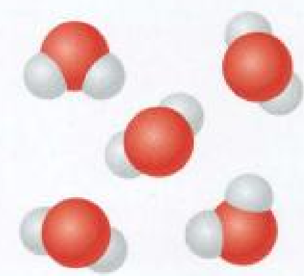


Figure 1 Five water molecules are described as 5 H_2O.

Using the coefficients and subscripts, we can easily count atoms. Arithmetically, 5 H_2O contains $5 \times 2 = 10$ H atoms and $5 \times 1 = 5$ O atoms (Figure 2).

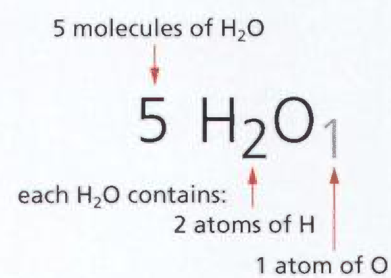


Figure 2 The coefficients and subscripts tell us how many atoms are represented by the expression 5 H_2O.

Consider this example: 5 $Ca_3(PO_4)_2$ contains 15 Ca atoms, 10 P atoms, and 40 O atoms. Recall that polyatomic ions such as PO_4 are written as a group in a formula.

This expression can be viewed as
Ca Ca Ca (PO_4) (PO_4)
Ca Ca Ca (PO_4) (PO_4)
Ca Ca Ca (PO_4) (PO_4)
Ca Ca Ca (PO_4) (PO_4)
Ca Ca Ca (PO_4) (PO_4)

The atoms can be calculated arithmetically
Ca atoms $= 5 \times 3 = 15$
P atoms $= 5 \times 1 \times 2 = 10$
O atoms $= 5 \times 4 \times 2 = 40$

Balancing Chemical Equations

Skeleton equations show the correct formulas for the reactants and products in a chemical reaction, but usually they are not balanced.

TRY THIS: *Modelling Chemical Equations*

Skills Focus: creating models

Chemical equations are the "sentences" or statements that chemists write in order to describe chemical reactions. In this activity you will use interlocking building blocks to better understand the nature of these equations.

Materials: an assortment of interlocking building blocks

1. Obtain the following blocks: eight identical red blocks and four identical white blocks. (You may use different colours, but have eight of one colour and four of another colour.)
2. On a piece of blank note paper, draw an arrow in the middle of the page and set up the words "reactants" and "products" as shown.

   reactants $\rightarrow$ products

3. Clip two of the red blocks together and place this "molecule" on the reactant side of the arrow. Do the same with two white blocks. You now have two molecules on the reactant side. Remember, some "atoms" just naturally pair up to form diatomic molecules. You have just built two diatomic molecules!
4. For the product side, build a molecule that has three joined blocks: one white block sandwiched between two reds. Assume that this is just the bonding nature of these blocks.

A. If R is the symbol for a red block, what is an appropriate symbol for a white block?

B. Sketch the difference between 2 R and R_2. What would be the formula for the red blocks and the white blocks on the reactant side? What would be the formula for the product you have built?

C. Make a sketch of your display. Write a "chemical" equation to describe the reaction on your display using formulas.

D. You have now constructed three molecules on your display, but what problem do you notice that would violate the Law of Conservation of Mass? Use the unused blocks to build more of the same molecules as necessary, and place them on your display to resolve this problem.

E. Make a sketch of your new display. Rewrite your equation to reflect your new display.

F. Record the number of reactant red "atoms" and reactant white "atoms." Record the number of product red "atoms" and product white "atoms." How do they compare?

G. In the world of chemistry, R could represent a hydrogen (H) atom and W could represent an oxygen (O) atom. Rewrite your equation and substitute the elements H and O. Is your chemical equation balanced? How do you know?

A **balanced equation** contains important information about the relative amounts of each chemical in the reaction. This vital information is similar to the relative amounts of ingredients that appear in a baking recipe. The process of balancing an equation involves starting with a skeleton equation, and then adjusting its coefficients so that the atoms of each element are equal on both sides of the equation.

Using our example again of hydrogen and oxygen reacting to form water, we know that the skeleton equation would be:

skeleton equation:	H_2	$+$	O_2	$\rightarrow$	H_2O
check atom count:	2 H atoms		2 O atoms		2 H atoms, 1 O atom

To balance the equation, we need 2 O atoms on the right side of the equation. A quick fix for O atoms would be:

$$H_2 + O_2 \rightarrow H_2O_2$$

But this would be incorrect. What just happened was that we changed the chemical, water, into a totally different chemical called hydrogen peroxide! We no longer have an accurate description for making water as we are now making hydrogen peroxide. You cannot change any chemical in a skeleton equation. That would be similar to changing a cake recipe so that powdered flour was replaced with powdered cement!

When balancing an equation, it is important to remember that you can never change the subscript numbers—only the coefficients can be altered.

To balance our equation for making water then, we must change the coefficients in order to change the atom count. If you need 2 atoms of O on the right side, then you can change the coefficient so that you have 2 H_2O. That corrects the O atom count.

skeleton equation:	H_2	+	O_2	→	H_2O
balancing Step 1:	H_2	+	O_2	→	***2*** H_2O
check atom count:	2 H	+	2 O	→	4 H, 2 O

Now the O atoms are equal, but the H atoms are unequal. You can change the coefficient for hydrogen on the left side so that you have 4 H atoms.

balancing Step 2:	***2*** H_2	+	O_2	→	2 H_2O
check atom count:	4 H	+	2 O	→	4 H, 2 O

To balance equations, choose one element at a time and alternate between the left side of the equation and the right side, changing and, if necessary, re-changing coefficients until the atom count works. The process of balancing equations is similar to puzzle solving and involves a lot of trial and error (guess and test). But because of its importance in describing chemical reactions, it is a skill that chemists must practise repeatedly. Since you may find yourself regularly changing coefficients, use a pencil and an eraser for all balancing equation exercises.

Some Balancing Tips

- Usually start with the furthest left element and work your way to the right. Remember, only change coefficients to balance.
- If O atoms appear in several different formulas, leave O until last.
- If polyatomic ion groups appear on both sides of the equation, count them as a group. For example, count SO_4 groups on both sides—don't count individual S and O atoms.

LEARNING TIP

A tip for balancing equations is to draw a box around the chemical formulas as a reminder that subscript numbers can't be changed. Since you may find yourself changing coefficients often, record all your changes. It is difficult to keep these numbers in your head for very long.

To practise your skills in balancing equations, go to **www.science.nelson.com**

9.2

CHECK YOUR Understanding

1. (a) What is the difference between a chemical word equation and a chemical formula equation?
   (b) Provide two reasons why a chemical formula equation is most commonly used by chemists.
2. Rewrite the following sentences, first as chemical word equations, and then as chemical formula equations.
   (a) Sodium carbonate reacts with hydrochloric acid to produce sodium chloride, carbon dioxide, and water.
   (b) Octane (C_8H_{18}) burns by reacting with pure oxygen gas to produce carbon dioxide and water.
   (c) Sodium metal reacts with water to form sodium hydroxide and hydrogen gas.
   (d) Sulfuric acid reacts with sodium hydroxide to give sodium sulfate and water.
   (e) Zinc metal reacts with copper sulfate solution to produce zinc sulfate solution and copper metal.
3. How many atoms of each element are represented in the following expressions?
   (a) 3 NaCl
   (b) H_2SO_4
   (c) $4H_2SO_4$
4. What are you trying to make equal when you balance a chemical equation?
5. Rewrite the following word equations as skeleton chemical equations, then balance:
   (a) Propane (C_3H_8) reacts with oxygen gas to produce carbon dioxide and water.
   (b) Calcium oxide reacts with hydrochloric acid to form calcium chloride and water.
   (c) Phosphoric acid and potassium hydroxide react to form potassium phosphate and water.
   (d) Calcium carbonate reacts with nitric acid to produce calcium nitrate, carbon dioxide, and water.
   (e) Silver nitrate reacts with copper to form copper(II) nitrate and silver.
   (f) Nitrogen trichloride and hydrogen gas react to produce hydrochloric acid and nitrogen gas.
6. Balance the following chemical equations:
   (a) $K + Cl_2 \rightarrow KCl$
   (b) $Li + O_2 \rightarrow Li_2O$
   (c) $K + N_2 \rightarrow K_3N$
   (d) $Ba + O_2 \rightarrow BaO$
   (e) $Ca + F_2 \rightarrow CaF_2$
   (f) $Sr + N_2 \rightarrow Sr_3N_2$
   (g) $NaNO_3 \rightarrow NaNO_2 + O_2$
7. Balance the following chemical equations:
   (a) $K + H_2O \rightarrow KOH + H_2$
   (b) $Ca + H_2O \rightarrow Ca(OH)_2 + H_2$
   (c) $Mg_3N_2 + H_2O \rightarrow MgO + NH_3$
   (d) $Ca(ClO_3)_2 \rightarrow CaCl_2 + O_2$
   (e) $(NH_4)_2SO_4 + KOH \rightarrow NH_3 + H_2O + K_2SO_4$
   (f) $Fe + H_2O \rightarrow Fe_3O_4 + H_2$
   (g) $AlBr_3 + Cl_2 \rightarrow AlCl_3 + Br_2$
8. Balance the following chemical equations. Show an atom count check for each equation (similar to the one on page 235).
   (a) $NH_4Cl + Ba(OH)_2 \rightarrow NH_3 + H_2O + BaCl_2$
   (b) $AgNO_3 + CuCl_2 \rightarrow AgCl + Cu(NO_3)_2$
   (c) $RuS_2 + O_2 \rightarrow RuO_3 + SO_2$
   (d) $SrCl_2 + (NH_4)_2CO_3 \rightarrow SrCO_3 + NH_4Cl$
   (e) $SnS_2 + O_2 \rightarrow Sn_2O_3 + SO_2$
   (f) $FeCl_2 + Li_3PO_4 \rightarrow Fe_3(PO_4)_2 + LiCl$
   (g) $CuSO_4 + Mn \rightarrow Mn_2(SO_4)_3 + Cu$
   (h) $C_6H_{14} + O_2 \rightarrow CO_2 + H_2O$
   (i) $Al + Pb(NO_3)_2 \rightarrow Al(NO_3)_3 + Pb$
   (j) $C_7H_6O_3 + O_2 \rightarrow CO_2 + H_2O$

9.3 Types of Chemical Reactions

You have learned how chemists describe chemical reactions with balanced chemical equations. Now we will examine a variety of different types of reactions that chemists have discovered by noticing patterns. Patterns such as metals reacting with non-metals and metals reacting with ionic compounds have been observed and classified. We will examine six types of reactions: synthesis, decomposition, single replacement, double replacement, acid–base neutralization, and combustion.

STUDY TIP

In preparation for reading Section 9.3, label six study cards, one for each type of reaction. As you read the section, write a brief summary for each type of reaction including a definition and equation. You can use your study cards later to study for a chapter test.

Synthesis Reactions

A **synthesis reaction** is one in which two elements combine to form a compound. Since combining elements makes a compound, this reaction type is also called "combination" by some chemists. A general equation to describe a synthesis reaction could be:

$$A + B \rightarrow AB$$

combine

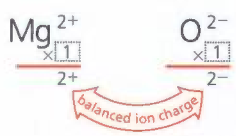
An example of a synthesis reaction is the combination of a metal with a non-metal to produce a metal oxide such as magnesium oxide:

$$Mg + O_2 \rightarrow MgO$$

combine

skeleton equation: $Mg + O_2 \rightarrow MgO$

Why is the product formed MgO and *not* MgO_2, since we are combining Mg and O_2? The reason is that metal/non-metal elements always form ionic compounds according to the rules of ion charge balancing learned in Chapter 7:



To complete our equation, we need to balance it:

balanced equation:	2 Mg	+	O_2	→	2 MgO
	element		element		compound

By examining the combination of elements in the above balanced equation, chemists are able to easily recognize the process of synthesis that occurs.

Another example of a synthesis reaction is the combination of sodium metal with chlorine gas to form sodium chloride (table salt). Recall that certain elements, such as chlorine, exist in pairs when they are free elements (not combined with others), and are called diatomic molecules. The balanced equation would be:

2 Na	+	Cl_2	→	2 NaCl
element		element		compound

Another example of a synthesis reaction occurs when carbonated beverages are made. Carbonation simply means that carbon dioxide gas has been added under pressure to water, where it reacts, and becomes "stored" in molecules of carbonic acid (Figure 1). The equation for the carbonation synthesis reaction is:

H_2O	+	CO_2	→	H_2CO_3
compound		compound		compound

Figure 1 Your favourite soft drink is produced in a carbonation system like this. The machine mixes water with a flavoured syrup and then infuses it with carbon dioxide before cooling.

Did You KNOW?

Atmospheric CO_2 (carbon dioxide) reacts with rainwater to make all rainwater slightly acidic (pH ≈ 6). When the atmospheric CO_2 exists in unnaturally high quantities, the rain produced is considered to be acid rain (pH < 5). Acid rain is also produced from polluting gases such as SO_2 and NO_2.

In general, a synthesis reaction is the combination of two substances to form one new compound. *In simple terms, two parts become one.* This would then include:

Na	+	Cl_2	→	NaCl (skeleton equation)
element		element		compound
KCl	+	O_2	→	$KClO_3$ (skeleton equation)
compound		element		compound
H_2O	+	CO_2	→	H_2CO_3 (balanced equation)
compound		compound		compound

Decomposition Reactions

In a **decomposition reaction**, a compound decomposes (breaks apart) into its parts. A decomposition reaction is really just the opposite of a synthesis reaction. A general equation to describe decomposition could be:

$$AB \rightarrow A + B$$

break apart

For example, molten (melted) table salt can be decomposed by using an electrical process called electrolysis to manufacture sodium metal and chlorine gas (Figure 2).

$$NaCl \rightarrow Na + Cl_2$$

break apart

skeleton equation:	$NaCl$	$\rightarrow$	Na	$+$	Cl_2
balanced equation:	$2\ NaCl$	$\rightarrow$	$2\ Na$	$+$	Cl_2
	compound		element		element

LEARNING TIP

Diagrams play an important part in reader comprehension. As you study Figure 2, look at the overall diagram and read the caption. Look at each part of the diagram and examine the use of labels, lines and arrows. Try to visualize (make a mental picture) of the decomposition of molten table salt.

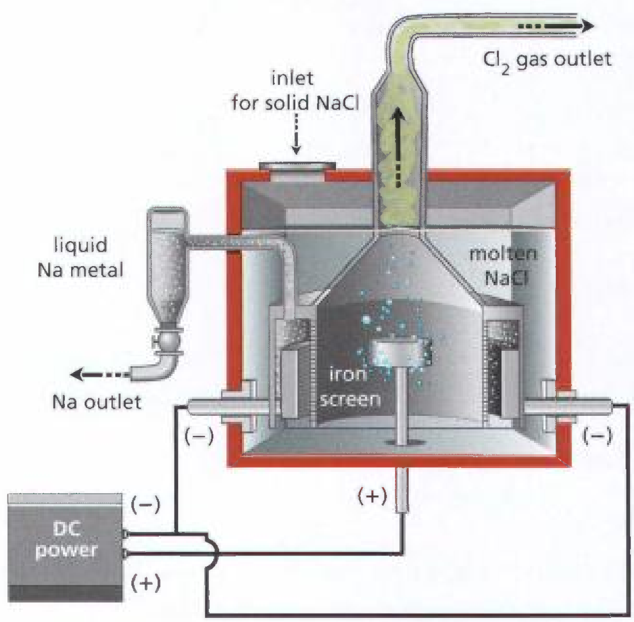


Figure 2 Molten table salt, NaCl (at 800 °C), is decomposed by electricity into sodium metal and chlorine gas. Chlorine is used in water purification and bleaches. Sodium is used in sodium vapour lights, the bright yellow streetlights that shine through fog.

Decomposition reactions can also involve the breaking apart of one compound into two new compounds. Consider a carbonated beverage. The carbonic acid in the pop remains stable as long as the pop is kept under pressure. As soon as the cap is removed, the carbonic acid breaks apart to form water and carbon dioxide gas (the bubbles) (Figure 3). The equation for the decomposition reaction of carbonic acid in pop is:

H_2CO_3	$\rightarrow$	H_2O	$+$	CO_2
compound		compound		compound

Figure 3 The carbon dioxide bubbles in a newly opened bottle of pop are products of a decomposition reaction.

The presence of a mild acid gives a carbonated beverage a desirable taste. When the acid is entirely decomposed, the beverage goes "flat" (no more bubbles) and a different taste results.

LEARNING TIP

Check your understanding of single and double replacement reactions. In your own words, explain to a partner how they are different.

Single Replacement Reactions

In a **single replacement reaction**, an element reacts with a compound (containing elements) and one of the elements is replaced.
A general equation to describe a single replacement reaction could be:

free

$$AB + C \rightarrow CB + A$$

replace

One element replaces another similar element from the compound. The most common single replacement reactions involve metals replacing metals, such as the metal Cd (cadmium) in $CdSO_4$ solution being replaced by Zn (zinc) metal in the following reaction:

free

$$CdSO_4 + Zn \rightarrow ZnSO_4 + Cd$$

replace

$CdSO_4$	+	Zn	$\rightarrow$	$ZnSO_4$	+	Cd
compound		element		compound		element

Consider another single replacement reaction:

skeleton equation: $AgNO_3 + Cu \rightarrow Cu(NO_3)_2 + Ag$

Why is this formula *not* $CuNO_3$? The more common ion charge for copper is Cu^{2+}, which leads us to a charge-balanced formula of $Cu(NO_3)_2$.

balanced equation:	$2\ AgNO_3$	+	Cu	$\rightarrow$	$Cu(NO_3)_2$	+	2 Ag
	compound		element		compound		element

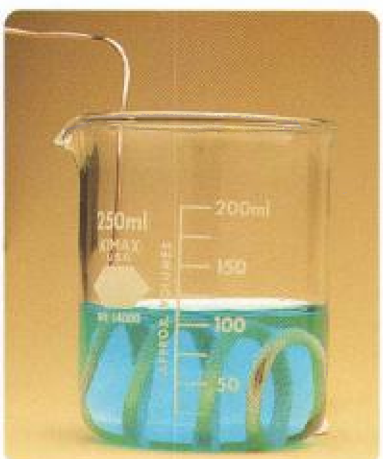


Figure 4 Copper metal is replaced by silver in a single replacement reaction.

This reaction is shown in Figure 4 where you can see that the silver crystals are growing in place of the copper wire, and the blue Cu^{2+} ions are now in solution as $Cu(NO_3)_2$.

Double Replacement Reactions

In a **double replacement reaction**, two compounds (containing elements) react and two of the elements replace each other.

A general equation to describe a double replacement reaction could be:

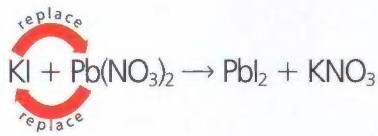
replace

$$AB + CD \rightarrow CB + AD$$

replace

For example, a solution of potassium iodide and a solution of lead(II) nitrate will react when mixed (Figure 5). What happens here is that the lead(II) and potassium ions exchange places and an interesting phenomenon occurs. One of the new compounds formed is a yellow solid called a precipitate.

Chemists describe this double replacement reaction by writing:



skeleton equation:	KI	+	$Pb(NO_3)_2$	$\rightarrow$	PbI_2	+	KNO_3
	colourless solution		colourless solution		yellow solid		colourless solution
balanced equation:	$2\ KI$	+	$Pb(NO_3)_2$	$\rightarrow$	PbI_2	+	$2\ KNO_3$
	compound		compound		compound		compound

Remember that one metal will usually exchange places with another metal. This means that in the reaction in Figure 5, potassium ions would only exchange places with the lead(II) ions and would not trade places with the nitrate ions.

Figure 5 Pb^{2+} ions and K^{+} ions exchange places in a double replacement reaction, and a yellow precipitate of PbI_2 is formed.

Acid–Base Neutralization Reactions

A special type of chemical reaction is an **acid–base neutralization reaction.** This name is appropriate because it describes what happens when an acid neutralizes (completely reacts with) a base resulting in a neutral solution (Figure 6).

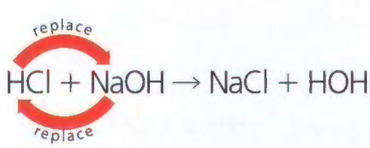
The products of a neutralization reaction are a salt and water.

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

A general equation for neutralization can be written as follows, where X represents the negative ion in the acid and B, the positive ion in the base:

$$\text{H-X} + \text{B-OH} \rightarrow \text{BX} + \text{HOH}$$

One example of acid–base neutralization is the reaction of hydrochloric acid with sodium hydroxide solution. This neutralization is expressed as:



$$HCl + NaOH \rightarrow NaCl + HOH$$
$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

Figure 6 Vinegar (acetic acid) is reacting with a base, baking soda (sodium bicarbonate). When the reaction is complete, the products will be water and sodium acetate, a salt.

Notice that a neutralization reaction is simply an example of a double replacement reaction. Note also the formula for water used in this reaction. Remember that in chemical reactions involving water forming from H^+ and OH^- ions, it is acceptable and encouraged to write the formula for water as HOH to aid your understanding (Figure 7).

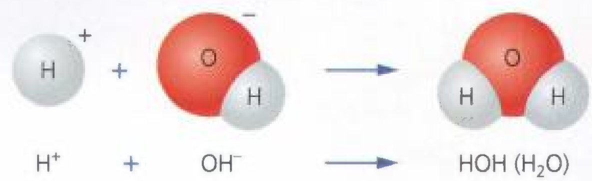
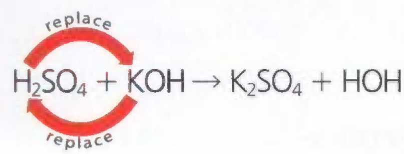


Figure 7 A water molecule can be formed from H^+ and OH^- ions.

Another example of neutralization is the reaction of sulfuric acid with potassium hydroxide:



skeleton equation:	H_2SO_4	+	KOH	→	K_2SO_4	+	HOH
	acid	+	base	→	salt	+	water
balanced equation:	H_2SO_4	+	2 KOH	→	K_2SO_4	+	2 HOH

Figure 8 A combustion reaction produces a flame to cook the marshmallow.

Combustion Reactions

In a **combustion reaction**, an organic (carbon–hydrogen) substance reacts with oxygen, releases heat, and perhaps light energy (Figure 8). It is a very common type of reaction. Combustion can be rapid or slow: burning is rapid combustion, whereas cellular respiration is slow combustion. A substance that burns is often classified as a fuel, and some common fuels are organic compounds such as hydrocarbons.

A general skeleton equation for the combustion of a hydrocarbon is:

$$C_xH_y + O_2 \rightarrow CO_2 + H_2O$$

Here, the formula C_xH_y suggests a variety of subscripts for the C and H atoms. You could argue that combustion is a double synthesis reaction since oxygen combines with both carbon and hydrogen! Nevertheless, chemists have chosen to use the term "combustion."

We rely on combustion reactions every day when we burn hydrocarbon fuels such as methane, also known as natural gas (CH_4), in our furnaces, propane (C_3H_8) in barbeques and some automobiles, and butane (C_4H_{10}) in lighters. The products of complete combustion reactions of hydrocarbons are always carbon dioxide gas and water vapour. Note the pattern of predictability in the following skeleton equations:

$$CH_4 + O_2 \rightarrow CO_2 + H_2O$$
$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$
$$C_4H_{10} + O_2 \rightarrow CO_2 + H_2O$$

Did You KNOW?

Incomplete Combustion

Incomplete combustion occurs when there is not enough oxygen available to react. As a result, some of the carbon atoms do not form CO_2 but instead form CO (carbon monoxide). Carbon monoxide reacts with the blood's hemoglobin and interferes with its ability to transport necessary oxygen to the cells. The result can be death.

You have just learned that chemists typically classify chemical reactions as one of six types, summarized in Table 1. 9B **Investigation**

Table 1 A Summary of Reaction Types

Reaction type	General form
synthesis (or combination)	A + B → AB
decomposition	AB → A + B
single replacement	AB + C → CB + A
double replacement	AB + CD → CB + AD
acid–base neutralization	H-X + B-OH → BX + HOH
combustion (of hydrocarbons)	$C_xH_y + O_2 \rightarrow CO_2 + H_2O$

9B **Investigation**

Types of Chemical Reactions

To perform this investigation, turn to page 260.

In this investigation, you will examine evidence from chemical reactions that allows you to classify them.

Predicting Products of Chemical Reactions

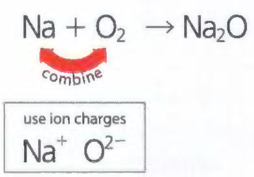
One of the most important activities in science is the ability to make predictions. Doctors must be able to predict the effect of certain medications on their patients. Engineers must be able to predict the effect of storms and earthquakes on certain structures like high-rise buildings and bridges. Similarly, chemists must be able to predict what will happen when certain chemicals are reacted. Will there be a release of useful and desirable new substances or will the products be dangerous and harmful?

Using what you have learned so far—formula writing of elements and compounds, writing chemical equations, balancing chemical equations, and recognizing reaction types—you will be able to predict the products of certain chemical reactions. Following are some examples of reaction predictions that you can make.

Example 1

Suppose you are asked to predict the products of a reaction between sodium and oxygen and write a balanced equation for the reaction. The reactants then are: $Na + O_2 \rightarrow$

Step 1: Predict the reaction type. Upon inspection of the reactants, it appears that two elements are about to combine, so it is a synthesis reaction.



Step 2: Write the skeleton equation for the reaction. Based on the reaction type, predict the product that will form. In this case, Na combines with O_2 as Na_2O (formula written according to ion charges).

skeleton equation: $Na + O_2 \rightarrow Na_2O$

Step 3: Balance the equation: $4\ Na + O_2 \rightarrow 2\ Na_2O$

Example 2
Predict the products if potassium chloride is heated, and write a balanced equation for the reaction. The reactant is KCl.

Step 1: Examine the reactants. Since no other reactants are involved, the reaction type has to be the decomposition of the compound KCl.

Step 2: Breaking up KCl results in the elements K and Cl_2 (a diatomic molecule).

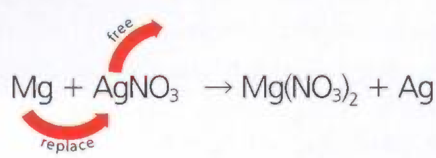
skeleton equation: $KCl \rightarrow K + Cl_2$

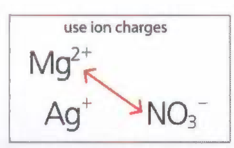
Step 3: Balance the equation: $2\ KCl \rightarrow 2\ K + Cl_2$

LEARNING TIP
Adjust your reading pace. Pause after each step in Examples 2 and 3 and think about what each step has asked you to do. Rephrase each step in your own words (paraphrase).

Example 3
Predict the products if magnesium reacts with silver nitrate, and write a balanced equation for the reaction. The reactants are $Mg + AgNO_3$.

Step 1: Examine the reactants. The reaction type appears to be a single replacement reaction, so replace the metal element in the compound with the free metal element.





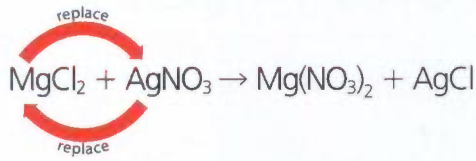
Step 2: Write the skeleton equation: $Mg + AgNO_3 \rightarrow Mg(NO_3)_2 + Ag$

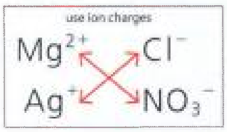
Step 3: Write the balanced equation: $Mg + 2\ AgNO_3 \rightarrow Mg(NO_3)_2 + 2\ Ag$

Note that the order of the products is unimportant. As in math:
$3 + 4 = 4 + 3$; $Mg(NO_3)_2 + 2\ Ag$ is the same as $2\ Ag + Mg(NO_3)_2$

Example 4
Predict the products if magnesium chloride reacts with silver nitrate and write a balanced equation for the reaction. The reactants are $MgCl_2 + AgNO_3$.

Step 1: Examine the reactants. The reaction type appears to be a double replacement reaction, so replace both metal elements with each other.





Step 2: Write the skeleton equation:

$$MgCl_2 + AgNO_3 \rightarrow Mg(NO_3)_2 + AgCl$$

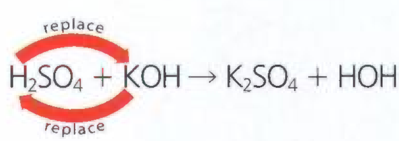
Step 3: Write the balanced equation:

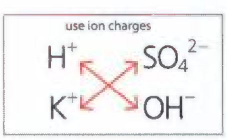
$$MgCl_2 + 2\ AgNO_3 \rightarrow Mg(NO_3)_2 + 2\ AgCl$$

Example 5

Predict the products if sulfuric acid reacts with potassium hydroxide, and write a balanced equation for the reaction. The reactants are $H_2SO_4 + KOH$.

Step 1: Examine the reactants. The reaction type appears to be an acid–base neutralization (double replacement) reaction in which a salt and water (HOH) is formed.





Step 2: Write the skeleton equation: $H_2SO_4 + KOH \rightarrow K_2SO_4 + HOH$

Step 3: Write the balanced equation: $H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2\ HOH$

Example 6

Predict the products of the combustion of methane (CH_4) and write a balanced equation for the reaction. Recall that combustion means to react a carbon–hydrogen (organic) compound with oxygen. Therefore, the reactants are $CH_4 + O_2$.

Step 1: Examine the reactants. This is a hydrocarbon combustion reaction, which always produces CO_2 and H_2O.

Step 2: Write the skeleton equation: $CH_4 + O_2 \rightarrow CO_2 + H_2O$

Step 3: Write the balanced equation: $CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$

9.3 CHECK YOUR Understanding

1. A decomposition reaction can be described by using the following symbols:

   △○ → △ + ○

   Use any symbol shapes (squares, circles, triangles, hearts) to describe what happens in each of the following reaction types:
   (a) synthesis
   (b) single replacement
   (c) double replacement
2. Classify each of the following reactions as synthesis, decomposition, single replacement, double replacement, acid–base neutralization, or combustion. Then, balance each equation.
   (a) $Fe + CuSO_4 \rightarrow Fe_2(SO_4)_3 + Cu$
   (b) $PCl_5 \rightarrow PCl_3 + Cl_2$
   (c) $KCl + O_2 \rightarrow KClO_3$
   (d) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$
   (e) $LiNO_3 \rightarrow LiNO_2 + O_2$
   (f) $HCl + Ca(OH)_2 \rightarrow CaCl_2 + HOH$
   (g) $Ca + N_2 \rightarrow Ca_3N_2$
   (h) $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$
3. Write a balanced chemical equation and state the reaction type for each of the following reactions:
   (a) Nitrogen gas reacts with hydrogen gas forming ammonia (NH_3).
   (b) Carbonic acid breaks down to form carbon dioxide gas and water.
   (c) Aluminum foil reacts with copper(II) chloride solution to produce aluminum chloride solution and copper metal.
   (d) Aluminum chloride reacts with lead(II) nitrate to form lead(II) chloride and aluminum nitrate.
   (e) Water undergoes electrolysis to produce hydrogen gas and oxygen gas.
4. Use the general equations for the following reactions to predict the most likely products. Then, classify each equation according to reaction type: synthesis, decomposition, single replacement, double replacement, acid–base neutralization, or combustion.
   (a) $A + B \rightarrow$
   (b) $AB + XY \rightarrow$
   (c) $H\text{-}X + A\text{-}OH \rightarrow$
   (d) $AB + X \rightarrow$
   (e) $AB \rightarrow$
   (f) $C_xH_y + O_2 \rightarrow$
5. Examine the reactants below to determine the reaction type. Then, predict the products by writing a skeleton equation. Balance each skeleton equation.
   (a) $K + O_2 \rightarrow$
   (b) $Pb(NO_3)_2 + Na_2SO_4 \rightarrow$
   (c) $C_5H_{12} + O_2 \rightarrow$
   (d) $H_2SO_4 + NaOH \rightarrow$
   (e) $Ca + Cl_2 \rightarrow$
   (f) $Li_2S \rightarrow$
   (g) $HgO \rightarrow$
   (h) $HCl + Ca(OH)_2 \rightarrow$
   (i) $C_3H_7OH + O_2 \rightarrow$
   (j) $Al + S \rightarrow$
   (k) $Al + CuSO_4 \rightarrow$
6. For the following, write the chemical formulas for the reactants and predict the most likely reaction type. Then, write balanced equations for each.
   (a) Magnesium chloride is heated.
   (b) Silver nitrate is reacted with sodium sulfide.
   (c) Methanol (CH_3OH) is burned in the presence of oxygen.
   (d) Hydrofluoric acid is reacted completely with strontium hydroxide.

CHEMICAL REACTIONS THAT SAVE LIVES

Thousands of lives are saved through the cushioning action of airbags during high-speed automobile accidents. What makes the airbag deploy faster than a blink of an eye?

The idea of landing against a protective air cushion in a crash is not a new one. In fact, the first inflatable crash-landing device was created for airplanes as early as the 1940s. Later, airbags were used in cushioning crash landings of spacecraft like the Soviet Luna 9 and Luna 13, NASA's Mars Pathfinder, and the two Mars Exploration Rover Mission landers (Figure 1). However, the most familiar airbags are the ones found in our cars.

So how do airbags work? They do not utilize a compressed gas, but rather the products of chemical reactions. The undeployed airbag is folded within a car's steering wheel, for example. At the front of a car is an airbag sensor that functions as an accelerometer (a device that measures acceleration). When the car decelerates very quickly, it triggers the inflator connected to the airbag. This produces an electric spark to initiate the chemical process that will deploy the airbag.

Figure 1 The Mars Pathfinder's airbags were tested under simulated Martian conditions.

At the core of airbag chemistry is a stable solid compound called sodium azide (NaN_3). Once ignited, the resulting explosion rapidly releases a large volume of non-toxic nitrogen gas (N_2) through the decomposition of the sodium azide pellets:

$$2NaN_3 \rightarrow 2Na + 3N_2$$

The other product of this first reaction is sodium metal (Na), an unstable and potentially explosive substance. The sodium metal then reacts with a second compound, potassium nitrate. This second reaction generates additional nitrogen for the airbag while stabilizing the sodium:

$$10Na + 2KNO_3 \rightarrow K_2O + 5Na_2O + N_2$$

Finally, the products potassium oxide and sodium oxide from the second reaction react with a compound, silicon dioxide, forming a harmless silicate glass:

$$K_2O + Na_2O + SiO_2 \rightarrow \text{alkaline silicate}$$

A handful of sodium azide will yield about 70 L of nitrogen gas, which is enough to inflate a normal airbag at a velocity up to 322 km/h in about a third of a second. Once an airbag deploys, deflation begins immediately as the gas escapes through vents to soften the impact of the forward-moving occupant. In addition, dust-like particles of cornstarch or talcum powder, used to lubricate the airbag during deployment, are also released during the process (Figure 2).

Issues around safety have surrounded the use of airbags. Landfills full of vehicles with unused airbags, hence, unused sodium azide (a very toxic compound), pose an environmental hazard. In addition, they could potentially cause explosions, and thus put workers' lives in danger. Consequently, many authorities now require airbags to be physically deployed before disposal, so that the sodium azide is converted to a harmless product.

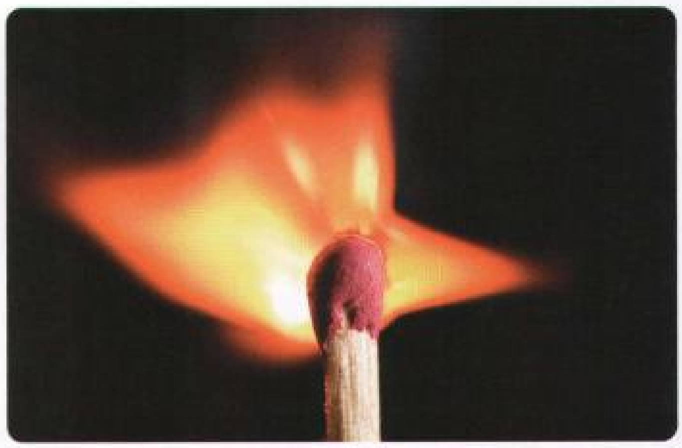
Figure 2 Deflation of an airbag begins immediately after deployment to protect the person from injury caused by the sudden inflation.

9.4 Rates of Chemical Reactions

We regularly observe that chemical reactions take place at different rates. That is, some reactions such as the corrosion of copper or bronze occur very slowly, whereas a matchstick burns quite rapidly (Figure 1). What factors affect the rates of reactions and what can you do if you want to change a reaction's rate? Imagine a campfire that is burning very slowly and you would like to speed it up. Experience and common sense might lead you to add more wood, or chop it into smaller pieces, or carefully blow on the fire. In this section, we will investigate methods we can use to increase or decrease the rates of chemical reactions and examine why these methods work. GO

To learn more about the need to control reaction rates, go to **www.science.nelson.com** GO

(a)



(b)

Figure 1 (a) The green coating on these bronze statues is a result of a slow chemical reaction. (b) The burning of a match is an example of a rapid chemical reaction.

STUDY TIP

Try this handy trick for remembering the formula for reaction rate by creating an example. On one side of a study card, write Finding Reaction Rate. On the other side, write out a problem and solve it.

Generally speaking, the **reaction rate** of a chemical reaction is the amount of a reactant consumed per unit time or the amount of a product formed per unit time. For example, if a gas such as hydrogen is being produced during the single replacement reaction of magnesium metal and nitric acid, the amount of hydrogen gas produced per minute could be used to describe the reaction's rate. This reaction is described as:

$$Mg(s) + 2\ HNO_3(aq) \rightarrow Mg(NO_3)_2(aq) + H_2(g)$$

Note that additional symbols (phase designations) are used in the above equation. Chemists use these symbols to describe the phases of matter when this information is relevant.

Using basic math concepts, the rate for the above reaction can be calculated using different formulas such as:

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{reaction time}}$$

or $$\text{reaction rate} = \frac{\text{volume of } H_2(g) \text{ produced}}{\text{reaction time}}$$

In any case, a reaction's rate can be calculated from any measurable change in any one chemical involved in the reaction.

For example, if 2.0 g of magnesium react with hydrochloric acid in 40.0 s, we can use the first formula to calculate the reaction rate.

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{reaction time}} = \frac{2.0\text{ g of Mg}}{40.0\text{ s}} = \frac{0.050\text{ g of Mg}}{\text{s}}$$

Whether using mass or volume, all reaction rates are expressed as change per unit of time.

TRY THIS: Calculating Reaction Rates

Skills Focus: measuring, interpreting data

In this activity, you will examine some data and use it to calculate rate in a variety of ways.

1. Consider the reaction between zinc metal and hydrochloric acid in which hydrogen gas is vigorously produced. Zinc metal is obviously a solid, and hydrochloric acid exists in an aqueous (water) solution. The balanced single replacement reaction is:

$$Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

2. In separate experiments, results were recorded for this reaction (Table 1).

A. Calculate the reaction rate for Trial 1 and show the units as $\frac{\text{g of Zn}}{\text{min}}$.

To calculate reaction rate, use the following formula:

$$\text{reaction rate} = \frac{\text{measurable change in any chemical}}{\text{change in time}}$$

Table 1

	Temperature (°C)	Before reaction	After reaction	Time
Trial 1	20.0 °C	4.8 g of Zn(s)	2.8 g of Zn(s)	1.2 min
Trial 2	25.2 °C	5.2 g of Zn(s)	3.2 g of Zn(s)	0.82 min
Trial 3	22.4 °C	0 mL of $H_2(g)$	20.4 mL of $H_2(g)$	25.6 s
Trial 4	24.8 °C	0 mL of $H_2(g)$	35.6 mL of $H_2(g)$	23.5 s

B. Calculate the individual reaction rates for Trials 2, 3, and 4, and include appropriate units for each.

C. Analyze the results and suggest a reason for the differences in rates between Trials 1 and 2, and the differences in rates between Trials 3 and 4.

What Makes Reactions Go? The Collision Theory

In previous chemistry courses, you learned about an idea that helps us explain the behaviour of matter in its different states. The **kinetic molecular theory** suggests that matter is made up of tiny particles in constant, random motion. Solid particles are very closely packed together and are barely moving. Liquid particles have very small spaces between them and are moving relatively slowly. Gas particles, on the other hand, are really spread out and move very fast.

An extension of this theory helps us understand why certain factors can affect reaction rates. In its simplest form, the **collision theory** states that in order for moving particles to react, they must first collide! However, there is more to it than that. In the air, a huge number of molecules of nitrogen and oxygen are colliding without reacting. But place these same gases in a combustion chamber, such as is found in an automobile engine, and a rapid reaction occurs.

LEARNING TIP

Diagrams play an important part in reader comprehension. As you examine Figure 2, look at each part carefully. Ask yourself, "How are they different visually? What does each part show?"

Not just any collision will result in a reaction. The collision must be an *effective collision*; that is, it must have a certain minimum amount of energy or it will be a dud. Effective collisions are strong enough to overcome repulsive forces between reactants and break the necessary reactant bonds to bring about the reaction. To illustrate this point, consider the reaction of hydrogen gas and iodine gas (Figure 2):

$$H_2(g) + I_2(g) \rightarrow 2\ HI(g)$$

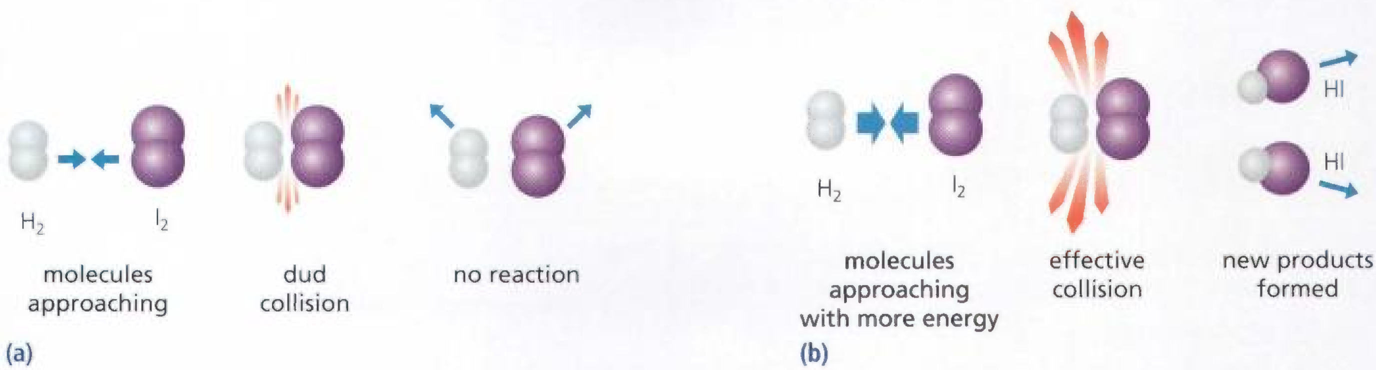


Figure 2 (a) Some collisions of H_2 and I_2 molecules are duds, and (b) some collisions are effective.

In any group (number) of collisions, only a certain fraction will be effective. For example, if 15 % of collisions are effective, then 100 total collisions would yield 15 that are effective, and 200 total collisions would yield 30 effective collisions. A chemical reaction's rate is determined by the number of effective collisions that occur in a given amount of time (the frequency of effective collisions).

Changing the frequency of effective collisions changes the reaction rate.

Based on the collision theory, there are four factors that can be changed in chemical reactions to increase or decrease their rates. The four factors are concentration of the reactants, surface area of the reactants, temperature, and the addition of catalysts. 9C **Investigation**

9C ***Investigation***

Factors that Affect Reaction Rates

To perform this investigation, turn to page 262.

In this investigation, you will examine two factors that affect reaction rate.

Concentration of Reactants

Concentration describes the number of particles of a substance that are present in a certain volume. Concentration can be varied in solutions and gases but not in solids. For example, a highly concentrated solution of sugar water will have many sugar molecules and taste very sweet, however, a solution that is not as highly concentrated will taste less sweet because it has fewer sugar molecules in it. Such a solution could be called dilute since it has a low concentration.

When the concentration of one of the reactants is increased, reaction rate also increases. Once again, consider the reaction of hydrochloric acid and zinc metal:

$$2\ HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$$

If the concentration of HCl is increased, the result is an increase in not only the frequency of total collisions, but more importantly, the frequency of effective collisions (Figure 3).

Figure 3 The beaker on the right has a higher concentration of hydrochloric acid reacting with zinc metal, which results in a higher rate of reaction than the beaker on the left.

Increasing the concentration of a reactant increases reaction rate by increasing the frequency of effective collisions.

To observe the relationship between rate of concentration and rate of reaction, view the animation at www.science.nelson.com

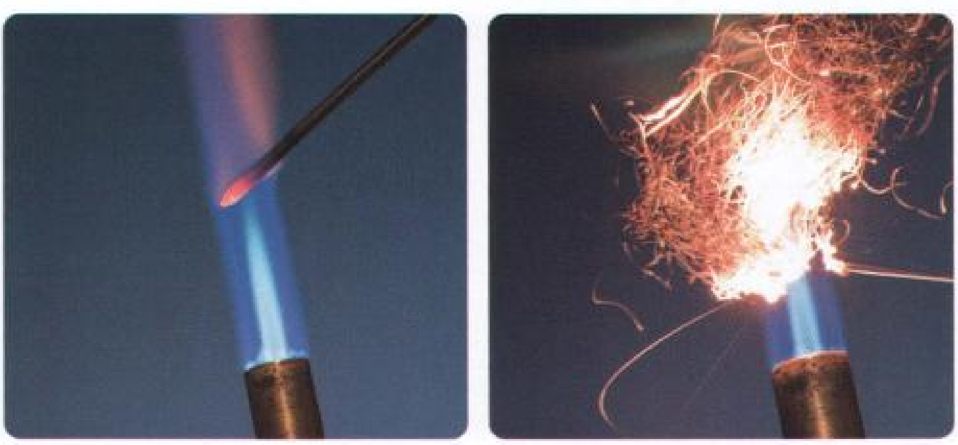
Surface Area of Reactants

We have all experienced the effect of surface area on the rate of chemical reactions. Surface area is the amount of area on a solid that is open and exposed. This exposure affects the number of collisions that can happen with other substances. The surface area of a piece of firewood is increased when the wood is chopped into kindling. The increased surface area allows for more collisions with oxygen molecules, and, as a result, the chopped wood will burn faster.

Another example is the reaction of iron with oxygen:

$$4\ Fe(s) + 3\ O_2(g) \rightarrow 2\ Fe_2O_3(s)$$

Even at high temperatures, iron reacts slowly with oxygen. However, if the surface area of the iron is increased, we observe a dramatic increase in reaction rate (Figure 4).



(a) (b)

Figure 4 (a) An iron nail reacts slowly with oxygen in air. (b) But when the surface area of iron is increased, as in steel (iron) wool, the rate dramatically increases.

In fact, many slow reacting solids become potential explosives when their surface areas have been increased (Figure 5).

(a) (b)

Figure 5 Increasing the surface area of combustible materials like coal and grain can create the opportunities for reactions that are so fast that they are explosive. (a) A pile of coal, and (b) a coal dust explosion.

Increasing the surface area of a solid reactant increases the amount of exposed solid, and this increases the reaction rate by increasing the frequency of effective collisions.

Temperature

Most chemical reactions have higher rates at higher temperatures. Examples of this are all around us. Hamburgers cook faster on a hotter grill. Meat spoils more rapidly if left outside on a summer's day compared to a winter's day. In fact, we typically use *low* temperatures to prevent food from spoiling.

Increasing temperature appears to have the most dramatic effect in increasing reaction rates. In many cases, a mere 10 °C increase in temperature can cause a reaction rate to double. How can we explain this using collision theory? The kinetic molecular theory reminds us that when the temperature of a substance increases, the added heat energy causes the particles to move faster, and as a result, with more energy. The resulting collisions between reacting molecules are therefore both more numerous and more energetic. An analogy here might be useful.

Clap your hands together slowly and softly for 30 s. This represents low temperature collisions. Now clap your hands much faster and harder for 30 s. This represents high-temperature collisions. At the "higher temperature," the "collisions" are obviously greater in number and also more of these have greater energy (louder). The end result is that a higher frequency of total collisions occur, and a larger fraction of these collisions are effective.

Increasing the temperature of reactants significantly increases reaction rate by increasing the frequency of effective collisions in two ways: (1) increasing the frequency of all collisions, and (2) increasing the energy of all collisions.

Catalysts

A **catalyst** is a substance that, when added to a reaction, increases the reaction rate without being consumed. In other words, a catalyst somehow assists the reactants in their collisions but remains unchanged at the end of the reaction. Catalytic behaviour can be very complex and is not always clearly understood. Catalysts are used in the industrial manufacture of chemicals where the rate of production is important. Some industries in British Columbia that use catalysts include oil refining to produce gasoline and ammonia manufacturing to produce fertilizers. Oil refineries use catalysts to "crack" (decompose) long hydrocarbon molecules into shorter ones to boost gasoline production. Fertilizer manufacturers rely on catalysts to increase the rate of synthesis of ammonia, NH_3, which is then combined with other chemicals to make a variety of fertilizers. GO

To learn how catalysts are used to reduce emissions in car exhausts, go to www.science.nelson.com GO

The nature of a catalyst is similar to the effect of climbing over a mountain and discovering a shortcut tunnel halfway up (Figure 6).

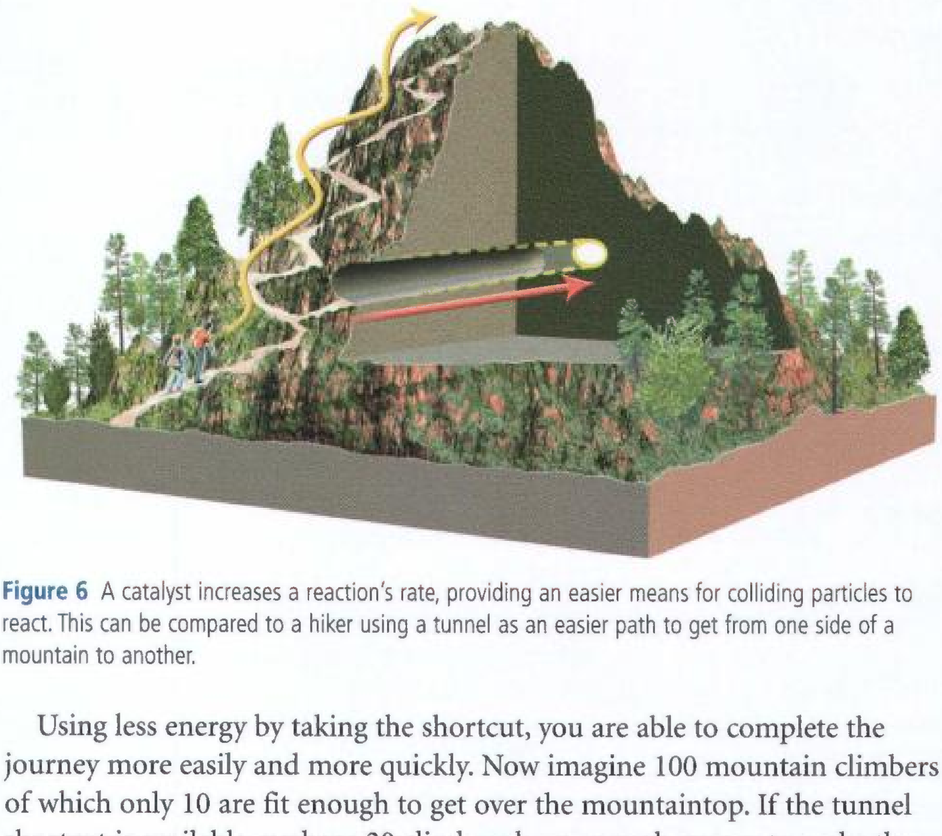


Figure 6 A catalyst increases a reaction's rate, providing an easier means for colliding particles to react. This can be compared to a hiker using a tunnel as an easier path to get from one side of a mountain to another.

Using less energy by taking the shortcut, you are able to complete the journey more easily and more quickly. Now imagine 100 mountain climbers of which only 10 are fit enough to get over the mountaintop. If the tunnel shortcut is available, perhaps 20 climbers have enough energy to make the trip. A higher percentage of climbers are now successful. A catalyst has a similar effect on reacting molecules by lowering the energy requirement for an effective collision. As a result, a higher *percentage* of the collisions are effective.

Adding a catalyst increases reaction rate by increasing the percentage of effective collisions.

9.4 CHECK YOUR Understanding

1. What is meant by the term "rate of a chemical reaction"?
2. What variable always appears in any reaction rate calculation?
3. A sample of magnesium metal reacts with hydrochloric acid solution to produce magnesium chloride solution and hydrogen gas.
   (a) Write a balanced chemical equation for this reaction and include phase designations.
   (b) If 0.80 g of magnesium react in 40.0 s, calculate the reaction rate.
   (c) If 20.0 mL of hydrogen gas are produced in 60.0 s, calculate the reaction rate.
4. The electrolysis (decomposition) of water produces hydrogen gas at the rate of 30.0 mL/min.
   (a) Write a balanced chemical equation for this reaction and include phase designations.
   (b) What volume of hydrogen gas can be produced in 4.5 min?
   (c) Based on your balanced equation, predict the rate of oxygen gas produced.
5. Name four factors that can affect the rate of a chemical reaction. How does the rate of a chemical reaction change in response to a change in each factor?
6. What is the fundamental premise of the collision theory?
7. What is necessary for a collision between reacting molecules to be effective?
8. Explain, using the collision theory, how each of the following factors affects reaction rate:
   (a) concentration of reactants
   (b) surface area of a solid reactant
   (c) temperature of the reactants
   (d) adding a catalyst
9. Describe the two features of a catalyst.
10. The following describes the reaction between a copper penny and nitric acid in an open beaker:
    $$Cu\ (s) + 4\ HNO_3\ (aq) \rightarrow Cu(NO_3)_2\ (aq) + 2\ H_2O\ (l) + 2\ NO_2\ (g)$$
    The mass of the beaker and contents was monitored until the reaction ended. The results are recorded in Table 2.

Table 2

Mass of beaker and contents (g)	Time (s)
224.6 g	0.0
215.8 g	118.6 s

    (a) What chemical is represented by the change in mass? Explain why it *cannot* be the mass change of copper.
    (b) Calculate the rate of reaction and express your answer with appropriate units.
    (c) Would this reaction be considered a closed system? Why or why not?
11. The following equation shows the reaction between marble chips (calcium carbonate) and hydrochloric acid:
    $$CaCO_3\ (s) + 2\ HCl\ (aq) \rightarrow CaCl_2\ (aq) + H_2O\ (l) + 2\ CO_2\ (g)$$
    The volume of the gas produced was monitored over time. The results are in Table 3 below. Calculate the rate of reaction and express your answer with appropriate units.

Table 3

Volume of CO_2 gas (mL)	Time (s)
0	0.0
24.8 mL	50.5 s

12. How could you experimentally determine if a substance acted as a catalyst in a chemical reaction?
13. Normally, as a reaction proceeds, its rate decreases. Explain using the collision theory.

Tech
CONNECT

FIREWORKS: FROM ALCHEMY TO PYROTECHNICS

"Ooooh" went the crowd, followed by "aaaaaah." Nothing seems to awe us more than watching sparkling lights explode to heart-stopping bangs. This is where art meets science in the craft of pyrotechnics, otherwise known as fireworks. Have you ever wondered how fireworks create these magnificent displays?

The history of fireworks dates back over a thousand years ago to India and China. From there, the work of these early alchemists spread throughout the Western world. What started out as a way to ward off evil spirits is now used to celebrate special occasions from New Year's to the Olympics. Vancouver hosts one of the largest musical fireworks competitions in the world—the *Celebration of Lights*—where countries compete to dazzle and delight the crowds as they cast their magical spells (Figure 1).

Figure 1 A fireworks display

Firework displays are a marvellous mixture of the arts, science, technology, and more importantly, a vivid imagination! A great pyrotechnician is one who understands the magic she or he can create by applying the principles of physics and chemistry. The physics involve velocities, vectors, the force of explosions, and other variables.

An understanding of chemistry is also essential from controlling reaction rates to balancing equations of synthesis, decomposition, and replacement reactions—in particular, combustion reactions. Once firework shells are ignited, a chemical reaction takes place where the bonds of the reactants break and rearrange to form new chemical compounds in an explosive reaction. Here, the combination of chemical powders are transformed into hot gases that cause shells to burst open, and the energy is converted into light, sound, and thermal energy, creating a spectacular show.

How are colours produced from fireworks? Firework shells are stuffed with potassium chlorate, along with other compounds. Lithium and strontium salts produce red; calcium salts produce orange; sodium compounds produce yellow; and barium compounds produce green. Aluminum compounds will generate brilliant white sparks. Like any artist, pyrotechnicians realize that they can produce any hue on their palette through the careful combination of compounds (Figure 2).

One of the greatest innovations in pyrotechnics involves advances in launch technology. Computers are now used to coordinate the launching of shells a tenth of a second apart, and as such, synchronize the firing of thousands of fireworks. Since explosions can happen faster and with greater accuracy, this revolutionized the design and coordination of firework shows, especially when harmonized to music.

Figure 2 Technicians prepare firework shells

9A Investigation

Mass and Chemical Reactions

What happens to the overall mass when chemicals change in chemical reactions? In all chemical reactions, the reacting chemicals (reactants) produce new substances (products). Chemists in industrial situations must keep track of the amounts of these reactants and products much like someone who is following a recipe in the kitchen.

INQUIRY SKILLS

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

Question

How is mass affected by chemical change?

Prediction

Predict what will happen to the mass of the chemicals in a container if a chemical change occurs, but none of the chemicals are allowed to escape.

Experimental Design

In this investigation, you will examine a chemical reaction in a container that has been sealed so that no matter will be able to enter or leave. The mass of the container and contents will be measured before and after the reaction.

Materials

- safety goggles
- 500 mL clear plastic bottle with lid
- mass balance (scales)
- weighing paper
- sodium bicarbonate (baking soda)
- 1 test tube (16 mm × 150 mm)
- test tube rack
- 5 % acetic acid solution (vinegar)

Do not use more than the recommended amount of sodium bicarbonate.
Any time gases are produced, there is a potential hazard to your eyes and lungs. When loosening the lid, keep the bottle pointed away from all involved.

Procedure

1. Put on your safety goggles.
2. Obtain from your teacher a plastic bottle with its lid and a test tube that will fit inside the bottle. Temporarily assemble this empty equipment as shown in Figure 1 to make sure that everything fits.

Figure 1 Assembled apparatus, ready for weighing before the reaction

3. On weighing paper, weigh approximately 1.0 g of sodium bicarbonate powder. The mass does not have to be exact, but it should be close. As a precaution, show the weighed amount to your teacher before proceeding.
4. Transfer the sodium bicarbonate powder to your bottle.
5. Place the test tube in the test tube rack and half fill with acetic acid.

6. Tilt the bottle at an angle and carefully lower the test tube into the bottle without spilling the acetic acid (Figure 2).

Figure 2

7. Place the lid on the bottle and give it a twist to ensure a tight seal. The acetic acid and the sodium bicarbonate powder are the reactants.
8. Record the appearance of the reactants in your copy of Table 1.

Table 1

	Observations	Total mass (g)
sealed apparatus + reactants		
sealed apparatus + products		
unsealed apparatus + contents		

9. Weigh your assembled apparatus containing the reactants and record this mass in Table 1.
10. Once again, make sure that the bottle is tightly sealed. Start the reaction by slowly and gently turning the bottle upside down to allow the reactants to mix and form products. Do this a few times to ensure good mixing. Observe what happens and record your observations.
11. Weigh your apparatus containing the products and record this mass.
12. Remove the sealed apparatus from the scales and *carefully* loosen the lid. As you unseal the apparatus, observe and record what happens.
13. With the lid on loosely, reweigh your apparatus and record this mass.
14. Empty the bottle into a sink to remove the test tube and all chemicals. Clean up all materials with lots of water.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

(a) What evidence indicates that a chemical reaction took place between the sodium bicarbonate and the acetic acid?

(b) Calculate the mass change between reactants and products in the sealed bottle. Use a positive value for a gain in mass, a negative value for a loss, and "0" if no change in mass occurs.

(c) Calculate the mass change between reactants and contents in the unsealed bottle. Again, use a positive or negative value or "0."

(d) Generally speaking, what change in mass results from a chemical reaction? How do you explain your results from (c)?

Evaluation

(e) Compare your results with those of another group. What might account for any differences in mass changes?

Synthesis

(f) With reference to atoms, suggest an explanation for the change (or no change) in mass in the sealed bottle.

(g) Again, with reference to atoms, suggest an explanation for the change (or no change) in mass in the unsealed bottle.

9B Investigation

Types of Chemical Reactions

As you have learned, there are certain patterns that exist in the ways that chemicals react to form products. Chemists have found six common types of chemical reactions: synthesis, decomposition, single replacement, double replacement, acid–base neutralization, and combustion.

Question

What evidence is presented by chemical reactions that will allow you to classify them?

Experimental Design

In this investigation, you will examine some chemical reaction types simply by studying reactions that can be used to analyze the products that appear when you exhale (breathe out).

Materials

- safety goggles
- 250 mL beaker
- water
- bromothymol blue indicator solution
- 2 drinking straws
- limewater

The chemicals used in this investigation are relatively harmless, but any time gases are produced, there is a potential hazard to your eyes.

Bromothymol blue can stain clothing. Use care when using this substance.

Procedure

1. Put on your safety goggles.
2. Obtain a 250 mL beaker and fill it with 100 mL of water.
3. Add four drops of bromothymol blue indicator to the water and record your results in your copy of Table 1.

INQUIRY SKILLS

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

Table 1

Sample tested	Test	Result
water in beaker	bromothymol blue	
water and bromothymol blue in beaker after blowing air into it	exhaled air	
limewater	bromothymol blue	
limewater after blowing air into it	exhaled air	

4. Use a drinking straw to gently blow bubbles in the water (Figure 1). Take care not to spill water out of the beaker or to suck in the water. Continue to blow gently, taking breaks, for about 3 min.

Figure 1

5. Observe what happens to the bromothymol blue and record your results. Rinse out the beaker and save it for later.

6. Class test a small sample of the limewater with bromothymol blue and record the results.
7. Obtain 100 mL of limewater in your beaker.
8. Use a new straw to once again gently blow bubbles into the limewater. Again, blow gently for about 3 min, then record your results.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

(a) The products of respiration are described by the following skeleton equation:

$$C_6H_{12}O_6(s) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$$

The products leave the body when you exhale. Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to its reaction type.

(b) Carbon dioxide will react with water according to the following skeleton equation:

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$$

Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to its reaction type.

(c) What evidence do you have that H_2CO_3 was produced when you blew into the water?

(d) Limewater is a solution of lime or calcium hydroxide, $Ca(OH)_2(aq)$. Calcium metal reacts with water according to the following skeleton equation:

$$Ca(s) + HOH(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$$

Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to its reaction type.

(e) What evidence do you have that limewater contains $Ca(OH)_2(aq)$?

(f) As you have learned, the CO_2 from your breath forms an H_2CO_3 solution when added to water. If limewater is mixed with the H_2CO_3 solution, a reaction occurs according to the following skeleton equation:

$$Ca(OH)_2(aq) + H_2CO_3(aq) \rightarrow CaCO_3(s) + H_2O(l)$$

Write a balanced chemical equation including phase designations for this reaction. Classify this reaction according to *two* possible reaction types.

(g) What evidence do you have that one of the products of the reaction in (f) is $CaCO_3(s)$?

Evaluation

(h) What kinds of evidence allowed you to identify the reaction types for each reaction?

Synthesis

(i) Create a chart to summarize the reactions studied in this investigation. Include balanced equations and reaction types in the chart.

9C Investigation

Factors that Affect Reaction Rates

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

All chemical reactions can occur at different rates depending on various conditions or factors. Some reactions will take place very slowly, while others are extremely fast. Recall that the rate of a reaction is expressed as the change in the amount of one of the chemicals involved (reactants or products) in a measured period of time.

Questions

What effect will increasing the concentration of a reactant have on the reaction rate? What effect will increasing surface area of a reactant have on reaction rate?

Prediction

Predict the effect of increasing reactant concentration on reaction rate. Predict the effect of increasing surface area on reaction rate.

Experimental Design

This investigation has two parts. In Part I, you will react magnesium metal with increasing concentrations of hydrochloric acid. In Part II, you will react an Alka-Seltzer tablet in water and observe what happens when its surface area is increased.

Materials

- safety goggles
- 3.0 cm length of magnesium ribbon
- metric ruler
- scissors
- 3 test tubes (18 mm × 150 mm)
- water-soluble marker
- test tube rack
- 3 hydrochloric acid (HCl) solutions (different concentrations)
- timer (in seconds)
- 2 250 mL beakers
- water
- 2 Alka-Seltzer tablets
- weighing paper
- mass balance (scales)
- teaspoon

Acids can cause chemical burns. Always wear eye protection when working with acids. If any solution splashes on skin or in eyes, flush immediately with plenty of cold water and inform your teacher.

Procedure

Part I: Effect of Concentration on Reaction Rate

1. Put on your safety goggles. Work with a partner.
2. Obtain a 3.0 cm length of magnesium ribbon from your teacher, and carefully measure and cut it into 3 identical 1.0 cm strips. Your teacher will provide you with the mass of a 1.0 cm strip. Record this mass 3 times in your copy of Table 1.

Table 1

Test tube	Concentration of HCl	Mass of magnesium ribbon (g)	Reaction time (s)	Reaction rate (g Mg/s)
A	50.0 % HCl			
B	25.0 % HCl			
C	12.5 % HCl			

3. Obtain three test tubes and use a water-soluble marker to label them A, B, and C near the top. Next, place a mark about one third up one of the tubes and mark the other tubes to match. Place these test tubes in a test tube rack.

4. In test tube A, add 50.0 % HCl solution to the mark. Similarly, in test tube B, add 25.0 % HCl, and in test tube C, add 12.5 % HCl.
5. Add one magnesium ribbon strip to test tube A and have your partner start timing as soon as the magnesium ribbon begins to react. Stop timing when the reaction ends. Record the reaction time in seconds in Table 1.
6. Repeat Step 5 for test tubes B and C.

Part II: Effect of Surface Area on Reaction Rate

Alka-Seltzer is often used by people for relief of upset stomachs. It contains a mixture of solid citric acid and baking soda (sodium bicarbonate), along with some aspirin.

7. Obtain two 250 mL beakers and label them A and B. Fill each one with 100 mL of water.
8. Using a piece of weighing paper, determine the mass of a whole Alka-Seltzer tablet and record just the mass of the Alka-Seltzer in your copy of Table 2.

Table 2

Beaker	Mass of Alka-Seltzer (g)	Reaction time (s)	Reaction rate (g Alka-Seltzer/s)
A (whole tablet)			
B (crushed tablet)			

9. Place a second Alka-Seltzer tablet on a piece of weighing paper and crush it with the back of a spoon. Press the spoon into the tablet carefully but firmly, to crush it into powder. Try not to spill any powder. Weigh this second crushed tablet on its weighing paper and record the mass of the Alka-Seltzer.
10. Add the whole (uncrushed) tablet to beaker A and time the reaction from start to finish. Record the time (in seconds) for the reaction to be completed.
11. Add the crushed tablet to beaker B and time the reaction from start to finish. Record the time taken for the reaction to be completed.

Conclusion

Complete the following items to answer the questions posed at the beginning of the investigation.

Analysis

Part I: Effect of Concentration on Reaction Rate

(a) Complete the last column in Table 1 by calculating the reaction rate for each test tube.

For the reactions in Part I use

$$\text{reaction rate} = \frac{\text{mass of Mg reacted}}{\text{reaction time}} = \text{g Mg/s}$$

(b) Analyze your rate calculations in Table 1. What effect does increasing reactant concentration have on the rate of a reaction?

Part II: Effect of Surface Area on Reaction Rate

(c) Complete the last column in Table 2 by calculating the reaction rate for each beaker.

For the reactions in Part II use

reaction rate =

$$\frac{\text{mass of Alka-Seltzer reacted}}{\text{reaction time}} = \text{g Alka-Seltzer/s}$$

(d) Analyze your rate calculations in Table 2. What effect does increasing surface area have on the rate of a reaction?

Evaluation

(e) Were your predictions supported by the experimental evidence? Explain.

Synthesis

(f) Using similar techniques as in this investigation, how could you maximize the rate of the reaction of magnesium metal and hydrochloric acid?

(g) Describe an experimental design that you might use to determine the effect of temperature on reaction rate.

Review

Investigating Chemical Reactions

Key Ideas

Chemical reactions are processes that involve chemical change and obey the Law of Conservation of Mass.

- Chemical reactions are descriptions of chemical change.
- Mass is conserved in a chemical reaction (Law of Conservation of Mass). This is true since the number of atoms of each element is conserved.

Chemical equations are used to describe chemical reactions.

- A chemical equation is balanced when the atoms of the reactant element(s) are the same as the atoms of the product element(s).
- Coefficients in a chemical equation describe the number of molecules of each compound or element, whereas subscripts describe the number of atoms of each element. Example: $2H_2O$ represents 2 molecules of H_2O, each of which contains 2 atoms of H and 1 atom of O.
- Balancing an equation involves changing the coefficients throughout the equation so that atoms are conserved.

$2H_2 \quad + \quad O_2 \quad \longrightarrow \quad 2H_2O$

There are six common types of chemical reactions.

- Patterns exist in chemical reactions that allow most to be classified as one of six types:

Reaction type	General form
1. synthesis (or combination)	A + B → AB
2. decomposition	AB → A + B
3. single replacement	AB + C → CB + A
4. double replacement	AB + CD → CB + AD
5. acid–base neutralization	H-X + B-OH → BX + HOH
6. combustion (of hydrocarbons)	$C_xH_y + O_2 \rightarrow CO_2 + H_2O$

Vocabulary

chemical reaction, p. 232

chemical equation, p. 233

reactants, p. 233

products, p. 233

Law of Conservation of Mass, p. 233

skeleton equation, p. 235

balanced equation, p. 236

synthesis reaction, p. 239

decomposition reaction, p. 241

single replacement reaction, p. 242

double replacement reaction, p. 242

acid–base neutralization reaction, p. 243

combustion reaction, p. 244

reaction rate, p. 250

kinetic molecule theory, p. 251

collision theory, p. 251

catalyst, p. 255

Chemists are able to predict the products of common reactions.

- Given the reactants for a reaction, you can often predict the products that will form, as well as relative amounts of reactants and products.
- Predicting the reactants or products of a reaction requires an understanding of reaction types, chemical formula writing, and balancing equations.

The rate of a chemical reaction is affected by various factors.

- Some chemical reactions are slow, some are fast.
- Reaction rate is a measure of the rate of change of any one of the chemicals in the reaction.
- Reaction rate is explained by the collision theory, which states that molecules must collide in order to react.
- Collisions must also be *effective*, which means that they must have sufficient energy for a reaction to occur.
- Reaction rate can be increased by increasing the concentration of reactants, increasing the surface area of reactants, increasing the temperature, or by adding a catalyst.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Chemists use chemical equations to describe which of the following?

I	chemical change
II	chemical reactions
III	physical change

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

K 2. Which of the following ideas apply to all chemical reactions?

I	mass is conserved
II	atoms are conserved
III	molecules are conserved

A. I only
B. I and II only
C. II and III only
D. I, II, and III

K 3. Which of the following is true for all balanced chemical equations?
A. The sum of the reactant subscripts equals the sum of the product subscripts.
B. The sum of the reactant coefficients equals the sum of the product coefficients.
C. The number of molecules of reactants equals the number of molecules of products.
D. The number of atoms of reactant elements equals the number of atoms of product elements.

K 4. Given the general equation:
$PQ + X \rightarrow XQ + P$,
which reaction type does this equation represent?
A. synthesis
B. combustion
C. single replacement
D. double replacement

K 5. Given the general equation:
$PQ \rightarrow P + Q$,
which reaction type does this equation represent?
A. synthesis
B. neutralization
C. decomposition
D. double replacement

6. What is the difference between a reactant and a product?

7. Generally speaking, how does a catalyst increase the rate of a chemical reaction?

Use What You've Learned

8. Explain how the Law of Conservation of Mass applies to chemical reactions.

U 9. How many atoms of each element are in the expression $4\ Ca(NO_3)_2$?
A. 1 atom Ca, 1 atom N, 6 atoms O
B. 4 atoms Ca, 8 atoms N, 24 atoms O
C. 4 atoms Ca, 2 atoms N, 6 atoms O
D. 2 atoms Ca, 2 atoms N, 24 atoms O

10. State the number of atoms of each element in each of the following:
(a) H_2SO_4
(b) $5\ H_2O$
(c) $3\ NH_4Cl$
(d) $2\ Al_2(SO_4)_3$
(e) $2\ (NH_4)_2HPO_4$

11. (a) Why is the following equation not balanced?
$C + H_2 \rightarrow CH_4$
(b) What is wrong with the following attempt to balance the above equation?
$C + H_4 \rightarrow CH_4$

U 12. Which of the following sets of ordered coefficients will correctly balance the skeleton equation below?
$Fe_3O_4 + H_2 \rightarrow Fe + H_2O$
A. 1, 4, 3, 4
B. 1, 2, 3, 4
C. 1, 1, 3, 4
D. 2, 4, 6, 4

13. Balance the following skeleton equations. Then, classify them according to reaction type.
(a) $Ca + HCl \rightarrow CaCl_2 + H_2$
(b) $Al + O_2 \rightarrow Al_2O_3$
(c) $Ca(NO_3)_2 + KOH \rightarrow KNO_3 + Ca(OH)_2$
(d) $Ba + H_3PO_4 \rightarrow Ba_3(PO_4)_2 + H_2$
(e) $Mg + HBr \rightarrow MgBr_2 + H_2$
(f) $BaCO_3 \rightarrow BaO + CO_2$
(g) $C_5H_{12} + O_2 \rightarrow CO_2 + H_2O$
(h) $H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$

14. Predict the products of the following reactions, then balance the equations. Classify the equations according to reaction type.
(a) $Ca + O_2 \rightarrow$
(b) $Mg + HBr \rightarrow$
(c) $Ba(NO_3)_2 + NaOH \rightarrow$
(d) $Al + CuSO_4 \rightarrow$
(e) $H_2SO_4 + Sr(OH)_2 \rightarrow$
(f) $NaCl \rightarrow$
(g) $C_8H_{18} + O_2 \rightarrow$
(h) $Fe + H_3PO_4 \rightarrow$

Think Critically

15. Consider the reaction between hydrochloric acid and marble chips ($CaCO_3$) in an open beaker:

$$HCl\ (aq) + CaCO_3\ (s) \rightarrow CaCl_2\ (aq) + H_2O\ (l) + CO_2\ (g)$$

(a) Balance the above equation and suggest two reaction types that would explain the products produced. Explain your choice of reaction types.
(b) State three methods (other than a catalyst) you would use to increase the rate of this reaction.
(c) Use the collision theory to explain how your methods would increase the rate.
(d) A 4.05 g sample of $CaCO_3$ was placed in a beaker containing hydrochloric acid (HCl). After 40 s, the sample was removed from the acid and weighed. Its new mass was 2.55 g. Calculate the rate of the reaction in g $CaCO_3$/s.

HMP 16. Refer to the reaction in question 15. What change, other than the mass of $CaCO_3$, could you measure to determine the rate of this reaction?
A. mass of CO_2 produced
B. mass of H_2O produced
C. mass of HCl consumed
D. volume of H_2O produced

17. Provide several reasons why chemists rely more on formula equations than word equations when describing chemical reactions.

18. *The Law of Conservation of Mass is based on common sense.* Support this statement.

19. Why aren't molecules balanced in a balanced chemical equation?

20. Many people think that oxygen gas is explosive. Explain the error of their reasoning.

21. Draw a model of a cube (10 mm × 10 mm × 10 mm) of sodium metal and show how the surface area increases when the soft sodium metal is cut in half. Provide surface area calculations to support your drawings.

22. Give one example of a slow chemical reaction that should be kept slow and one that should have its reaction rate increased. Explain why.

23. Why do fuels such as gasoline not start to burn as soon as they come in contact with oxygen? What would be the consequences if they did?

Reflect on Your Learning

24. A skeleton equation is often compared to an incomplete recipe for baking. Do you think this is a good analogy? Explain why or why not.

25. How would your world be different if all chemical reactions were synthesis reactions?

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

UNIT B

Review

Elements, Compounds, and Reactions

Unit Summary

In this unit, you have extended your understanding of matter. You have learned that matter can take different forms, and that the structure of matter helps explain how elements can combine to form compounds. Compounds can be placed in various groups depending on different classification schemes. Elements and compounds can also undergo chemical change at different rates, and chemical change can be described by chemical equations.

Create a mind map (concept map) that relates these ideas. Use sketches, diagrams, and text to show how the ideas interconnect. Check the chapter reviews to make sure that you have included all of the major concepts in your map.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. Which subatomic particles are responsible for chemical bonding?
   A. protons
   B. electrons
   C. neutrons
   D. nucleons

K 2. In a Bohr diagram, how many electrons fill each shell?
   A. 2, 2, 2
   B. 2, 2, 8
   C. 2, 8, 8
   D. 8, 8, 8

K 3. Which of the following describes the atomic number of an element?
   A. It is equal to the mass of the nucleus.
   B. It is the number of protons in the nucleus.
   C. It is the number of electrons in the nucleus.
   D. It is the number of neutrons in the nucleus.

K 4. What appears on the Periodic Table, in order, when reading it from left to right?
   A. metals, metalloids, non-metals
   B. metalloids, metals, non-metals
   C. alkali metals, noble gases, halogens
   D. alkali metals, halogens, alkaline earths

K 5. What determines the number of electrons transferred when an atom becomes an ion?
   A. the ion charge balance
   B. the number of protons in the nucleus
   C. the number of valence electrons in the first shell
   D. the number of valence electrons of the nearest noble gas

K 6. What is the smallest particle of a covalently bonded compound?
   A. ion
   B. atom
   C. electron
   D. molecule

K 7. How is a Lewis diagram different from a Bohr diagram of an atom?
A. All electrons are shown.
B. Only valence electrons are shown.
C. Electrons are drawn in pairs when possible.
D. The nucleus contains important information.

K 8. When you balance a chemical equation, what are you balancing or making equal between the reactants and products?
A. the number of subscripts
B. the number of coefficients
C. the number of atoms of each element
D. the number of molecules of each compound

K 9. Which reaction type does this general equation represent?

$$PQ + XY \rightarrow XQ + PY$$

A. synthesis
B. combustion
C. single replacement
D. double replacement

10. Write the chemical symbols for the following particles:
(a) fluorine atom
(b) oxygen ion
(c) oxygen molecule
(d) potassium ion

11. Draw Bohr diagrams for atoms of the following elements:
(a) lithium
(b) aluminum
(c) carbon
(d) neon

12. Write the chemical formulas for the seven elements that exist as diatomic molecules.

13. What does the crisscross method for writing chemical formulas actually do?

14. How are ionic compounds different from molecular compounds in their composition?

15. Ionic compounds can be classified as acids, bases, or salts. Match the following:

(a) acids	(i) release OH^- ions in solution
(b) bases	(ii) release ions other than H^+ or OH^- in solution
(c) salts	(iii) release H^+ ions in solution

K 16. Which of the following applies only to acids and not to bases or salts?
A. They turn litmus red.
B. They turn phenolphthalein pink.
C. Their solutions conduct electricity.
D. They react with metals to form oxygen gas.

K 17. What is the Arrhenius definition of a base?
A. It tastes sour.
B. It turns phenolphthalein pink.
C. It releases H+ ions in solution.
D. It releases OH- ions in solution.

18. Make a sketch of the pH scale and label the acidic, basic, and neutral sections.

19. State a modern definition of an organic compound.

20. Write a statement that describes the Law of Conservation of Mass for chemical reactions.

21. In order to react, what must colliding reactant molecules have and how can this be achieved?

K 22. Which of the following sets of ordered coefficients will correctly balance the skeleton equation below?

$HBrO_3 + HBr \rightarrow H_2O + Br_2$

A. 1, 5, 3, 3
B. 1, 2, 1, 1
C. 2, 4, 6, 3
D. 2, 4, 3, 2

K 23. Which of the following factors does not increase the rates of all chemical reactions?
A. adding oxygen
B. adding a catalyst
C. increasing the concentration of reactants
D. increasing the surface area of a solid reactant

Use What You've Learned

U 24. Which of the following is a chemical property?
A. Water boils at 100 °C.
B. Acids have a sour taste.
C. Sugar dissolves in water.
D. Copper turns green when exposed to water and air.

25. An atom has 6 protons and 8 neutrons.
(a) Identify the element.
(b) Explain how that number of neutrons is possible.
(c) Draw a Bohr diagram of this atom.

26. Write the name of the elements described below.
(a) 7 protons and 8 neutrons
(b) 92 protons and mass number 240
(c) atomic number 84 and 126 neutrons

27. Explain why an ion cannot exist on its own.

28. Match each of the following elements with its nearest noble gas (from the choices given) and the number of valence electrons it would have when bonding is complete. You may use matching items more than once.

(a) Al	(i) He	(A) 2 valence electrons
(b) H	(ii) Ne	(B) 8 valence electrons
(c) Li	(iii) Ar	
(d) Mg		
(e) S		

29. Draw Bohr diagrams for the ions of magnesium and phosphorous.

U 30. Which of the following does *not* represent a molecule?
A. CO_2
B. NH_3
C. H_2O
D. NaCl

U 31. Why do molecular compounds have relatively low melting points?
A. Attractive forces between molecules are relatively weak.
B. Attractive forces between atoms are relatively weak.
C. Attractive forces between molecules are relatively strong.
D. Attractive forces between atoms are relatively strong.

32. First, classify each of the following compounds as ionic or molecular. Then, write the chemical formula for each compound.
(a) beryllium nitrate
(b) ammonium carbonate
(c) lead(II) fluoride
(d) aluminum selenide
(e) carbon tetrachloride

33. First, classify each of the following compounds as ionic or molecular. Then, write the chemical name for each compound.
(a) RbCl
(b) $(NH_4)_3P$
(c) N_3Br_6
(d) Ti_2O_3
(e) $Sr_3(PO_4)_2$

34. First, classify each of the following compounds as ionic or molecular. Then, write the chemical formula or name depending on what is given.
(a) KCl
(b) calcium nitrate
(c) N_2O_4
(d) lead(IV) sulfide
(e) $Ba(ClO_4)_2$

35. Describe the results you would expect from electrical conductivity tests on ionic and molecular solutions.

36. Write either the acid name or chemical formula, depending on what is given.
   (a) HCl
   (b) perchloric acid
   (c) H_2SO_4
   (d) chlorous acid
   (e) HNO_2

37. Draw Lewis diagrams for ions of the following elements:
   (a) Cl
   (b) O
   (c) Ca

38. Draw Lewis diagrams of atoms for the following elements:
   (a) O
   (b) N
   (c) C
   (d) B

39. Draw Lewis diagrams of the following molecules:
   (a) BCl_3
   (b) CF_4
   (c) H_2O

40. Given that strontium chloride is a white crystalline solid with a high melting point, predict two properties of the compound barium chloride. Refer to the position of relevant elements in the Periodic Table to explain your predictions.

41. Balance the following skeleton equations. Then, classify the equations according to reaction type.
   (a) $Ba + HCl \rightarrow BaCl_2 + H_2$
   (b) $Al + S \rightarrow Al_2S_3$
   (c) $Sr(NO_3)_2 + NaOH \rightarrow NaNO_3 + Sr(OH)_2$
   (d) $Mg + H_3PO_4 \rightarrow Mg_3(PO_4)_2 + H_2$
   (e) $CaCO_3 \rightarrow CaO + CO_2$
   (f) $C_{10}H_{22} + O_2 \rightarrow CO_2 + H_2O$

42. Predict the products of the following reactions, then balance the equations. Classify the equations according to reaction type.
   (a) $Ba + O_2 \rightarrow$
   (b) $C_5H_{12} + O_2 \rightarrow$
   (c) $Ba(NO_3)_2 + KOH \rightarrow$
   (d) $Al + ZnSO_4 \rightarrow$
   (e) $H_2SO_4 + Sr(OH)_2 \rightarrow$
   (f) $NaCl \rightarrow$

Think Critically

43. Write out and number your own set of rules on how to place electrons in a Bohr diagram. Provide an example diagram with your rules.

HMP 44. When hydrogen chloride gas and ammonium hydroxide gas react, a white solid forms. What is the white solid?
   A. HCl
   B. H_2O
   C. NH_4Cl
   D. NH_4OH

45. When acids and bases are transported to industrial plants, there is a potential hazard for spills along the route. When spills occur, groups trained to deal with hazardous materials spring into action. Use the Internet to learn how these groups deal with these kinds of spills.

www.science.nelson.com GO

HMP 46. Which of the following will increase the percentage of collisions that are effective, thereby increasing reaction rate?

I	adding a catalyst
II	increasing temperature
III	increasing concentration of reactants

   A. I only
   B. I and II only
   C. I and III only
   D. I, II, and III

Reflect on Your Learning

47. Write a short essay on "Chemical Reactions in My World" to share what you have learned. Give examples of reactions that are important to you and classify them according to reaction type. Where possible, provide chemical equations with your examples. In many cases, Internet research will be helpful.

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Visit the Quiz Centre at

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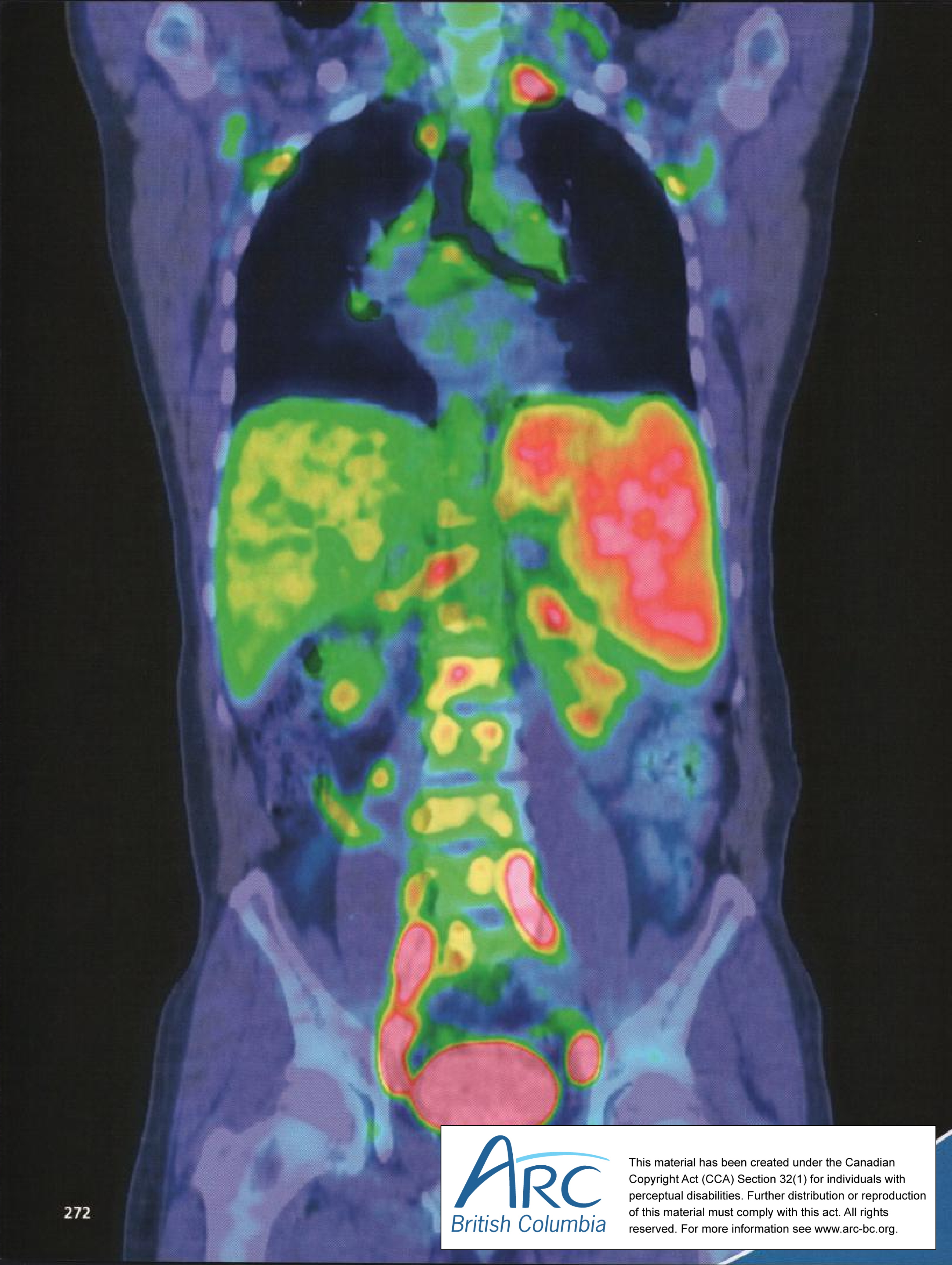


UNIT

C

RADIOACTIVITY

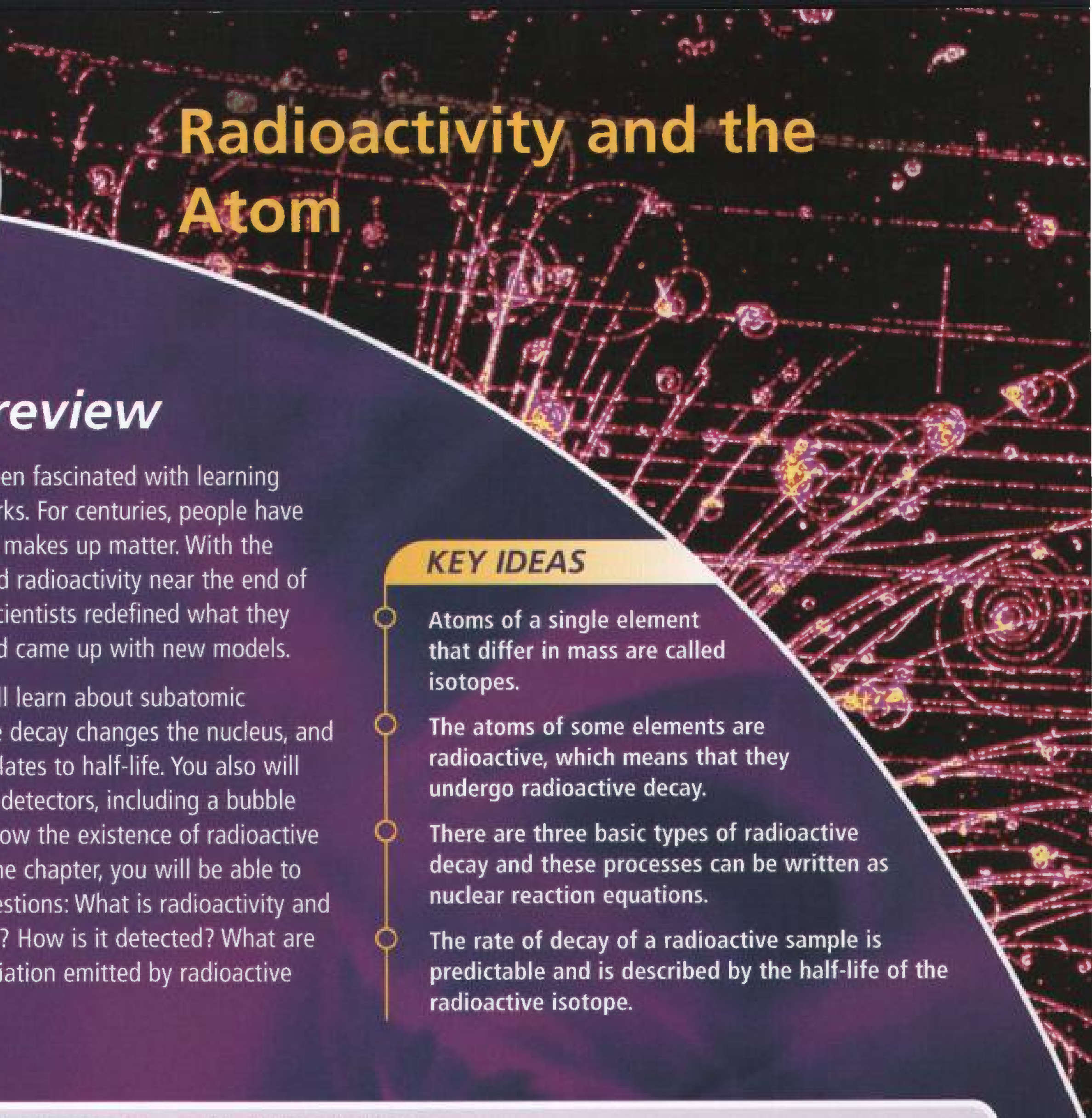
Unit Preview

When you think of radiation, do you think only of its destructive power? Radiation can destroy, but it also can help. The aftermaths of the nuclear bombs dropped on Hiroshima and Nagasaki, and the nuclear accident at Chernobyl are examples of the destructive nature of radiation. However, there are many people who have benefited from radiation. Radiation is used to give detailed images of the body, through radiographs (X-rays), computed tomography (CT), and positron emission tomography (PET) scans. This image shows a PET scan of a human body superimposed on a CT scan. PET scans are just one tool that use radioactive isotopes injected into the body to diagnose cancer. Radioactive isotopes and beams of high-energy X-rays are also used to kill cancer cells.

In this unit, we will look at the history of radioactivity, investigate the different types of radiation, and look at how nuclear reactions produce energy.

CHAPTER 10

Radioactivity and the Atom



Chapter Preview

Scientists have always been fascinated with learning about how the world works. For centuries, people have tried to understand what makes up matter. With the discovery of the X-ray and radioactivity near the end of the nineteenth century, scientists redefined what they knew about the atom and came up with new models.

In this chapter, you will learn about subatomic particles, how radioactive decay changes the nucleus, and how radioactive decay relates to half-life. You also will learn about how particle detectors, including a bubble chamber, were able to show the existence of radioactive particles. By the end of the chapter, you will be able to answer the following questions: What is radioactivity and where does it come from? How is it detected? What are the different types of radiation emitted by radioactive atoms?

KEY IDEAS

- Atoms of a single element that differ in mass are called isotopes.
- The atoms of some elements are radioactive, which means that they undergo radioactive decay.
- There are three basic types of radioactive decay and these processes can be written as nuclear reaction equations.
- The rate of decay of a radioactive sample is predictable and is described by the half-life of the radioactive isotope.

TRY THIS: *Radioactivity All Around Us*

Skills Focus: observing, recording, communicating

In this activity, you will observe some sources of nuclear radiation in your environment. Since nuclear radiation is invisible, your teacher will use a Geiger counter to detect radiation given off from some samples.

Materials: Geiger counter, glass crystal, pottery glaze, smoke detector, wristwatch

1. Copy Table 1 into your notebook and list all your samples.

Table 1

Sample	Counts per minute
background	
glass crystal	

2. Turn on the Geiger counter without any of the samples placed near it and see how many counts there are in one minute. Record this number as the background radiation.
3. As your teacher places the samples in front of the Geiger counter, record the counts per minute for each sample.

A. Which sample had the highest number of counts per minute? Which had the lowest?

B. Would it be more accurate to record the number of counts per hour instead of counts per minute? Why or why not?

10.1 Radioactivity and its History

Around the late 1800s, scientists determined that there were different types of radiation in addition to visible light. Electric currents produced some types of radiation while others seemed to be produced directly by matter. Each type of radiation had different properties. Some radiation had mass whereas others did not. Electrically, different types of radiation were positive, negative, or neutral.

The history of radioactivity involved the work of many people over a relatively short amount of time (Figure 1). Some discoveries were serendipitous, or accidental, while others required dedication and determination. For the purposes of this chapter, the history of radioactivity begins with the detection of cathode rays.

STUDY TIP

Study cards are an effective way to study for multiple-choice exams. On the front of the card, write the name of the scientist. On the back of the card, write how the scientist's discovery contributed to the understanding of radioactivity and the atom.

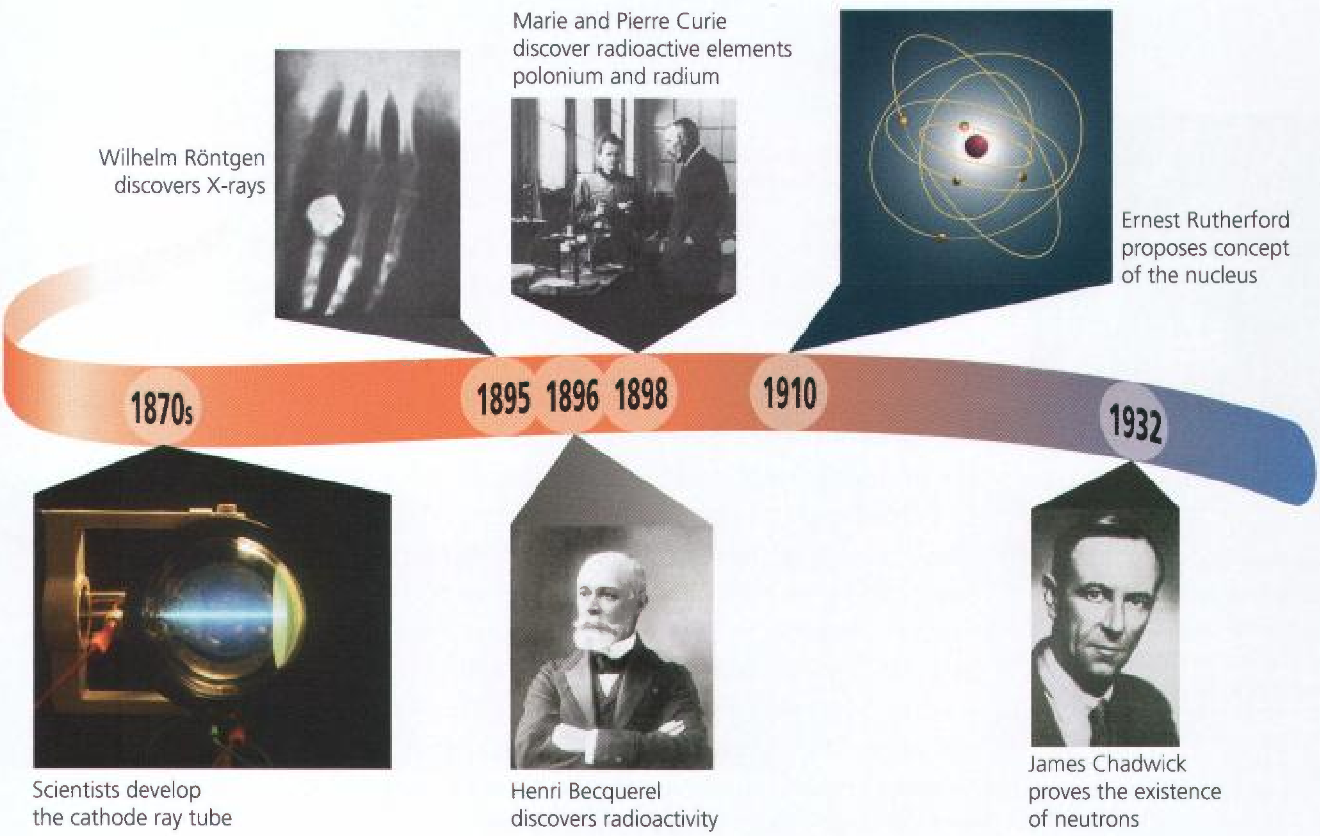


Figure 1 A brief history timeline of radioactivity and nuclear physics

Cathode Rays

In Grade 9 you learned about conductors and insulators when you studied electricity. During the middle to late 1800s, scientists believed that all gases were very poor conductors of electricity and, therefore, were insulators. However, scientists found that when most of the air inside a glass tube was removed by a vacuum pump, and a high voltage was applied to two electrodes inside the tube, a small electric current would pass through the remaining gas.

The current produces a beam, or ray, from the negative electrode (called the cathode) that goes to the positive electrode (called the anode) and causes the fluorescent screen at the end of the glass vacuum tube to glow. Since the beam comes from the cathode, the beam was said to be made of cathode rays, and the tube was called a cathode ray tube, or CRT (Figure 2).

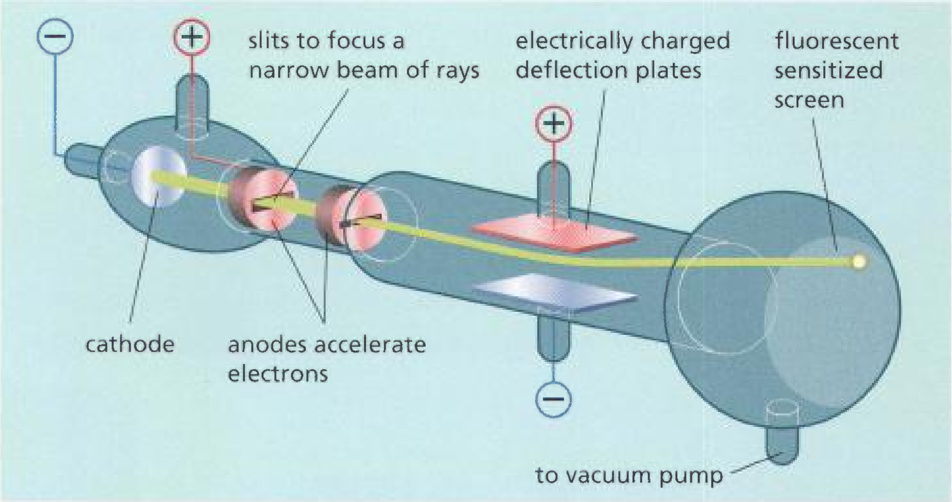


Figure 2 A cathode ray tube is used to show that electricity can be conducted in a gas under low pressure in a vacuum tube.

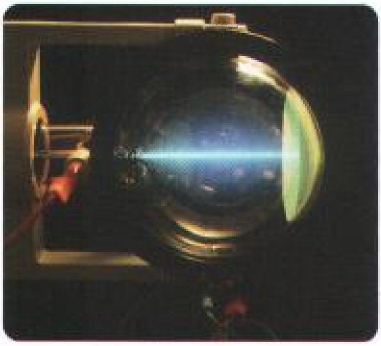


Figure 3 A Crookes tube

To learn more about how charged plates and a magnetic field can affect cathode rays view the animation at **www.science.nelson.com**

A Crookes tube (Figure 3) is a type of cathode ray tube. It is made from a glass cylinder with a partial vacuum inside. The tube contains a metal plate bent at right angles. It has a slit at one end and the visible surface is coated with a fluorescent material that glows when struck by the cathode rays. There are two electric terminals inside the tube that are connected to high voltage. The glow of fluorescence down the middle of the metal plate indicates that the cathode is emitting a beam of particles that is striking the plate.

Cathode rays can be deflected by electric charges and by magnets. The direction of the deflection of the cathode rays showed that they had a negative charge. When scientists placed a small paddle wheel inside the cathode ray tube, the cathode rays turned the wheel, which showed that the cathode rays behaved like particles. In 1897, Sir J.J. Thomson identified the negatively charged particles of the cathode ray as electrons.

Cathode ray tubes were used both in science and society. Prior to the development of liquid crystal screens and plasma screens, a cathode ray tube was the basic component of a television.

X-Rays

In 1895, Wilhelm Röntgen was experimenting with a cathode ray tube to investigate the secondary emissions caused by cathode rays. He covered a cathode ray tube with thick black paper, allowed cathode rays to strike a metal plate, and observed the emissions outside the tube (Figure 4). He discovered that the rays outside the tube caused fluorescent minerals to glow and also exposed photographic film. Since the rays that he discovered had no name, he called them X-rays. ("X" is used to refer to an unknown.)

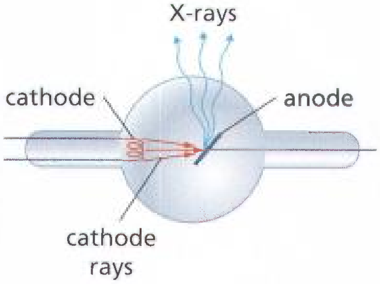


Figure 4 A simple X-ray tube

Röntgen found that X-rays were able to penetrate some materials, such as paper and skin, but not others, such as bone and metal. Röntgen took the first X-ray image (Figure 5). He received the first Nobel Prize in Physics in 1901 for his discovery.

Further investigations revealed that X-rays were actually a high-energy component of the electromagnetic spectrum. You may remember that the electromagnetic spectrum goes from low-energy radio waves to high-energy gamma rays (Figure 6).

In a cathode tube, the electrons are accelerated from the negative cathode to the positive anode and given a high speed. In fact, X-rays are produced by converting the kinetic energy of the high-speed electrons directly into electromagnetic radiation when they strike the metal plate.

Although you may think that X-rays are only used to take pictures of broken bones or cavities in teeth, X-rays also play an important role in the diagnosis and treatment of various diseases. Doctors use CAT (computerized axial tomography) scans, or multiple X-rays, to film slices of the body so that they can detect abnormal tissue or cancerous growths. Mammograms are used to detect breast cancer. High-energy X-rays are used to kill or shrink cancer cells.

Figure 5 Röntgen took the first X-ray of his wife's hand. Since X-rays cannot penetrate bones or metal, you can see the bones of her fingers as well as her wedding ring.

The Discovery of Radioactivity

At the same time Röntgen was experimenting with cathode rays, Henri Becquerel was experimenting with fluorescent minerals, some containing uranium. He thought the minerals might produce X-rays when exposed to sunlight. He put samples of the minerals on photographic film. When he developed the film, it showed an image of the shape of the sample.

Since Becquerel thought that the Sun was giving the minerals energy, his experiments were delayed by cloudy days, and he stored the samples and film in a drawer. One cloudy day, after storing the uranium sample on unexposed film, he decided to develop the film anyway, expecting to see nothing. To his surprise, the film showed a strong image of the shape of the mineral.

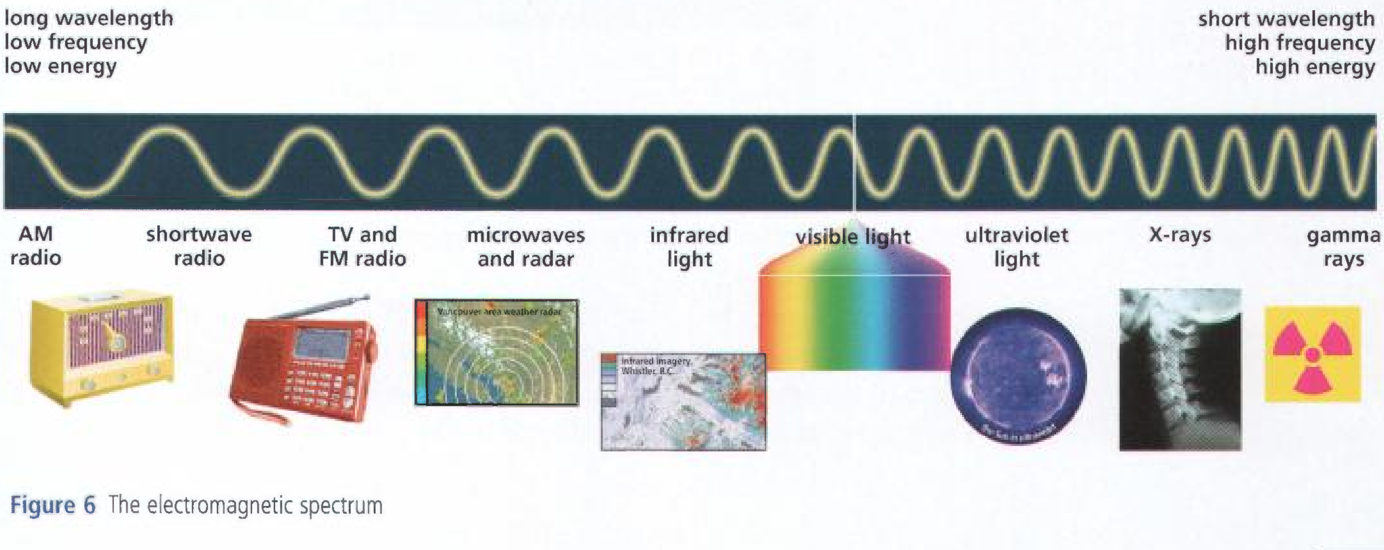


Figure 6 The electromagnetic spectrum

He concluded that the mineral did not need the Sun's energy. Since further study of the emissions produced by the uranium showed that they were deflected by electric charges and magnets and, therefore, had an electric charge, the emissions were not X-rays. The emissions became known, for a time, as Becquerel rays.

After Becquerel's discovery, Marie Curie and her husband Pierre Curie (Figure 7) began to analyze uranium to see what caused it to produce Becquerel rays. They determined that it was the uranium itself that was the source of the emissions. Marie Curie also investigated other elements to see if they emitted Becquerel rays. She found that other elements, such as thorium, also produced similar emissions. The Curies determined that the strength of the emissions produced by a compound depended only on the amount of uranium or thorium in the compound. During their study of uranium (pitchblende), Marie and Pierre Curie discovered two entirely new elements, radium and polonium.

Did You KNOW?

Facts about Marie

Marie Curie was born Maria Sklodowska in Warsaw, Poland in 1867. When she was 24 years old, she moved to Paris to study physics. She met her future husband, Pierre, at the university and they teamed up to conduct research into radioactive substances. She was so intrigued by radioactive isotopes that not only did she keep a sample of radium on her bedside table (because she liked the glow), but she also carried test tubes of radioactive isotopes in her pocket. She died in 1934 from leukemia caused from prolonged exposure to radiation.

Figure 7 In 1903, Marie and Pierre Curie shared the Nobel Prize in Physics with Henri Becquerel for their research on radiation. In 1911, Marie was awarded the Nobel Prize in Chemistry, the first person to ever win two Nobel Prizes in different fields.

Other scientists joined the investigation to learn about Becquerel rays. They found that physical factors, such as pressure and temperature, and chemical changes had no effect on the amount of radiation emitted from the nucleus of an atom. Scientists concluded that the radiation came from the core of the atom. Marie Curie coined the term **radioactivity** for the spontaneous emission of radiation from the nucleus of an atom.

10.1

CHECK YOUR Understanding

1. As the frequency of an electromagnetic radiation increases, what happens to the wavelength?
2. X-rays and visible light are both part of the electromagnetic spectrum. Identify whether the following descriptions apply to X-rays or to visible light:
   (a) the longest wavelength
   (b) the highest frequency
   (c) the lowest energy
3. Are gases insulators or conductors of electricity? Explain your answer.
4. What type of electromagnetic radiation is emitted by the nucleus of an atom?
5. Figure 8 shows a Crookes tube with a cathode ray inside. There are metal plates above and below the tube. One plate has a positive electric charge and the other has a negative electric charge. Copy the diagram into your notebook. The green line on the screen inside the tube shows the cathode ray. Label the direction of the cathode ray on your diagram. Indicate on your diagram which plate is positive and which is negative. Explain how you know the charges of the plates.

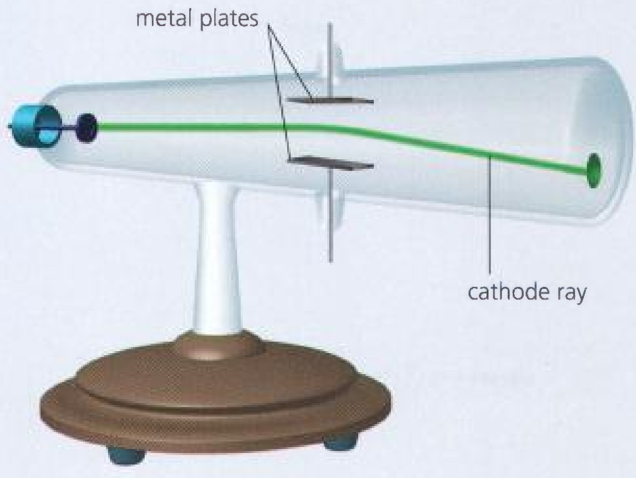


Figure 8

6. When cathode rays were first discovered, scientists thought they were radiation in the form of waves. Describe an experiment that showed that cathode rays behaved like particles.
7. It is recommended that students be at least 3 m away from an operating Crookes tube. Why should students do this?
8. When a high-speed electron strikes a metal plate inside a vacuum tube, an X-ray is produced.
   (a) What happens to the electron? Does the electron cease to exist?
   (b) The X-ray has energy. Where did the energy come from?
9. List the similarities and differences between visible light and X-rays.
10. Describe how X-rays are used to create images of broken bones (Figure 9).

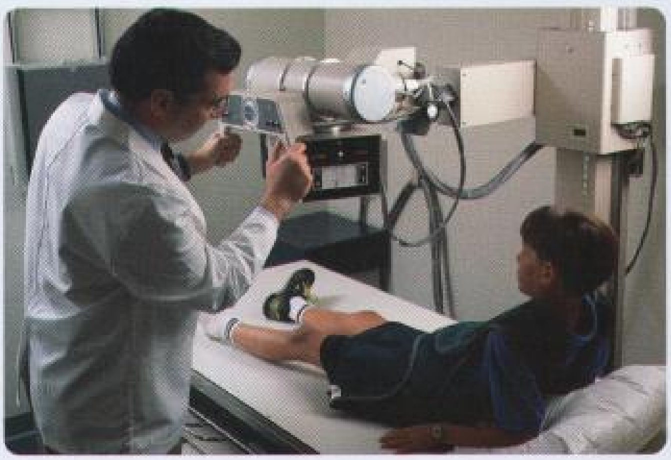


Figure 9

11. What two elements were discovered by Marie and Pierre Curie?
12. Write your own definition of the word "radioactivity."
13. List three physical factors that have no effect on the amount of radiation emitted by a radioactive source.

10.2 Radioactivity and the Nucleus

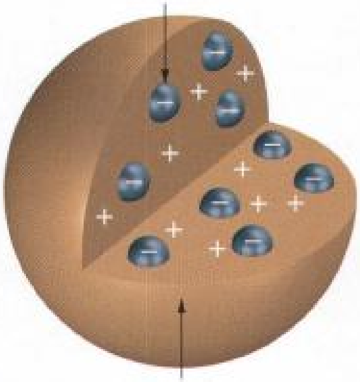


Figure 1 Thomson's model of the atom, called the "raisin bun model," was that an atom consisted of matter that had a positive charge (the bun part) with negatively charged particles (the raisins) inside.

The development of an accurate model of the atom was an ongoing process that occurred over thousands of years and involved many different people. The different atomic models are briefly described in Chapter 6.

An understanding of radioactivity led scientists to discover more about the internal structure of atoms. Thomson's discovery of the electron identified the first internal structure of the atom (Figure 1).

The Rutherford Experiment

New Zealand physicist Ernest Rutherford and his colleagues at the University of Manchester used the newly discovered radioactivity as a means to explore the atom. They directed a stream of positively charged particles at a thin sheet of gold foil. According to the Thomson model of the atom, the positively charged particles would simply pass through the gold atoms or would be deflected by small amounts. Rutherford found that, although most of the particles went straight through the foil, some particles were deflected and some were even bounced straight back from the gold foil (Figure 2). The result was as unexpected as shooting a cannon ball at a piece of paper and having the cannon ball bounce back!

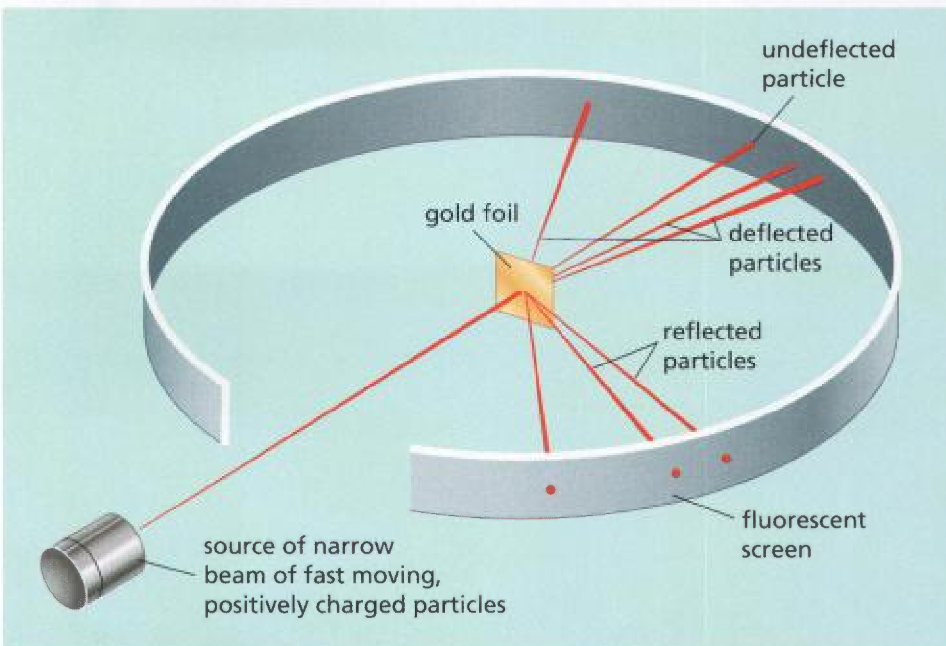


Figure 2 Rutherford's gold foil experiment used alpha particles, a type of radiation, to show that most of the atom is empty space.

To explore an interactive version of the Rutherford experiment and to test your knowledge, go to **www.science.nelson.com**

Rutherford concluded from the gold foil experiment that most of an atom is empty space, and that all of the positive charge and almost all of the mass of the atom is concentrated at the centre. This part of the atom came to be called the **nucleus**.

Once the nucleus (with its positive charge) and the electrons (with their negative charge) were known, Rutherford developed a model of the atom that resembled the solar system and became known as the planetary model (Figure 3). In the planetary model, the nucleus is the Sun, and the electrons are the planets orbiting the Sun. The electric force between the positive nucleus and the negative electrons holds the electrons in their orbits, just as the force of gravity holds the planets in their orbits about the Sun.

The planetary model of the atom suffered from some problems. Electrons in an orbit are accelerated, and accelerated charges always emit energy in the form of light. However, electrons orbiting the nucleus do not continuously give off energy. Niels Bohr proposed a solution: electrons exist in specific orbits. Each orbit can accommodate a specific number of electrons. For further information on Bohr's theory, refer to Section 6.2.

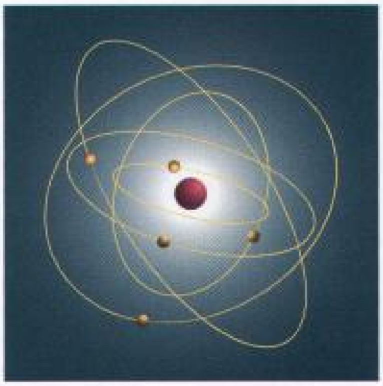


Figure 3 Rutherford's planetary model of the atom

Protons, Neutrons, and Isotopes

Although Rutherford discovered the nucleus almost one hundred years ago, it was not well understood. In 1918, through experiments, Rutherford became convinced that the hydrogen nucleus was an elementary particle, and named it the **proton**. The proton had a charge equal, but opposite, to the electron and a mass about 1800 times greater than the electron. GO

In 1932, British physicist James Chadwick discovered that atomic nuclei contained neutral particles that he called **neutrons**. The neutron has no electric charge and is similar in mass to a proton. Since it is neutral, it was difficult to detect. However, unlike protons and electrons, when the neutron is outside a nucleus, it is not stable.

To review the particles that make up an atom, go to **www.science.nelson.com** GO

Based on the development of the atomic theory over the years, there are several things that we know: everything is made of atoms; an atom is the smallest piece of an element; the Periodic Table lists all of the elements; and each element has a different number of protons. The atomic number is the number of protons in the nucleus. The mass of the atom comes from the protons and neutrons in the nucleus since the electrons have very little mass. The mass number of an atom is the sum of the number of protons and the number of neutrons. Figure 4 shows the standard notation for carbon.

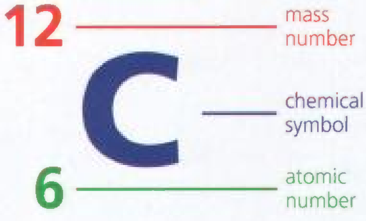


Figure 4 The atomic number of carbon means that it has six protons. The mass number means that the sum of protons and neutrons is 12. Therefore, we know that carbon has 6 neutrons.

Isotopes are atoms of the same element that have different mass numbers. That means that they have the same number of protons, but a different number of neutrons. Since the electrons in an atom are responsible for the chemical properties of an element, isotopes of an element share almost identical chemical properties. However, the physical properties can be very different. For example, carbon has three important isotopes, all with six protons. The most common isotope of carbon (about 99 % of all carbon atoms) has six protons and six neutrons for a mass number of 12. This isotope is called carbon-12. A very small amount of all natural carbon, about 1 %, has six protons and seven neutrons for a mass number of 13. This isotope is called carbon-13. Carbon-14 is a radioactive isotope that is constantly created by the action of cosmic rays in the upper atmosphere. How many neutrons does it have?

Did You KNOW?

Why the Nuclei of Atoms Do Not Fly Apart

We know that the nucleus of an atom has protons, all with a positive charge, tightly packed together. But we also know that like charges repel. So why do nuclei with more than one proton not fly apart because of repulsion? A strong nuclear force—an attractive force acting between protons and neutrons over very short distances—holds the nucleus together. As the number of protons increases, the repulsion increases. However, because there are also more neutrons in the nucleus, the strong nuclear force increases to keep the nucleus together.

LEARNING TIP

Check your understanding of the three isotopes of hydrogen by explaining Table 1 to a partner.

Figure 5 shows the different ways to express the names of the three isotopes of carbon.

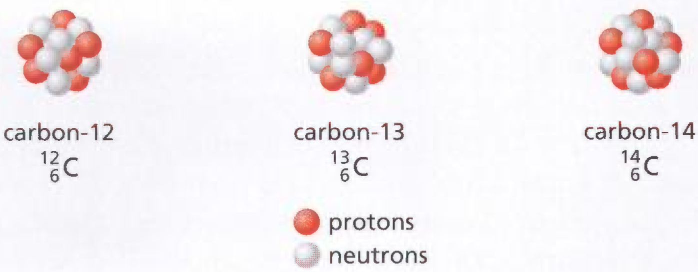


Figure 5 The three isotopes of carbon. Carbon-12 is stable, but carbon-14 is radioactive.

The isotopes of all other elements are written in a similar manner. However, hydrogen is an exception. Hydrogen has three isotopes and they each have their own name. Table 1 shows the isotopes of hydrogen.

Table 1 Isotopes of Hydrogen

Name	Symbol	Comment
hydrogen	$^{1}_{1}H$	• one proton, no neutrons • most common form of hydrogen (99.985 %)
deuterium	$^{2}_{1}H$	• one proton, one neutron • approximately 0.015 % of all hydrogen
tritium	$^{3}_{1}H$	• one proton, two neutrons • radioactive • trace amounts

The names and symbols give us information about isotopes. For example, given an isotope's name, we can determine the number of protons and neutrons it has.

SAMPLE PROBLEM

Determine the Number of Protons and Neutrons

Write the symbol for silver-107. How many protons and neutrons does it have?

Solution

The symbol is $^{107}_{47}Ag$. From the Periodic Table, we know that silver has 47 protons. Since $107 - 47 = 60$, we know that there are 60 neutrons.

Practice

Write the symbol for beryllium-9. How many protons and neutrons does it have?

10.2 CHECK YOUR Understanding

1. In Thomson's raisin bun model of the atom, what do the raisins and the bun represent?
2. Thomson assumed that the amount of positive charge and negative charge in an atom was equal. Was this a reasonable assumption? Give reasons to support your answer.
3. Figure 6 shows a diagram of Rutherford's gold foil experiment. Explain what is happening in the diagram. How did the experiment prove that the nucleus is very small and that it is positive?

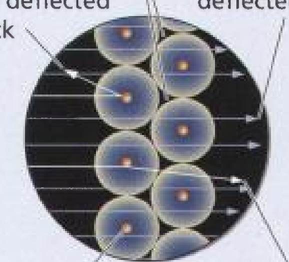


Figure 6

4. In the planetary model of the atom, what do the Sun and the planets represent? The force of gravity holds the solar system together. According to the planetary model of the atom, what holds the atom together?
5. What is the difference between a hydrogen atom and a proton?
6. The mass of an electron is 9.11×10^{-31} kg and the mass of a proton is 1.67×10^{-27} kg. How many electrons does it take to equal the mass of one proton?
7. The neutron was discovered long after electrons and protons. Why was it so difficult to discover?
8. How is a neutron different from both a proton and an electron?
9. Explain the difference between the atomic number and the mass number.
10. Write a definition of an isotope in your own words.
11. Draw a diagram of an oxygen-18 atom. Label the protons, neutrons, and electrons.
12. Chlorine occurs naturally as either chlorine-35 or chlorine-37. What is the difference between the two isotopes?
13. Copy Table 2 into your notebook and complete the missing information. The first row has been completed for you.

Table 2 Isotopes of Elements

Isotope name	Symbol	Number of protons	Number of neutrons
astatine-211	$^{211}_{85}At$	85	126
		92	143
magnesium-25			
	$^{209}_{86}Rn$		
		17	20
deuterium			
	$^{30}_{14}Si$		
palladium-102			
		53	74
tantalum-180			
	$^{182}_{74}W$		

14. Why do different isotopes of an element have the same chemical properties?

10.3 Radioactive Decay

10A → *Investigation*

Penetrating Ability of Nuclear Radiation

To perform this investigation, turn to page 298.

In this investigation, you will look at radioactive decay.

Henri Becquerel, and Pierre and Marie Curie found that uranium, radium, and polonium were radioactive. We now know that there are other naturally occurring radioactive elements including astatine, radon, and francium. The nuclei of some isotopes are unstable and emit radiation. Such isotopes are called radioactive isotopes, or radioisotopes. An unstable nucleus that emits radiation is undergoing **radioactive decay.** There are three main types of radioactive decay: alpha decay, beta decay, and gamma decay. Table 1 and Figure 1 summarize their characteristics. 10A → *Investigation*

Table 1 Three Main Types of Radioactive Decay

Method of decay	Radiation	Radiation symbol	Electric charge	Mass (electron = 1)	What is it?	Characteristics
alpha decay	alpha particle	α	+2	7000	a helium nucleus $^{4}_{2}He$	• slow moving • can only penetrate a piece of paper or skin
beta decay	beta particle	β	−1	1	an electron $^{0}_{-1}e$	• can only penetrate a few sheets of aluminum foil
gamma decay	gamma rays	γ	0	0	energetic "light" $^{0}_{0}\gamma$	• can only penetrate a few centimetres of lead

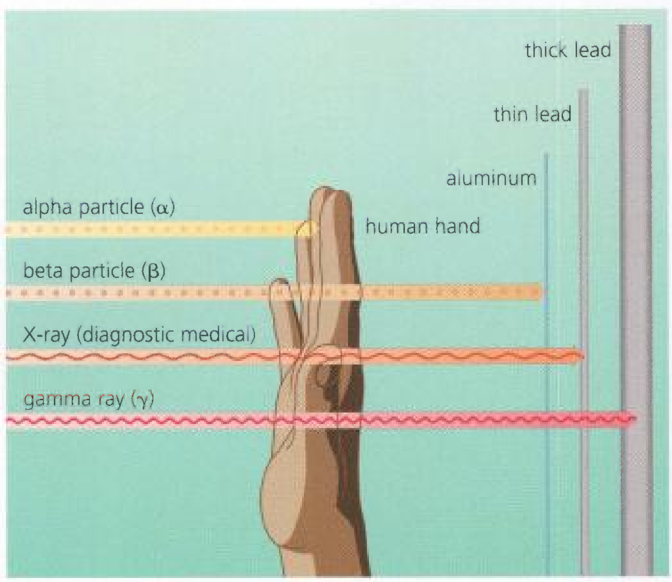


Figure 1 The penetrating ability of radiation. This is a measure of how much material is required to stop most, but not all, of the radiation going through the material.

In alpha and beta decays, the nucleus emits a particle and changes its identity. In other words, the atom has changed from one element to another. This is called transmutation. Transmutation changes a **parent nucleus** into a **daughter nucleus.** In gamma decay, the charge of the nucleus does not change, it just loses some energy. GO

To learn more about radioactive decay, go to www.science.nelson.com GO

Alpha Decay

Alpha decay occurs when a radioactive atom emits an **alpha particle**, α, which consists of two protons and two neutrons bound together into a particle identical to a helium nucleus, ^4_2He. For example, the isotope polonium-210, the radioactive element discovered by Marie Curie, undergoes radioactive decay by emitting a helium nucleus. During the decay, the polonium-210 is changed into lead-206 (Figure 2). In this case, polonium-210 is the parent nucleus and lead-206 is the daughter nucleus. The process can be written as a nuclear reaction equation:

$$^{210}_{84}\text{Po} \rightarrow {}^{206}_{82}\text{Pb} + {}^4_2\text{He}$$

LEARNING TIP

Active readers adjust their reading to fit the difficulty of the text. If you find the text difficult to understand, go back and forth between the text and the diagram. Read more slowly, and reread.

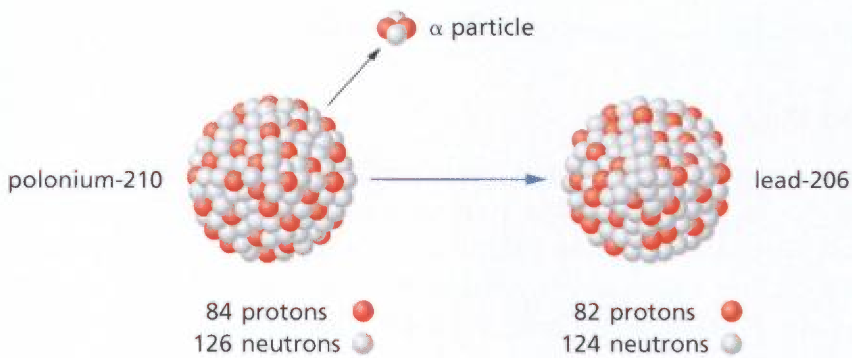


Figure 2 The alpha decay of polonium-210

After the alpha particle (remember, this is really a helium nucleus) has been emitted, it will slow down by crashing into surrounding atoms and eventually acquire two electrons to become a helium atom. Until the alpha particle becomes a stable helium atom, it moves around and collides with other atoms.

There are basically two rules for writing balanced nuclear equations: conservation of electric charge (atomic number) and conservation of the total number of protons and neutrons (mass number). The conservation of electric charge means that the amount of charge on the left-hand side of the arrow—in this case, +84—must equal the total charge on the right-hand side of the arrow—in this case, 82 + 2 = 84. The mass number on the left side of the arrow, which is 210, must also equal the sum of the mass numbers on the right side of the arrow: 206 + 4 = 210. Therefore, the mass number is conserved.

All alpha decays follow this pattern because the charge of all alpha particles is 2. We can write the general equation for alpha decay as:

$$^A_Z N_{\text{parent}} \rightarrow {}^{A-4}_{Z-2}N_{\text{daughter}} + {}^4_2\text{He}$$

where N_{parent} is the parent nucleus and N_{daughter} is the daughter nucleus. The letter Z represents the atomic number (number of protons) of the parent element, and A represents the mass number of the parent isotope (the number of protons plus neutrons).

Did You KNOW?

Polonium and the Spy

Former Russian spy Alexander Litvinenko was murdered using a radioactive isotope. He died three weeks after ingesting polonium-210, which had been dissolved most likely in a pot of tea. Polonium-210 is a strong emitter of alpha particles. Although alpha particles cannot travel very far, they can do tremendous damage to cells if they get inside the body through swallowing or inhaling. Doctors suspected that Mr. Litvinenko ingested less than a microgram of polonium-210.

SAMPLE PROBLEM 1

Determine the Nuclear Equation for Alpha Decay

Write the nuclear equation for the alpha decay of americium-241. What element has americium been transmuted into?

Solution

The atomic number of americium is 95 from the Periodic Table. Since the element undergoes alpha decay, the products will be a daughter nucleus and an alpha particle, ${}^{4}_{2}He$.

$$ {}^{241}_{95}Am \rightarrow {}^{237}_{93}Np + {}^{4}_{2}He $$

Americium has been transmuted into neptunium.

Practice

Write the nuclear equation for the alpha decay of radium-226.

Beta Decay

In beta decay, the nucleus emits a **beta particle**, β, which is actually an electron, ${}^{0}_{-1}e$. Since the nucleus contains only protons and neutrons, how is it possible for the nucleus to emit an electron? Protons and electrons are very stable, but a neutron is not stable. A neutron in an unstable nucleus can decay into a proton, an electron, and a neutrino. Therefore, the electron comes from the decay of a neutron. Note that a neutrino is a subatomic particle that has energy, but has no mass or electric charge.

An example of beta decay is when carbon-14 undergoes radioactive decay to transmute into nitrogen-14 (Figure 3). The nuclear equation is:

$$ {}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e \text{ and a neutrino} $$

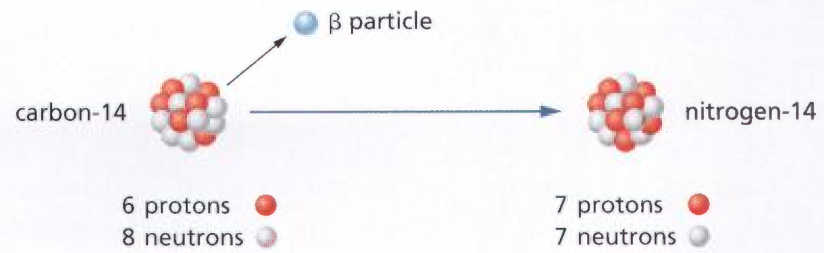


Figure 3 The beta decay of carbon-14

Note that in beta decay, the mass number of the daughter nucleus is the same as the parent nucleus. However, the atomic number of the daughter nucleus increases by one. For example, in the beta decay of carbon-14, when -1 is added to $+7$, the result is $+6$, which is the initial amount of electric charge. The neutrino often is omitted from beta decay equations.

Because the charge of all beta particles is -1 and the mass is close to 0, all beta decays follow this pattern. We can write the general equation as:

$$ {}^{A}_{Z}N_{\text{parent}} \rightarrow {}^{A}_{Z+1}N_{\text{daughter}} + {}^{0}_{-1}e $$

where N_{parent} is the parent nucleus, N_{daughter} is the daughter nucleus, Z represents the atomic number, and A represents the mass number.

SAMPLE PROBLEM 2

Determine the Nuclear Equation for Beta Decay

Write the nuclear equation for the beta decay of the isotope cesium-137. What element has cesium been transmuted into?

Solution

The atomic number of cesium is 55 from the Periodic Table. Since the element undergoes beta decay, the products will be a daughter nucleus and a beta particle.

$$^{137}_{55}\text{Cs} \rightarrow {}^{137}_{56}\text{Ba} + {}^{0}_{-1}\text{e}$$

Cesium has been transmuted into barium.

Practice

Write the nuclear equation for the beta decay of xenon-133.

STUDY TIP

Summarizing (condensing main points in your own words) is a helpful study tool. After reading Section 10.3, write a brief summary for each type of radioactive decay. Compare your summaries with a friend. Is there anything important that should be added?

Gamma Decay

In gamma decay, the nucleus emits a **gamma ray**, γ, which is very high-energy electromagnetic radiation. When the nucleus of an atom is in an excited state following the emission of an alpha or beta particle, the nucleus has a surplus of energy. The nucleus lowers its amount of energy by emitting a gamma ray. Since a gamma ray has no electric charge or mass, gamma decay does not change the type of isotope—it only changes the isotope's energy.

The following example shows the production of an excited nucleus followed by gamma decay. When americium-241 undergoes alpha decay, the daughter nucleus produced is neptunium-237.

$$^{241}_{95}\text{Am} \rightarrow {}^{237}_{93}\text{Np}^* + {}^{4}_{2}\text{He}$$

The asterisk beside the symbol for neptunium indicates that the nucleus is in an excited state. The excited nucleus then undergoes gamma decay and changes to a normal, or ground, state.

$$^{237}_{93}\text{Np}^* \rightarrow {}^{237}_{93}\text{Np} + {}^{0}_{0}\gamma$$

Because the gamma ray has no charge and no mass, all gamma decays follow this pattern and we can write the general equation for gamma decay as:

$$^{A}_{Z}N^* \rightarrow {}^{A}_{Z}N + {}^{0}_{0}\gamma$$

Remember that gamma decay adjusts the energy levels in a nucleus, but does not otherwise change the nucleus.

Did You KNOW?

Harold Johns and Cobalt-60

Harold Johns (1915–1998) is regarded as the Father of Medical Physics. Johns was born in China, but moved to Canada in the mid-1920s. He developed the first cobalt-60 cancer treatment unit in Saskatchewan. Cobalt-60 units are still built in Canada and distributed around the world. In 1977, Johns was elected as an Officer of the Order of Canada. He was inducted into the Canadian Medical Hall of Fame in 1998.

SAMPLE PROBLEM 3

Determine the Nuclear Equation for Gamma Decay

Boron-12 undergoes beta decay to produce an excited daughter nucleus. Write the nuclear equation for this decay, and then write the nuclear equation for the gamma decay of the excited daughter nucleus. What element has boron been transmuted into?

Solution

$$^{12}_{5}\text{B} \rightarrow {}^{12}_{6}\text{C}^{*} + {}^{0}_{-1}\text{e}$$

$$^{12}_{6}\text{C}^{*} \rightarrow {}^{12}_{6}\text{C} + {}^{0}_{0}\gamma$$

Boron has been transmuted into carbon.

Practice

The isotope cobalt-60 undergoes beta decay to produce a daughter nucleus in an excited state. Write the nuclear equation of the beta decay, and then write the nuclear equation that shows how the nucleus lowers its internal energy level.

Figure 4 In a cloud chamber, the alpha particles produce a thick, short track. Beta particles make a thin irregular track. Gamma rays have no charge and, thus, no track.

Figure 5 Tracks made by alpha and beta particles in a bubble chamber

To view an animation of a Geiger counter in action and to test your knowledge, go to **www.science.nelson.com**

Detection of Radioactive Emissions

How can scientists detect radioactive decay when alpha particles, beta particles, and gamma rays are invisible to the human eye? One device used to detect radioactivity is a cloud chamber. A diffusion cloud chamber is a small, clear plastic, sealed cylinder inside of which is a sponge saturated with alcohol. When the bottom of the cylinder is placed on dry ice, the air becomes supersaturated with alcohol. When a radioactive source is placed inside, it emits charged particles that remove some electrons from the atoms in the air as they travel, converting the atoms to positive ions. These ions cause the vapour to condense and create a visible track (Figure 4).

A bubble chamber is similar to a cloud chamber. The chamber contains a superheated liquid, such as propane or liquid hydrogen. When a charged particle passes through the liquid, bubbles form around the tracks of the particles. An electromagnet causes the charged particles to be deflected. Alpha and beta particles are deflected in opposite directions (Figure 5).

Another device that can detect radiation is a Geiger counter. Geiger counters also are based on the fact that some radiations produce trails of charged atoms (ions) as they pass through a gas. It consists of a cylinder containing a gas and a wire inside. There is a high voltage between the cylinder case and the wire. Charged particles enter through a window at one end of the cylinder and ionize the gases inside the cylinder. The positive ions are attracted to the negatively charged wire, which produces a current that can be detected and read as a count. Each burst of current represents the detection of one particle. The Geiger counter is connected to a counting device that keeps count of radiation entering the tube. Geiger counters can detect beta particles and gamma rays. Alpha particles are not able to penetrate the window of most counters.

10.3 CHECK YOUR Understanding

1. What happens when a radioactive atom undergoes radioactive decay?
2. How many beta particles would it take to have the same mass as a single alpha particle?
3. Why are alpha and beta radiation referred to as particles, while gamma radiation is referred to as rays?
4. Write a definition of transmutation in your own words.
5. What happens to the atomic number (Z) and mass number (A) of a parent nucleus during alpha decay?
6. List two differences between an alpha particle and a helium atom.
7. The following parent isotopes undergo alpha decay. Write the nuclear equation for these transmutations.
   (a) tungsten-180
   (b) samarium-147
   (c) sodium-20
8. Write a brief description of beta decay in your own words.
9. The mass number of an atom undergoing beta decay does not change. However, the daughter nucleus is a different element than the parent. Explain how this is possible.
10. The following parent isotopes undergo beta decay. Write the nuclear equation for this transmutation.
    (a) nickel-64
    (b) tritium
    (c) iron-59
11. How do the atomic number and the mass number of an atom change as a result of gamma decay? Why does an atom emit gamma radiation?
12. Iron-60 undergoes beta decay. The daughter produced is in an excited state and undergoes gamma decay. Write nuclear equations to show these two processes.
13. State whether the following descriptions apply to alpha, beta, or gamma radiation:
    (a) has a negative charge
    (b) is a helium nucleus
    (c) its path is deflected by a magnet
    (d) is similar to X-rays
    (e) is stopped by a few sheets of paper
    (f) an electric charge does not affect its path
    (g) has the most mass
    (h) easily penetrates skin and tissue
14. Complete the following nuclear equations:
    (a) ${}^{239}_{93}\text{Np} \rightarrow \textbf{?} + {}^{0}_{-1}\text{e}$
    (b) ${}^{232}_{90}\text{Th} \rightarrow \textbf{?} + {}^{4}_{2}\text{He}$
    (c) ${}^{14}_{6}\text{C} \rightarrow {}^{14}_{7}\text{N} + \textbf{?}$
    (d) ${}^{152}_{66}\text{Dy}^{*} \rightarrow {}^{152}_{66}\text{Dy} + \textbf{?}$
    (e) ${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + \textbf{?}$
    (f) $\textbf{?} \rightarrow {}^{209}_{81}\text{Tl} + {}^{4}_{2}\text{He}$
    (g) ${}^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + \textbf{?}$
    (h) $\textbf{?} \rightarrow {}^{239}_{94}\text{Pu} + {}^{0}_{-1}\text{e}$
    (i) $\textbf{?} \rightarrow {}^{99}_{43}\text{Tc} + {}^{0}_{0}\gamma$
15. Name and describe three devices that are used to detect radioactivity.
16. Alpha and beta radiation leave visible tracks in a cloud chamber. However, gamma rays do not. Why?
17. Why do alpha particles leave short thick tracks in a cloud chamber, while beta particles leave long thin tracks?
18. How is a Geiger counter similar to a cloud chamber?
19. Why are some Geiger counters unable to detect alpha radiation?

10.4 Half-Life

Figure 1 Pitchblende, the major uranium ore, is a heavy mineral that contains uranium oxides, lead, and trace amounts of other radioactive elements. Pierre and Marie Curie found radium and polonium in pitchblende residues.

10B — *Investigation*

The Half-Life of Popcorn

To perform this investigation, turn to page 300.

In this investigation, you will simulate the radioactive decay using popcorn kernels.

A sample of radioactive material, such as uranium ore (Figure 1), contains an immense number of radioactive atoms, any of which can undergo radioactive decay. The decay of a nucleus is an individual random event. The rate of radioactive decay of a sample is not affected by physical or chemical changes, including temperature and pressure. In addition, the age of a nucleus does not affect the probability that it will decay. Although there is no way of determining when an individual nucleus will decay, we can predict the average rate of decay for a large number of nuclei. In the beginning, there are a large number of radioactive parent nuclei and, therefore, there will be a high rate of decay per second. As time passes and parent nuclei decay, there will be fewer and fewer parent nuclei, and more and more daughter nuclei. Over time, both the number of parent nuclei present and the rate of decay will decrease.

The number of decays per second of a sample is known as the activity of the sample and is measured in becquerels (Bq). A becquerel is equal to one decay per second. The average length of time for half of the parent nuclei in a sample to decay is called the **half-life**. The half-life is different for different isotopes, but is a constant number for a given isotope. 10B — *Investigation*

The activity of a sample depends on the size of the sample (how many radioactive nuclei were present initially) and the age of the sample (how many radioactive nuclei are left). However, for any sample, the number of parent nuclei left in the sample and the activity level of the sample always follow the curves shown in Figures 2 and 3. These curves are for a fictitious (made up) radioactive source.

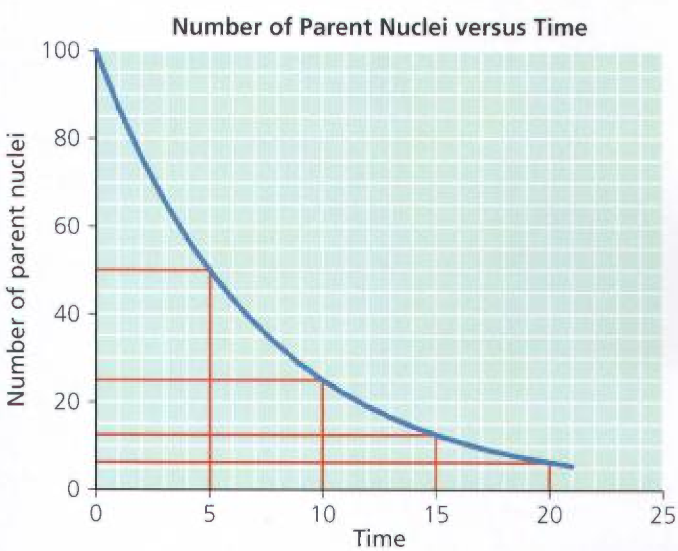


Figure 2 Parent nuclei decay curve

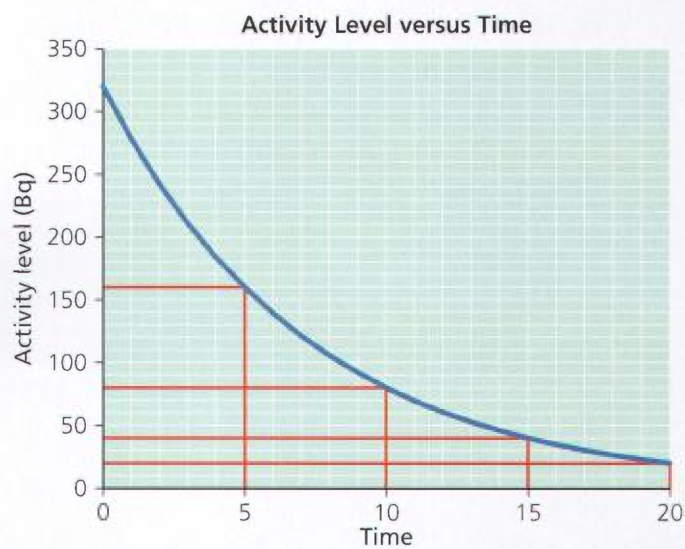


Figure 3 Activity curve

Both curves have an identical shape. You can see from the figures that the sample has a half-life of 5 units of time. The number of parent nuclei goes from 100 to 50 to 25 to 12.5 to 6.25 at times of 0, 5, 10, 15, and 20 time units. Similarly, the activity level of the sample goes from 320 to 160 to 80 to 40 to 20 at times of 0, 5, 10, 15, and 20 time units.

Some radioactive isotopes are used in medicine. For example, the radioactive isotope thallium-201 can be injected into a patient's bloodstream where it is carried to the patient's heart. A camera detects the radiation given off from the decay of thallium-201 and produces an image of the heart (Figure 4). Comparison of scans made during exercise and at rest may show areas of the heart not receiving adequate blood flow. Figure 5 shows how the activity level of an injection of thallium-201 decreases.

LEARNING TIP

A line graph can be used to show a trend over a period of time. Ask yourself, "What information is presented on the left side and along the bottom of Figure 5? What has happened to thallium-201 over a period of time?"

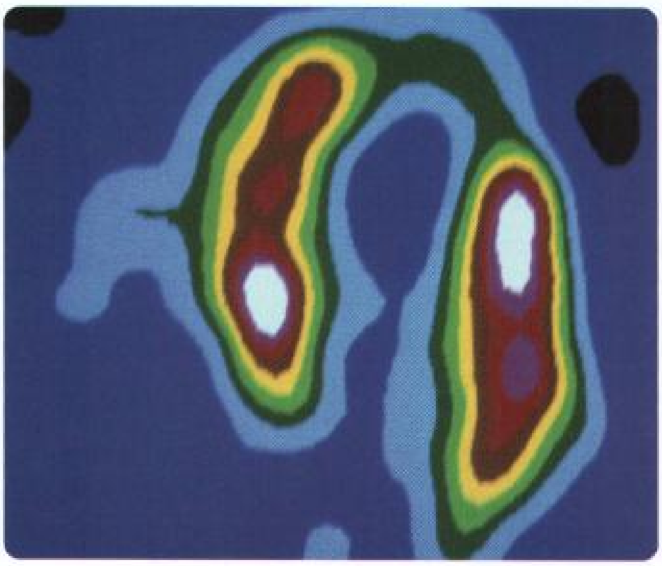


Figure 4 A thallium scan of a normal heart

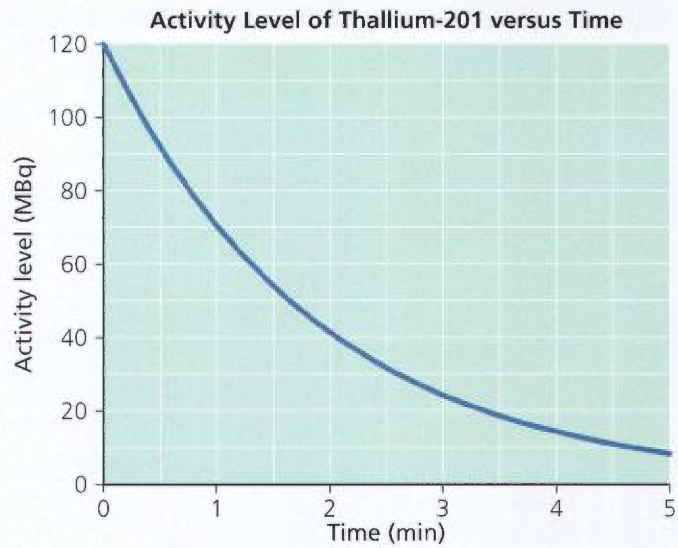


Figure 5 Activity of thallium-201

We can use the graph to determine the half-life of thallium-201. The initial activity of 120 MBq is reduced to 60 MBq after 1.3 min. This means that the half-life is 1.3 min. Note that the half-life is so short that most of the thallium will decay quickly and not stay in the blood for much time.

As every half-life passes, the number of parent nuclei present and the activity level decreases by half. To find out how many half-lives have passed, divide the time by the half-life of the isotope. Table 1 shows how these fractions can be expressed.

Table 1 Calculating Half-Lives Using Fractions

Number of half-lives	1	2	3	4	5	n
Fraction remaining	$\frac{1}{2}$	$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$	$\frac{1}{4} \times \frac{1}{2} = \frac{1}{8}$	$\frac{1}{8} \times \frac{1}{2} = \frac{1}{16}$	$\frac{1}{16} \times \frac{1}{2} = \frac{1}{32}$	
Exponential notation	$\frac{1}{2^1} = \frac{1}{2}$	$\frac{1}{2^2} = \frac{1}{4}$	$\frac{1}{2^3} = \frac{1}{8}$	$\frac{1}{2^4} = \frac{1}{16}$	$\frac{1}{2^5} = \frac{1}{32}$	$\frac{1}{2^n}$

Another way to calculate the amount of the parent nuclei remaining is to use percentages. The original amount is 100 %. Therefore, we can calculate the amount left after every half-life by dividing the previous amount by two. Table 2 shows the percentage left after the first five half-lives. This table can be used for problems calculating the amount of parent nuclei left. Can you determine the percentage that would be left after six half-lives?

Table 2 Calculating Half-Lives Using Percentages

Number of half-lives	1	2	3	4	5
Percent remaining	50 %	25 %	12.5 %	6.25 %	3.25 %

SAMPLE PROBLEM 1

Use Half-life to Determine the Time Passed

Cesium-124 has a half-life of 31 s. A sample of cesium-124 in a laboratory has an initial mass of 20 mg.

(a) Calculate the amount of time it will take for the sample to decay to 5 mg.

(b) Calculate how much cesium-124 will remain after 93 s.

Solutions

(a) First determine how many half-lives have passed. This can be done using either the fraction or percentage method.

Fraction Method

The fraction left is

$$\frac{5}{20} = \frac{1}{4} = \frac{1}{2^2}$$

Percentage Method

The percent left is

$$\frac{5}{20} \times 100\ \% = 25\ \%$$

By using either method, we can see that two half-lives have passed.

Now calculate the total amount of time that has passed.

Since two half-lives have passed, the total time that has passed will be $2 \times 31\ s = 62\ s$.

Figure 6 shows a graph of the mass–time. From the graph, we can see that at about 62 s, the mass is reduced to 5 mg. This is in agreement with the calculated solution.

(b) Since the half-life of cesium-124 is 31 s, we can determine the number of half-lives:

$$\text{number of half-lives} = \frac{\text{total time}}{\text{half-life}} = \frac{93\ s}{31\ s} = 3\ \text{half-lives}$$

Now calculate the mass (m) remaining. This can be done using either the fraction or percentage method.

Fraction Method

$$m = \frac{1}{2^3}(20\ mg)$$

$$m = 2.5\ mg$$

Percentage Method

After three half-lives, there is 12.5 % remaining.

$$m = \left(\frac{12.5\ \%}{100\ \%}\right) 20\ mg$$

$$m = 2.5\ mg$$

The mass remaining is 2.5 mg. We can also see on the graph that the approximate mass remaining is about 2.5 mg.

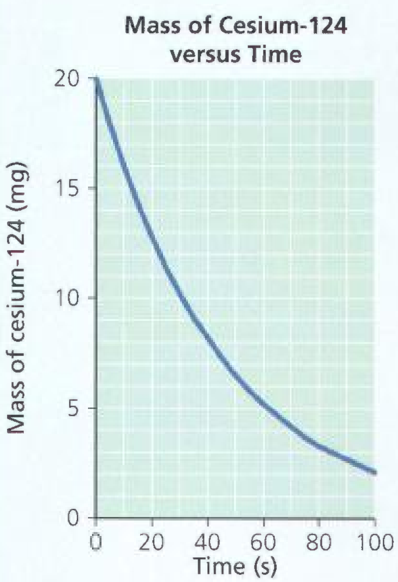


Figure 6 Decay curve for cesium-124

Practice

A sample of fluorine-18 in a laboratory has an initial mass of 50 mg. Fluorine-18 has a half-life of 1.8 h. Figure 7 shows the decay curve for fluorine-18.

(a) Calculate the amount of time it will take for the initial mass of fluorine-18 to be reduced from 50 mg to 12.5 mg. You can use the graph to confirm your answer.

(b) Calculate what mass of fluorine-18 remains after 5.4 h. You can use the graph to confirm your answer.

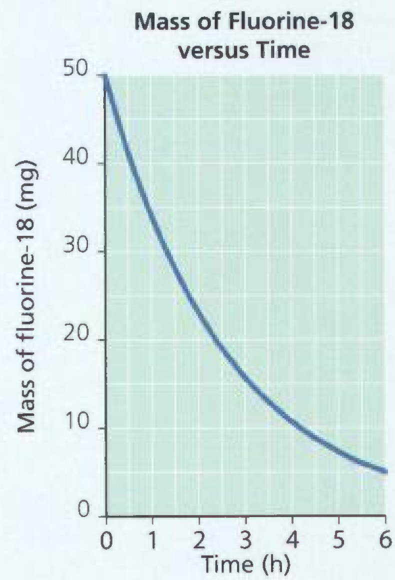


Figure 7 Decay curve for fluorine-18

SAMPLE PROBLEM 2

Determine the Activity Level Using Half-life

Radium-226 has a half-life of 1600 years. A material containing radium-226 has an activity of 500 MBq.

(a) Determine what the activity level will be in the material after 8000 years.

(b) How many years earlier was the activity level in the material 2000 MBq?

Solutions

(a) First, determine the number of half-lives.

$$\frac{8000 \text{ years}}{1600 \frac{\text{years}}{\text{half-life}}} = 5 \text{ half-lives}$$

Now determine the activity level.

$$\text{activity} = 500 \text{ MBq} \times \frac{1}{2^5} = 15.625 \text{ MBq}$$

After 8000 years, the activity level will be 16 MBq.

(b) The activity level of 500 MBq is one-quarter the activity level of 2000 MBq.

$\frac{1}{4} = \frac{1}{2^2}$ This represents a period of two half-lives.

We can calculate the amount of time as

$t = 2 \times 1600 \text{ years} = 3200 \text{ years}$

The activity level was 2000 MBq 3200 years earlier.

Practice

Silicon-32 has a half-life of 160 years. A material containing silicon-32 has an activity of 80 MBq.

(a) Determine what the activity level of the material will be after 320 years.

(b) How many years earlier was the activity level of the material 640 MBq?

Table 3 Decay Series of Uranium-238

Decay	Half-life
$^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$	4.5×10^9 years
$^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e$	24 d
$^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e$	6.7 h
$^{234}_{92}U \rightarrow {}^{230}_{90}Th + {}^{4}_{2}He$	2.5×10^5 years
$^{230}_{90}Th \rightarrow {}^{226}_{88}Ra + {}^{4}_{2}He$	7.5×10^4 years
$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$	1600 years
$^{222}_{86}Rn \rightarrow {}^{218}_{84}Po + {}^{4}_{2}He$	3.8 d
$^{218}_{84}Po \rightarrow {}^{214}_{82}Pb + {}^{4}_{2}He$	3.1 min
$^{214}_{82}Pb \rightarrow {}^{214}_{83}Bi + {}^{0}_{-1}e$	27 min
$^{214}_{83}Bi \rightarrow {}^{214}_{84}Po + {}^{0}_{-1}e$	20 min
$^{214}_{84}Po \rightarrow {}^{210}_{82}Pb + {}^{4}_{2}He$	1.6×10^{-4} s
$^{210}_{82}Pb \rightarrow {}^{210}_{83}Bi + {}^{0}_{-1}e$	22 years
$^{210}_{83}Bi \rightarrow {}^{210}_{84}Po + {}^{0}_{-1}e$	5 d
$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He$	138 d

Decay Series

In biological families, a parent can have a daughter. After time passes, the daughter becomes a parent and produces another generation. In a similar way, a radioactive parent nucleus produces a daughter nucleus, which can also be radioactively unstable. In turn, the daughter nucleus becomes a parent nucleus, which continues the sequence of events. When radioactive nuclei form such a chain, it is called a **decay series**. The decay series always ends in the formation of a stable isotope.

For example, uranium-238 forms a decay series ending with the stable isotope lead-206 as shown in Table 3. Note that some of the isotopes have very short half-lives. However, uranium-238 has a half-life of about 4.5 billion years. The decay series of uranium-238 provides some isotopes that would not otherwise be present on Earth. The decay series of uranium-238 can be graphed as shown in Figure 8.

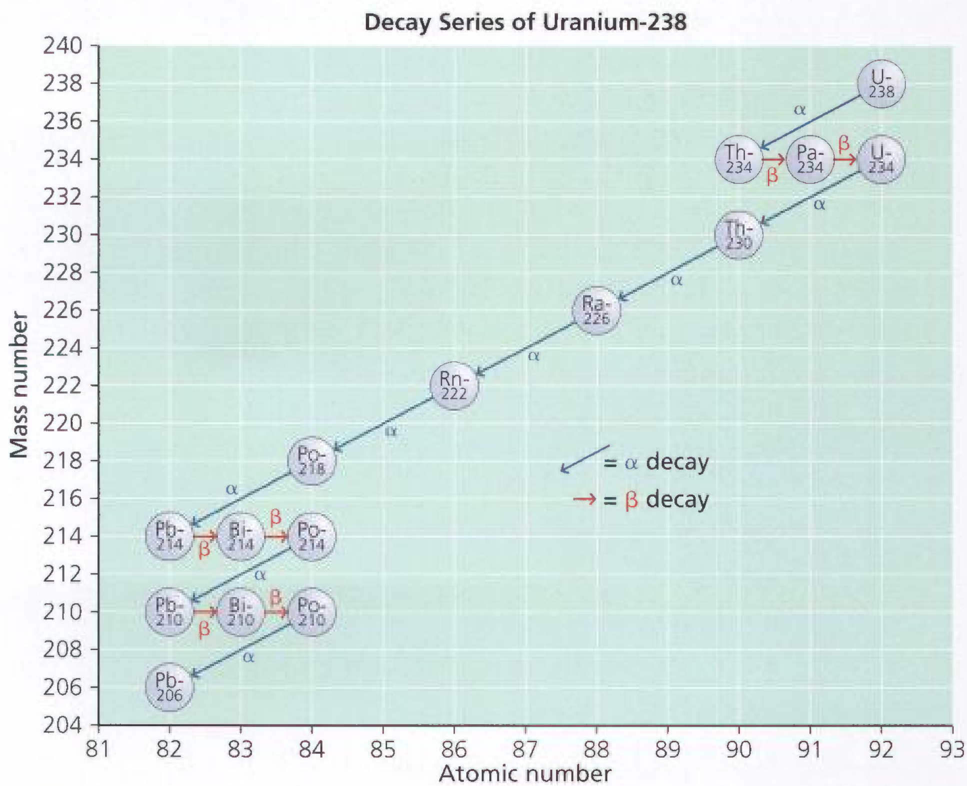


Figure 8 Uranium-238 is changed into lead-206 in a decay series of 14 steps.

Figure 9 The remains of a human were found in glacial ice in the Alps. Scientists used carbon-14 dating to determine that he lived about 5300 years ago.

Radioactive Dating

Since radioactive isotopes decay according to their half-lives, it is possible to date materials using appropriate isotopes. Carbon-14 is a radioactive isotope that can be used to date material that was once alive (Figure 9). Almost all naturally occurring carbon is carbon-12. However, an extremely small fraction of carbon (about one atom in a trillion) is carbon-14. The half-life of carbon-14 is 5730 years. With this half-life, there should be no carbon-14 left on Earth, which is about 4.5 billion years old. However, our Sun and all the stars in the universe produce cosmic radiation. Energetic neutrons are part of cosmic radiation, and the neutrons combine with nitrogen in the upper atmosphere to form carbon-14 and a proton according to the following nuclear equation:

$$^{14}_{7}\text{N} + ^{1}_{0}\text{n} \rightarrow ^{14}_{6}\text{C} + ^{1}_{1}\text{p}$$

This process keeps the level of carbon-14 constant on Earth and in living organisms.

When an organism dies, the amount of carbon-14 in the organism starts to decrease as it radioactively decays, and no new carbon-14 enters the organism through eating or respiration. Carbon-14 has a half-life of 5730 years, which means that the ratio of carbon-14 in an organism decreases by half every 5730 years. Figure 10 shows the decay curve for carbon-14. It is clear from the graph that carbon-14 can only be used to date objects less than 40 000 years old. With a more accurate graph (or by calculation), the useful time range can be extended to about 60 000 years. Note that carbon-14 dating will only date things that were once alive. GO

Other isotopes can be used to date things that are more than 60 000 years old or that were never alive. For example, uranium-235 decays to lead-207 with a half-life of 704 million years, and uranium-238 decays to lead-206 with a half-life of 4.46 billion years. Dating materials using two different isotopes make the age estimates very accurate. Uranium-238 has been used to determine that the oldest rocks that have been dated on Earth are about 4 billion years old.

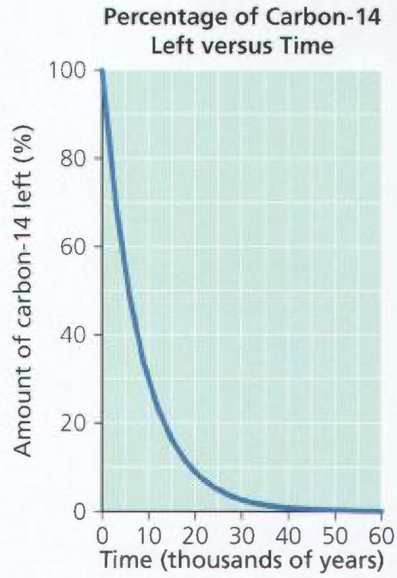


Figure 10 Decay curve for carbon-14

To find out more about carbon-14 dating go to **www.science.nelson.com** GO

To test your skills on half-life and radioactive dating, go to **www.science.nelson.com**

SAMPLE PROBLEM 3

Use Radioactive Dating to Determine the Age of a Sample

A piece of leather was found to have 12.5 % of its original carbon-14 present. Determine the age of the leather using Figure 10 and by calculation.

Solution

From the graph, we can see that the time is approximately 17 000 years.

The decrease from 100 % to 12.5 % is a ratio of $\frac{12.5\ \%}{100\ \%} = \frac{1}{8} = \frac{1}{2^3}$

Therefore, the time taken is $5730\ \frac{\text{years}}{\text{half-life}} \times 3\ \text{half-lives} = 17\ 190\ \text{years}$

The piece of leather is approximately 17 000 years old.

Practice

A bone fragment was found to have 25 % of its original carbon-14 present. Determine the age of the bone fragment using Figure 10 and by calculation.

10.4 CHECK YOUR Understanding

1. How are the terms "activity" and "becquerel" related?
2. What is the activity level of the following samples?
   (a) 3600 decays in 42 s
   (b) 35 decays in 35 min
   (c) 45 000 decays in 7.5 min
   (d) 1200 decays in 3 h
   (e) 250 000 decays in 55 min and 17 s
3. Nitrogen-13 decays to produce carbon-13. A laboratory sample contains 500 000 nitrogen-13 atoms. Use the decay curve for the sample over time shown in Figure 11 to answer the following questions.

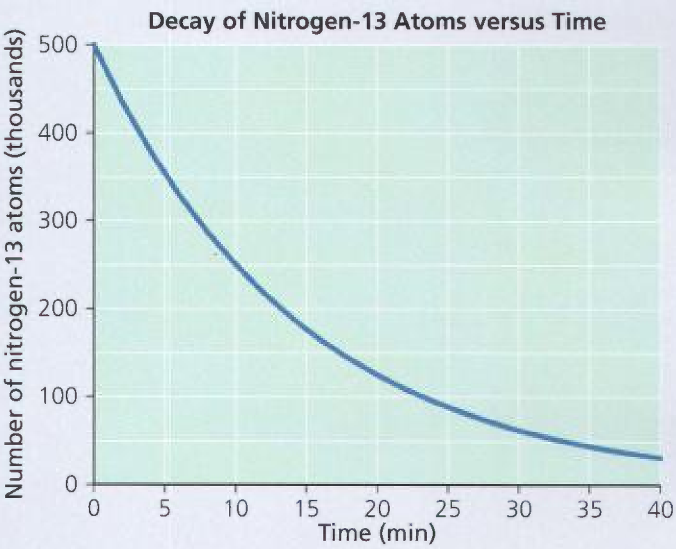


Figure 11 Decay curve for nitrogen-13

   (a) How many nitrogen-13 atoms will be left after 16 min?
   (b) How many carbon-13 atoms will be present after 25 min?
   (c) What is the half-life of nitrogen-13?
   (d) How many nitrogen-13 atoms will be present after 40 min?
4. A radioactive isotope source has a mass of 120 µg. If the isotope had a half-life of 20 s, what would be the mass of the isotope after 2 min?
5. Beryllium-7 has a half-life of 53 d. A sample was observed for 1 min and there were 26 880 decays.
   (a) What is the activity level of the sample?
   (b) What will the activity level of the sample be after 265 d?
   (c) After how many days will the activity level of the sample be 112 Bq?
   (d) What was the activity level 106 d before the sample was observed?
   (e) How many days earlier was the activity level eight times greater than the observed level?
6. A granite rock is thought to be about two billion years old. Why is it not possible to determine the age of the rock using carbon-14 dating?
7. A hair sample has 80 % of its original carbon-14 present. What is the age of the sample?
8. A bone fragment has lost 75 % of its original carbon-14. What is the age of the bone fragment?
9. An organic sample is 28 650 years old. What percentage of the original carbon-14 is still present in the sample?

Tech **CONNECT**

BRACHYTHERAPY

Brachytherapy is a powerful tool used to kill cancer cells. A radioactive isotope is implanted directly within the tumour. By placing all of the radioactivity in the tumour, the damage to surrounding normal cells is minimized.

Did you know that almost 73 000 people will die from cancer this year in Canada? In fact, according to the Canadian Cancer Society, one out of every four Canadians will die from cancer. The good news is that mortality rates from certain types of cancer are declining, in part because the disease is being detected earlier and in part because of advances in treatments.

Soon after Marie and Pierre Curie discovered radium, it was used to treat skin cancer. Doctors who administered the radiation had little understanding about how radiation worked although they did know that it killed cancer cells. We now know that not only does radiation kill cancer cells, but it also harms normal cells. To help minimize the damage done to normal cells, while maximizing damage to cancer cells, medical physicists and doctors use brachytherapy to treat cancer. Brachytherapy (which means treatment from a short distance) involves implanting radioactive isotopes directly into a cancerous tumour. Radioactive isotopes can be inserted directly into the body cavity to treat bronchial, gynecological, and esophageal tumours, or through needles that puncture the tumour for prostate, breast, lip, and tongue tumours.

When treating cancers with brachytherapy, it is important to choose the right radioisotope. Radioisotopes are chosen based on their half-life, activity (source strength), and the energy of the gamma rays that they produce. Sometimes the radioisotopes are implanted permanently in the tumour. In this case, it is important that the radioisotope have a relatively short half-life. For example, iodine (^{125}I), which has a half-life of 60 d, or palladium (^{103}Pd), which has a half-life of 17 d, is used to treat prostate cancer (Figure 1). An isotope of gold (^{198}Au), which has a half-life of 2.7 d, is used to treat lip cancer. These radioisotopes are referred to as seeds because they are sealed inside a metal capsule (usually titanium) that keeps the isotope and decay products inside.

Sometimes the radioisotopes are inserted temporarily into the body, and then removed after a few minutes or even days. This is usually done using a robot called a remote afterloader (Figure 2). The robot can pull the radioisotope in or out of the tumour, and can even move it within the tumour. The radioisotope is kept inside a tube so that it can be re-used for many patients. Radioisotopes such as cesium (^{137}Cs) with a half-life of 30 years, and iridium (^{192}Ir) with a half-life of 74 d, are used for this type of therapy. These radioisotopes have a longer half-life so that they can be used many times.

Brachytherapy is a promising way of treating many types of cancer. Placing the radioactive seeds directly into a tumour is the best way to make sure that the radiation reaches the target cells and keeps away from healthy tissues.

Figure 1 Eighty-eight iodine seeds were implanted permanently in the prostate gland. It is important that the seeds not be too close to the urethra.

Figure 2 One or more fine tubes are inserted into or adjacent to the tumour. The radiation seeds travel from the machine, through the tube to the tumour, and deliver a high dosage of radiation in minutes.

10A Investigation

Penetrating Ability of Nuclear Radiation

The radiation that is emitted from the nucleus of radioactive atoms comes in different types. The types have different characteristics, such as electric charge, mass, and penetrating ability. By knowing the characteristics of different types of radiation, you can identify the types of radiation that different materials emit. If you know the penetrating ability of the radiation, you can design safety shields for the particular radiation.

In this investigation, you will observe the penetrating ability of three different types of radiation. You will look at alpha, beta, and gamma radiation.

Question

What type and amount of material is needed to stop alpha, beta, and gamma radiation?

Experimental Design

Your teacher will perform this experiment using a Geiger counter (Figure 1). A Geiger counter is able to detect these types of radiation and keeps count of the number of emissions that strike the Geiger counter.

Figure 1 Geiger counters are particle detectors that measure ionizing radiation. There are several different types of Geiger counters that you may see in your studies.

INQUIRY SKILLS

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

Materials

- set of radioactive samples (alpha, beta, and gamma sources)
- Geiger counter
- 10 sheets of paper
- 10 sheets of aluminum foil
- 10 lead sheets

The radioactive sources used are very weak. However, care needs to be taken around any radioactive sources. Do not come any closer to them than needed, and keep them in storage until needed.

Procedure

1. Your teacher will turn the Geiger counter on without any radioactive sources nearby. Make sure nobody is wearing a watch near the Geiger counter as it may invalidate the reading. Record the number of counts, if any, made in 1 min.
2. As material is placed between the radioactive source and the Geiger counter, the rate of radiation should decrease from 100 % to 0 %. However, because of background radiation, the rate may not decrease to 0 %. As a class, choose a percentage that you think is acceptable to consider the radiation to be effectively stopped.
3. Hold the Geiger counter above a source and observe the counting rate of the Geiger counter. Slowly move the Geiger counter away from the source. Note what happens to the rate as the distance increases.

4. Copy Table 1 into your notebook.

Table 1

	Alpha radiation	Beta radiation	Gamma radiation
paper			
aluminum			
lead			

5. Place the Geiger counter over the alpha source. Insert sheets of paper between the source and the Geiger counter (Figure 2). Keep adding sheets until the rate of counts is almost stopped. This is the penetrating ability of alpha radiation with paper. Repeat this with sheets of aluminum foil and lead.

Figure 2

6. Repeat step 5 using the beta sample and the gamma sample.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) What happened to the decay rate as the Geiger counter moved away from the source? Why do you think this happened?

(b) During this investigation, did you or your teacher receive more exposure to radiation?

(c) List the three types of radiation from least penetrating to most penetrating.

Evaluation

(d) In step 1, you observed the behaviour of the Geiger counter without any sources nearby. If it "counted" without any sources nearby, did this influence the investigation? If so, how did you make accommodation for this count?

(e) Some Geiger counters come equipped with a holder for the tube. Why should the tube be placed in the holder rather than held in the teacher's hand?

Synthesis

(f) Counts were detected by the Geiger counter when your teacher turned it on, even when there were no radioactive sample sources nearby. What could cause the Geiger counter to detect these counts?

(g) How would you compare the penetrating ability of X-rays with alpha, beta, and gamma radiation?

(h) If you worked in an area of a hospital that used radioactive sources, what would you do to protect yourself? Research to find out how hospital workers protect themselves from radiation.

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10B Investigation

The Half-Life of Popcorn

INQUIRY SKILLS

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

When a radioactive sample decays, there is one less parent nuclei and one more daughter nuclei. As this decay process continues, the number of parent nuclei decreases and the number of daughter nuclei increases. Eventually there are no parent nuclei left to decay into daughter nuclei and no further decays occur.

In this activity, you will use a model to see how the rate of radioactivity of a sample changes over time. In this investigation, you will use popcorn kernels to represent parent nuclei.

Question

What happens to the rate of radioactive decay in a sample as time passes?

Prediction

Write a prediction of how you think the rate of radioactive decay will change.

Materials

- 100 popcorn kernels
- container such as an empty film canister or a Petri dish

Procedure

1. Copy Table 1 into your notebook. You will begin with 100 popcorn kernels. Since these represent parent nuclei, they will be referred to as parent kernels. The first row in the table shows that there are 100 parent kernels and no daughter kernels.
2. Count the popcorn kernels to make sure that there are exactly 100. Put the kernels in a container, shake the container, and carefully drop the kernels on your desk. Imagine each kernel as the hour hand of a clock. If the point of the kernel is between 12 and 3 on the "clock," assume that the kernel has decayed. Figure 1 shows how to determine which kernels have decayed and which are still alive. Decayed kernels represent daughter nuclei. Count the number of daughter kernels and record the number in your table. Record in your table how many parent kernels are left. This is one unit of time as measured in shakes.

Table 1

Time (shakes)	Number of parent kernels	Number of daughter kernels
0	100	—

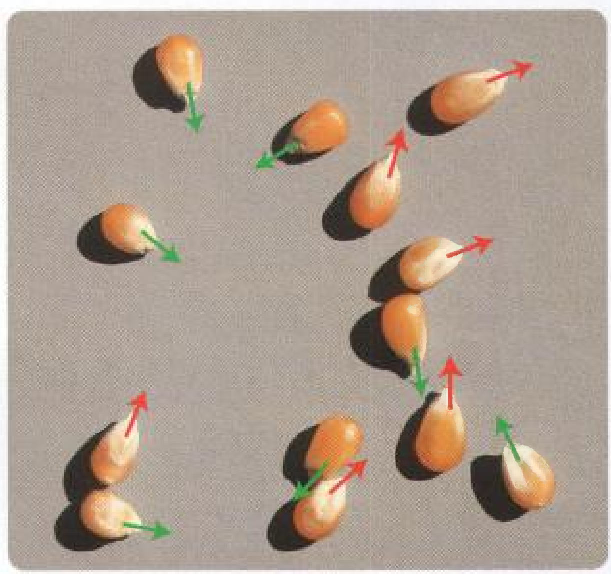


Figure 1 The popcorn kernels with the red arrows are pointing between 12 and 3 on your "clock." They are decayed.

3. Remove the daughter kernels. Put the parent kernels back in the container and repeat step 2. This is the second unit of shake time.
4. Repeat step 3 until all of the parent kernels have decayed and there are no parent kernels left. Always record the number of decayed popcorn—even if that number is zero!
5. Make two graphs. On the first graph, plot the number of daughter kernels produced versus time as measured in shakes. On the second graph, plot the number of parent kernels remaining versus time as measured in shakes. Draw a line of best fit for each graph. In this case, the line is not a straight line and will need to be drawn with a curve. (Refer to Appendix B5.)

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) What happened to the number of parent kernels over time?

(b) What happened to the rate at which daughter kernels are produced over time?

(c) How many shakes did it take until all the parent kernels had decayed? How did your number compare with other students in the class?

(d) On the graph of parent kernels versus time, at what time (as measured in shakes) did the number of parent kernels become approximately 50? How much more time passed before the number of parent kernels was reduced to approximately 25? How do these two numbers compare?

(e) Using your response to (d), what is the half-life of popcorn as determined by your results?

Evaluation

(f) In this investigation, popcorn represented parent nuclei. In what ways did the popcorn behave similar to parent nuclei, and in what ways was it different?

Synthesis

(g) Are your popcorn decay results identical to your classmates? Explain your answer.

(h) If you had performed this activity with 10 000 kernels of popcorn, do you think that the answers would be different? Give reasons for your answer.

(i) If the parent kernel decayed when the point was between the hours of 12 and 1 (instead of between 12 and 3), how would this affect the results?

(j) What other materials or devices could have been used to simulate radioactive decay? For example, how could you use a computer to generate random numbers and then use them?

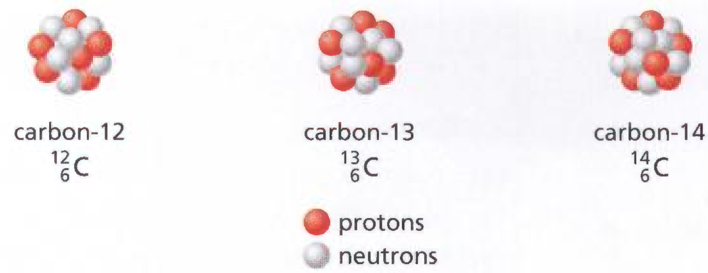
CHAPTER 10 Review

Radioactivity and the Atom

Key Ideas

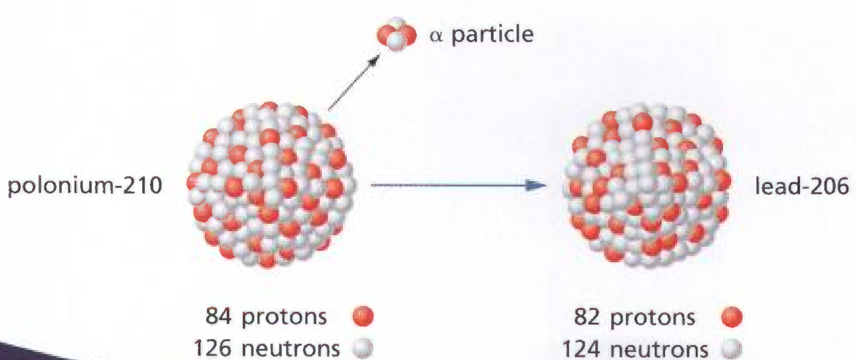
Atoms of a single element that differ in mass are called isotopes.

- All atoms are made of subatomic particles.
- All atoms of an element have the same chemical properties, although the atoms of an element can have different masses.
- An isotope of an element has the same atomic number, but a different mass number, as other isotopes of the same element.
- Isotopes can be written in standard atomic notation; for example, uranium-238 is ${}^{238}_{92}U$ and carbon-12 is ${}^{12}_{6}C$.



The atoms of some elements are radioactive, which means that they undergo radioactive decay.

- Radioactive atoms emit radiation of three different types: alpha, beta, and gamma radiation.
- Alpha, beta, and gamma radiation have different properties of mass, charge, penetrating ability, and reaction to electric and magnetic charges.
- The amount of radiation emitted by a radioactive source is not affected by chemical or physical factors.
- Cathode rays and X-rays are types of radiation that are not produced by radioactive sources.



Vocabulary

radioactivity, p. 278
nucleus, p. 280
proton, p. 281
neutron, p. 281
isotope, p. 281
radioactive decay, p. 284
parent nucleus, p. 284
daughter nucleus, p. 284
alpha particle (α), p. 285
beta particle (β), p. 286
gamma ray (γ), p. 287
half-life, p. 290
decay series, p. 294

There are three basic types of radioactive decay and these processes can be written as nuclear equations.

- During alpha decay, a radioactive isotope emits an alpha particle, which is a helium nucleus. The nuclear equation is

$$^{A}_{Z}N_{\text{parent}} \rightarrow \, ^{A-4}_{Z-2}N_{\text{daughter}} + \, ^{4}_{2}\text{He}$$

- During beta decay, a radioactive isotope emits a beta particle, which is an electron. The nuclear equation is

$$^{A}_{Z}N_{\text{parent}} \rightarrow \, _{Z+1}^{\;\;A}N_{\text{daughter}} + \, ^{\;\;0}_{-1}\text{e}$$

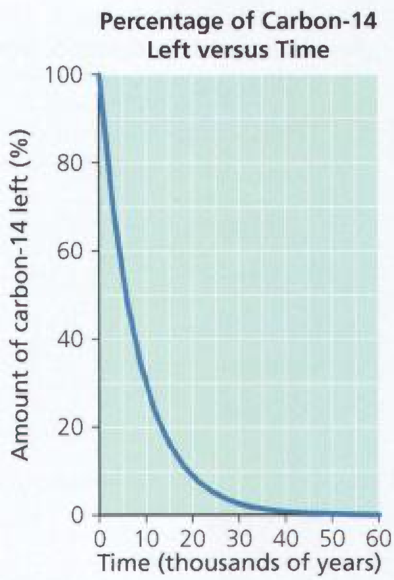
- During gamma decay, a radioactive isotope emits a gamma ray. The nuclear equation is

$$^{A}_{Z}N^{*} \rightarrow \, ^{A}_{Z}N + \, ^{0}_{0}\gamma$$

- Alpha and beta decay transmute atoms into different elements. Gamma decay simply releases energy from an atom's nucleus, but does not transmute the element.
- Radioactive decay can be detected by different devices, such as cloud chambers, bubble chambers, and Geiger counters.

The rate of decay of a radioactive sample is predictable and is described by the half-life of the radioactive isotope.

- The activity level of a radioactive isotope is the rate of decays and is measured in becquerels (Bq). A becquerel is one decay per second.
- An isotope of a radioactive element has a half-life, which is the amount of time it takes for the activity level to be reduced by one-half. This is equal to the time for half of the parent nuclei to decay.
- The half-life of a radioactive isotope can be determined from graphs of number of parent nuclei versus time and activity level versus time.
- Some radioactive isotopes decay in a characteristic series of events.
- Some radioactive isotopes are useful in medicine for diagnosis and treatment.
- Radioactive isotopes can be used to determine the age of some materials.
- Carbon-14 has a half-life of 5730 years and is useful for radioactive dating of material that was once living.



Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. Draw a model of carbon-14 in your notebook, and include protons, neutrons and electrons. What is the relationship between the number of protons and neutrons? What is the relationship between the number of protons and electrons?
2. Explain the difference between an atom and an isotope.

K 3. Which of the following statements correctly compares protons and neutrons?
   A. Outside a nucleus a proton is stable, whereas a neutron is unstable.
   B. The mass of a proton is very much greater than the mass of a neutron.
   C. The electric charge of a proton is equal but opposite to the electric charge of a neutron.
   D. Protons can be found in the nucleus of the atom; neutrons are never found in the nucleus.

4. Describe the difference between alpha decay and beta decay.

K 5. Which of the following correctly identifies a material that will stop each type of radiation?

	Alpha	Beta	Gamma
A.	aluminum	paper	lead
B.	lead	paper	aluminum
C.	paper	aluminum	lead
D.	paper	lead	aluminum

K 6. Which of the following describes gamma radiation?
   A. an electron
   B. a helium nucleus
   C. a hydrogen nucleus
   D. high energy electromagnetic radiation

Use What You've Learned

7. Heavy water is composed of deuterium atoms instead of hydrogen atoms. How much heavier is one molecule of heavy water than one molecule of normal water?

8. Copy Table 1 into your notebook and fill in the missing data.

Table 1 Decay Series of Thorium-232

$^{232}_{90}Th \rightarrow {}^{228}_{?}Ra + ?$	1.4×10^{10} year
$^{228}_{88}? \rightarrow {}^{228}_{89}Ac + {}^{0}_{-1}e$	5.8 year
$^{228}_{89}Ac \rightarrow {}^{228}_{?}Th + ?$	6.1 h
$^{228}_{90}Th \rightarrow {}^{224}_{?}? + ?$	1.9 year
$^{224}_{88}Ra \rightarrow ? + {}^{4}_{2}He$	3.6 d
$^{?}_{88}Rn \rightarrow {}^{216}_{?}? + {}^{4}_{2}He$	54 s
$^{216}_{84}Po \rightarrow {}^{212}_{82}Pb + ?$	0.16 s
$^{212}_{82}Pb \rightarrow ? + {}^{0}_{-1}e$	10.6 h
$^{212}_{83}Bi \rightarrow ? + {}^{0}_{-1}e$	60.5 min
$^{212}_{84}Po \rightarrow ? + {}^{4}_{2}He$	0.3 μs

U 9. Gadolinium-164 decays by beta emission. If a 15 g sample of gadolinium-164 undergoes 3400 decays in 2 min, what is the activity rate of the sample?
   A. 0.125 Bq
   B. 7.5 Bq
   C. 28.3 Bq
   D. 75.6 Bq

10. Krypton-83 has a half-life of 4.5 h.
   (a) How many half-lives is 27 h?
   (b) If an original sample of krypton-83 had a mass of 600 g, how much would be left after 27 h?
   (c) If a sample had an activity of 200 Bq, what was its activity 13.5 h earlier?

U 11. Ten years ago, a hospital bought a radioactive source of cobalt-60, which produces gamma rays. Which of the following describes what has happened to the activity level of the source since it was bought?
   A. The activity level increased.
   B. The activity level decreased.
   C. The activity level remained constant.
   D. The activity level first decreased and then increased.

12. Calcium-47 undergoes beta decay. Figure 1 shows how the activity level of a sample of calcium-47 changes over time.

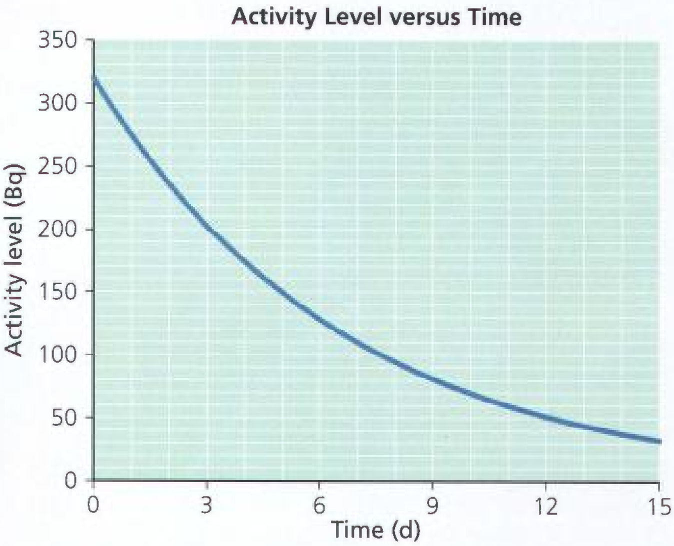


Figure 1

(a) Write the nuclear equation for the beta decay of calcium-47.
(b) After how many days has the activity level of the sample been reduced to 100 Bq?
(c) What is the half-life of calcium-47?
(d) After how much time will the activity level of the sample be reduced to $\frac{1}{8}$ of its initial value of 320 Bq?
(e) At what rate are scandium-47 atoms being produced after seven days?

U 13. The following nuclear equation represents the decay of barium-129:

$^{129}_{56}Ba \rightarrow ^{129}_{55}Cs + ?$

Which of the following is the missing decay product?

A. $^{0}_{0}\gamma$
B. $^{0}_{-1}e$
C. $^{0}_{1}e$
D. $^{4}_{2}He$

14. A sample contained 6000 radioactive atoms. The number of radioactive atoms left was counted every 0.5 s. Figure 2 shows a graph of the number of atoms left. What is the half-life?

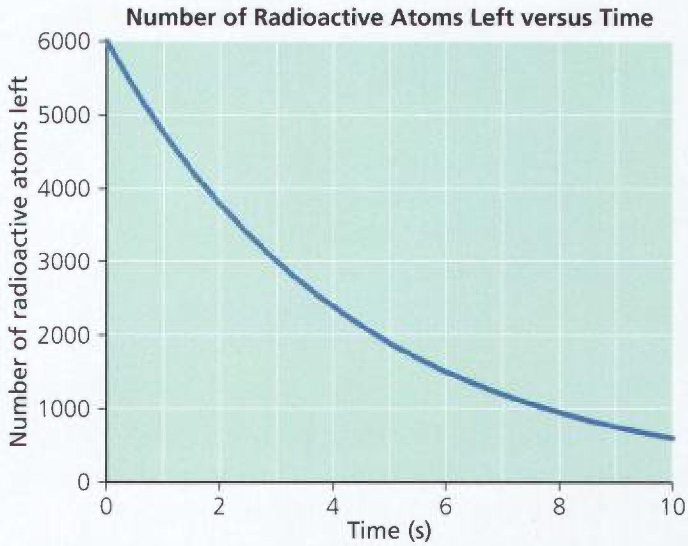


Figure 2

A. 1 s
B. 2 s
C. 3 s
D. 5 s

Think Critically

15. Is it possible to change the amount of radiation emitted by a material by chemical means? If so, provide an example.

16. Research some applications of natural radioactivity.

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17. Explain why radioisotope dating cannot be used directly on fossils of dinosaur bones. Research how scientists age fossils.

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Reflect on Your Learning

18. Describe how your understanding of radiation has changed as a result of studying this chapter.

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

CHAPTER 11

Atomic Energy

Chapter Preview

Nuclear energy—never has an issue been more controversial. Do you agree with those who see nuclear energy as an environmentally clean and viable alternative to producing electricity using fossil fuels? Or, do you agree with those who see nuclear energy as dangerous and destructive, associated with nuclear accidents or nuclear weapons?

In this chapter, you will learn about nuclear reactions: nuclear fission and nuclear fusion. You will also learn about radiation dose. Building on some of the concepts developed in Chapter 10, this chapter will provide a more complete picture of radioactivity.

KEY IDEAS

- Radioactive bombardment can change an isotope that is not radioactive into a radioisotope.
- Nuclear fission occurs when a large nucleus splits into two smaller nuclei.
- Nuclear fusion occurs when two small nuclei are joined into one nucleus.
- Nuclear energy can be generated from the fission or fusion of atoms.

TRY THIS: Chain Reactions

Skills Focus: planning, conducting, observing, evaluating, communicating

In this activity, you will investigate what happens during a chain reaction. A chain reaction is a series of events in which each event causes the next event to occur.

Materials: 100 dominoes, timer

1. Stand one domino on its end. Place the other dominoes in positions near, but not touching, the first domino. The dominoes should be arranged around the first domino so that tipping over the first domino causes the other 99 dominoes to fall.
2. Sketch your arrangement. Tip over the first domino and start the timer. Stop the timer when all of the dominoes have fallen over. Record how many seconds the chain reaction took.
3. Repeat the activity with different arrangements of dominoes. Sketch each arrangement and record how many seconds each chain reaction took.

A. Which arrangements of dominoes took the least time to all fall over?

B. What factor(s) do you think caused the chain reaction to take the least amount of time?

C. How could you arrange the dominoes so that the chain reaction took the longest amount of time?

D. Sometimes a series of accidents on a highway are called chain reactions. How are they similar to the chain reaction produced in this activity?

11.1 Nuclear Reactions

For centuries, alchemists dreamed of changing one element into another without success. Unfortunately, they did not know that most radioactive elements were naturally changing into other elements because of radioactive decay. Today, nuclear scientists are able to change stable isotopes into radioactive isotopes using particle accelerators.

Particle accelerators are devices that accelerate charged particles to very high speeds (near the speed of light) and then smash the particles into target nuclei. There are two designs of particle accelerators: linear and circular. The 3.2 km long Stanford Linear Accelerator Center (SLAC) is the longest linear accelerator in the world. It uses over 80 000 copper discs to create electric and magnetic fields that push particles to very high speeds. A cyclotron (Figure 1) is a circular accelerator that accelerates the particles around a circular path. The particles are accelerated constantly from one side of the circle to the other side, and their path is bent into a circle by very strong magnets. GO

Using accelerators, nuclear scientists are able to study subatomic particles. Nuclear scientists are even able to make elements that do not occur naturally using a process called artificial radioactivity.

STUDY TIP

The key ideas identify the most important ideas found in a chapter. In preparation for creating an exam-study game plan for Chapter 11, make four-column study notes. Write one key idea in each column. As you progress through the chapter, write notes of important things you want to remember under each key idea.

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

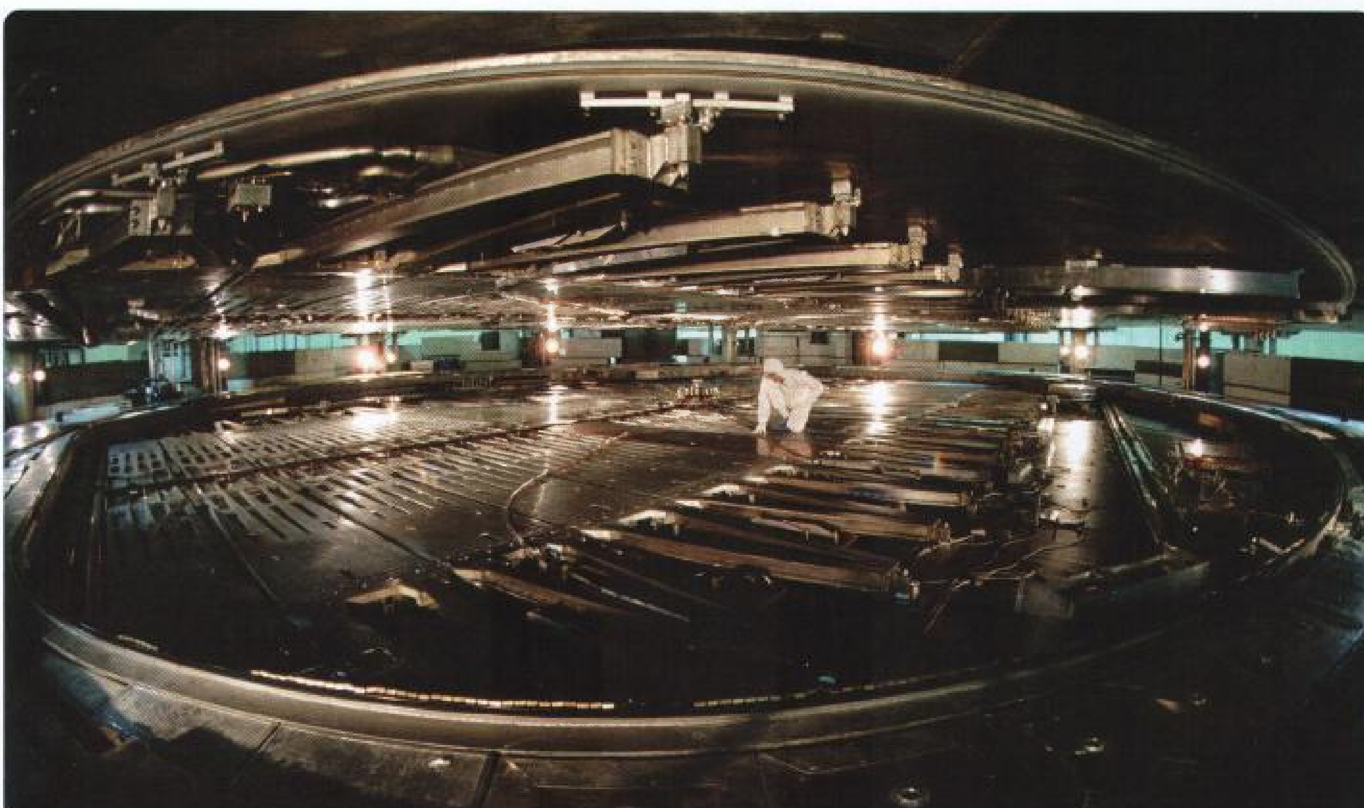

Figure 1 The TRIUMF cyclotron at the University of British Columbia is used to accelerate charged particles.

Figure 2 Irène Joliot-Curie and Frédéric Joliot won the Nobel Prize in Chemistry in 1935 for their synthesis of new radioactive elements.

Artificial Radioactivity

In Chapter 10, we looked at what happens to an atom that undergoes radioactive decay. Radioactive decay occurs spontaneously because the nuclei are unstable.

However, what happens when a stable nucleus is bombarded with a particle, such as an alpha particle or a neutron? In 1934, Irène Joliot-Curie and her husband, Frédéric Joliot (Figure 2), discovered that when they fired alpha particles at a thin sheet of aluminum, the aluminum changed into a radioactive element. In other words, they found that they could change an isotope that was not radioactive into a radioactive isotope by combining it with an alpha particle.

The process is summarized with the following nuclear equation:

$$^{27}_{13}\text{Al} + {}^{4}_{2}\text{He} \rightarrow {}^{30}_{15}\text{P} + {}^{1}_{0}\text{n}$$

The aluminum-27 bombarded with alpha particles changes to produce phosphorus-30 and a neutron. Phosphorus-30 does not occur naturally and spontaneously decomposes. This process is known as artificial radioactivity.

To use an alpha particle to bombard a nucleus, the particle must be travelling at a high enough speed to overcome the repulsion of the positively charged target nucleus. Using neutrons to bombard the nuclei offers an advantage over using alpha particles because neutrons have no charge and, therefore, are not repelled by the target nucleus. Following the discovery of artificial radioactivity, Italian physicist Enrico Fermi realized that neutrons could easily penetrate the nucleus and began bombarding elements with neutrons. Fermi was able to produce several new elements with atomic numbers greater than uranium.

Many other examples of artificial radioactive elements were created. For example, if magnesium-24 is bombarded with high-speed deuterium nuclei, then the following reaction occurs:

$$^{24}_{12}\text{Mg} + {}^{2}_{1}\text{H} \rightarrow {}^{22}_{11}\text{Na} + {}^{4}_{2}\text{He}$$

The discovery of artificial radioactivity meant that radioactive atoms could be prepared relatively easily using particle accelerators. This meant that further discoveries involving the use of radioisotopes were possible, for example in medical diagnostics and cancer therapy.

Did You KNOW?

Base Metal to Gold

Alchemists have dreamed of turning lead into gold. In 1980, Glenn Seaborg, who co-discovered plutonium, and his colleagues used a particle accelerator to transmute bismuth into gold. The process, however, was far too expensive to be used to manufacture gold.

Nuclear Reactions and the Effects on Humans

Nuclear reactions produce radiation when radioactive isotopes decay. Radiation can affect humans by interacting with the DNA in cells. While the body can repair much of the damage caused by exposure to radiation, a double strand break in the DNA is lethal to the cell (Figure 3). Errors in the repair process can also cause mutations, which can lead to cancer.

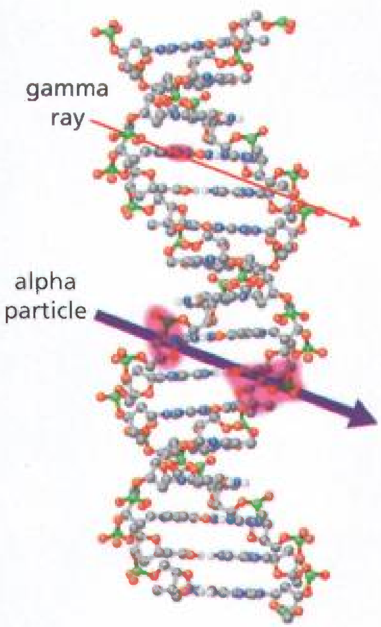

Figure 3 A gamma ray damages a strand of DNA, while an alpha particle completely breaks the strand.

We are constantly exposed to natural background radiation from cosmic radiation, terrestrial sources, and even sources inside our bodies. Cosmic radiation, which is created by the Sun and other bodies outside our solar system, constantly bombards Earth. Terrestrial sources of radiation include rocks, soil, water, air, and buildings. Even our bodies contain radioactive atoms, such as potassium-40 and carbon-14, from the foods we eat and the air we breathe. Of particular concern is rock containing uranium that produces radon gas as a decay product. The gas escapes into the air and can be inhaled. Although radon is chemically inert, it is radioactive.

To learn more about sources of radiation, listen to the audio clip at www.science.nelson.com

In addition to natural background radiation, people receive radiation from artificial radioisotopes and medical X-rays. Artificial radioisotopes are used to treat cancerous tumours.

When radiation interacts with the human body, it gives its energy to body tissues. The absorbed dose is the amount of energy in joules deposited by the radiation per kilogram of absorbing material, or tissue. The absorbed dose is measured in grays (Gy): 1 Gy = 1 J/kg. However, equal absorbed doses of different types of radiation do not cause equal amounts of harm. For example, for a given absorbed dose, alpha particles, which travel relatively slowly, transfer more energy and cause more damage in a shorter distance than beta particles or gamma rays. To account for this difference, we express radiation dose as equivalent dose in units of sieverts (Sv). Table 1 lists some typical exposures of radiation in terms of equivalent dose.

LEARNING TIP

As you read, pause to evaluate information. Ask yourself, "What do I now know about nuclear reactions that I did not know before? Have any of my ideas changed as a result of my reading?"

Table 1 Radiation Exposure

Whole body equivalent dose (mSv)	Exposure
0.0010	annual dose from nuclear power
0.04	dose during coast-to-coast flight across Canada
0.1	typical chest X-ray
1	dose limit for general public above natural background radiation
3	average annual dose from natural radiation
10	CT body scan
12	Apollo astronaut on lunar mission
20*	annual dose limit for radiation workers averaged over a 5-year period

*Most radiation workers receive much less than 20 mSv.

There are four ways to minimize the effects of radiation on your body: limit your exposure time to radiation, keep far away from radioactive sources, shield yourself from radioactive sources, and make sure that radioactive sources in your environment are contained whenever possible.

While there are safety limits for exposure to radiation, any radiation is potentially harmful. Always keep the exposure time to high levels of radiation as short as possible. Although we are constantly exposed to low-level background radiation, our cells are usually able to repair damage done by this radiation. However, an intense burst of radiation may cause an irreparable amount of damage.

The distance to radioactive sources is also a factor. Since a radioactive source emits radiation in all directions, the intensity of the radiation decreases as it spreads out. For example, if you are exposed to a certain level of radiation when you are 1 m from the source, when you move to 2 m (twice the distance) from the source, the intensity of the radiation is one-quarter; at three times the distance, the intensity of the radiation is only one-ninth, and so on. In other words, the intensity reduces with the square of the distance. The most effective way to protect yourself from radiation is to shield yourself from radioactive sources. Shields can either be made of thin layers of dense materials, such as lead, or thick layers of less dense materials, such as concrete. The amount of shielding required depends on the type of radiation emitted.

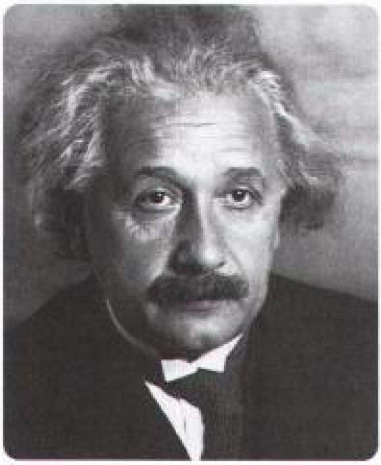

Figure 4 Albert Einstein received the 1921 Nobel Prize in Physics.

Mass and Energy in Nuclear Reactions

Energy comes in many forms, including kinetic, chemical, elastic, gravitational, and nuclear. During nuclear reactions, large amounts of energy are released. Where does nuclear energy come from?

In 1905, Albert Einstein (Figure 4) published his *Special Theory of Relativity*. In his theory, he proposed some very interesting relationships between space and time. However, Einstein also proposed that mass and energy are not separate entities, but are equivalent. Einstein showed that mass is related to energy by his famous equation:

$$E = mc^2$$

where E is the energy (measured in joules), m is the mass (measured in kilograms), and c is the speed of light (3.0×10^8 m/s). GO

To learn more about the life and work of Albert Einstein, go to www.science.nelson.com GO

How does Einstein's equation relate to nuclear reactions? In general, the mass of the products produced in a nuclear reaction is less than the mass of the original materials. The missing mass appears as energy.

LEARNING TIP

Check your understanding. Einstein's equation shows that mass is related to energy. Work with a partner to explain what he meant by this. In the equation $E = mc^2$, what does each of the variables represent?

Let's look at an example. How much energy is available in a 75 g lump of coal? About 1.5×10^6 J of chemical energy is available if the coal is burned completely. However, if all of the coal's mass is converted into energy according to Einstein's formula, the nuclear energy available is

$$E = mc^2 = (0.075 \text{ kg})(3.0 \times 10^8 \text{ m/s})^2$$
$$E = 6.8 \times 10^{17} \text{ J}$$

In other words, 450 billion times more nuclear energy is available. The energy is released as the kinetic energy of the emitted radiation and daughter nuclei. As the high-energy radiation interacts with matter, it spreads to many atoms, eventually taking the form of an increase in the temperature of the material. This increase in temperature represents an increase in thermal energy, which can be converted into other forms of energy, such as electrical energy.

11.1 CHECK YOUR Understanding

1. Compare radioactive decay and artificial radioactivity.
2. The following nuclear equations represent the creation of different isotopes by bombardment of atoms. Complete each nuclear equation.
   (a) $^{14}_{7}N + ^{4}_{2}He \rightarrow ? + ^{1}_{1}H$
   (b) $^{9}_{4}Be + ^{1}_{1}H \rightarrow ? + ^{4}_{2}He$
   (c) $^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ?$
   (d) $^{197}_{79}Au + ^{1}_{0}n \rightarrow ?$
   (e) $^{19}_{9}F + ^{1}_{1}H \rightarrow ? + ^{4}_{2}He$
3. Bombarding a nucleus with alpha particles can be used to create artificial radioactive isotopes. James Chadwick used alpha particles to bombard boron-11 and beryllium-9 to discover the neutron. Complete the following nuclear equations that describe his nuclear reactions:
   (a) $^{11}_{5}B + ^{4}_{2}He \rightarrow ? + ^{1}_{0}n$
   (b) $^{9}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + ?$
4. State two reasons why it is easier for a neutron to penetrate a nucleus than for an alpha particle to penetrate a nucleus.
5. Why do alpha particles have a greater effect on the health of human beings than beta or gamma radiations?
6. Why are internal organs unlikely to be affected by alpha radiation? What do you think is one organ that could easily be affected by alpha radiation?
7. Write a definition of natural background radiation in your own words and list five sources of natural background radiation.
8. Radiation is measured in absorbed dose and equivalent dose. What are the units of each and what is the difference between the two measurements?
9. If you stand twice as far away from a nuclear radiation source as your friend, how much less radiation will you receive?
10. For equal amounts of radiation, is it better to be exposed to an intense burst of radiation for a short length of time or have the radiation spread out over a long time? Why?
11. Shielding is used to protect people from nuclear radiation. What types of materials make good shields? Explain your answer.
12. After the Chernobyl nuclear accident some of the workers involved in the initial clean-up received nuclear doses of up to 100 mSv. How many times greater than the average yearly dose from natural sources is this amount?
13. In the equation $E = mc^2$, what does each of the variables represent?
14. If 10.0 kg of a substance is converted entirely into energy, how much energy would be produced?
15. A mosquito has a mass of 2 mg.
    (a) If it were possible to convert the mosquito's mass into energy, how much energy could be produced?
    (b) Burning a litre of gasoline produces 34.6 MJ (3.46×10^7 J) of energy. Compare the energy in a mosquito with the energy in a litre of gasoline.

RADIONUCLIDE IMAGING

Radionuclides allow us to see inside the body and understand the physiology, including blood flow and chemical changes. In PET imaging, tiny amounts of radioactive materials are injected in the body. PET imaging is causing a revolution in such medical fields as cancer diagnosis.

In futuristic science fiction movies, doctors typically are seen diagnosing and curing patients using a hand-held electronic device. While our medical knowledge and tools may not be as "advanced" as in the movies, scientists have developed some amazing techniques to diagnose diseases.

One technique uses radioisotopes to help diagnose many diseases, especially those of the bones, thyroid, heart, and liver. This is a branch of medical imaging called "nuclear medicine." A radioisotope is incorporated into a chemical compound that is specifically designed to highlight physiological changes of a particular organ. The substance is injected or given orally to the patient. Since the radioisotope emits radiation, its location within the body can be pinpointed using special gamma cameras (Figure 1).

The radioisotopes used in imaging include technetium (^{99m}Tc), thallium (^{201}Tl), and gallium (^{67}Ga). These radioisotopes have fairly short half-lives, which means that they quickly decay or are eliminated from the body.

A recent development in radionuclide imaging is PET (positron emission tomography) imaging, which can help to diagnose and locate cancer, Alzheimer's disease, and Parkinson's disease. The most common tracer used in PET imaging is fluorine (^{18}F), which emits positrons as it decays. A positron has the same mass as an electron, but it has a positive charge. When a positron collides with an electron, the positron and the electron annihilate each other and emit two gamma rays. The interesting thing is that the gamma rays are emitted in opposite directions from each other. The PET imager is ingeniously designed to exploit this fact. By using a ring of detectors, the PET imager can pinpoint the exact location of the annihilation event within the body, thereby building up an image.

Radionuclide imaging can give useful information about the body. One drawback is that the images do not contain sufficient information about the body to enable doctors to precisely determine the location of the disease. Recently, PET images are being overlaid with CT (computed tomography) images (Figure 2). This combination has caused a revolution in cancer diagnosis and treatment.

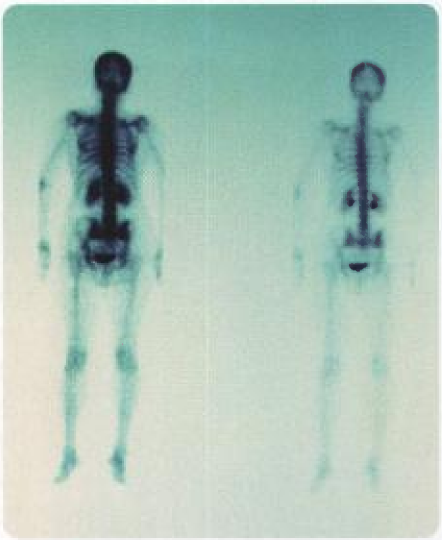

Figure 1 Technetium (^{99m}Tc) bone scan using a gamma camera. The scan shows that the patient has cancer in the bones (shown as dark areas).

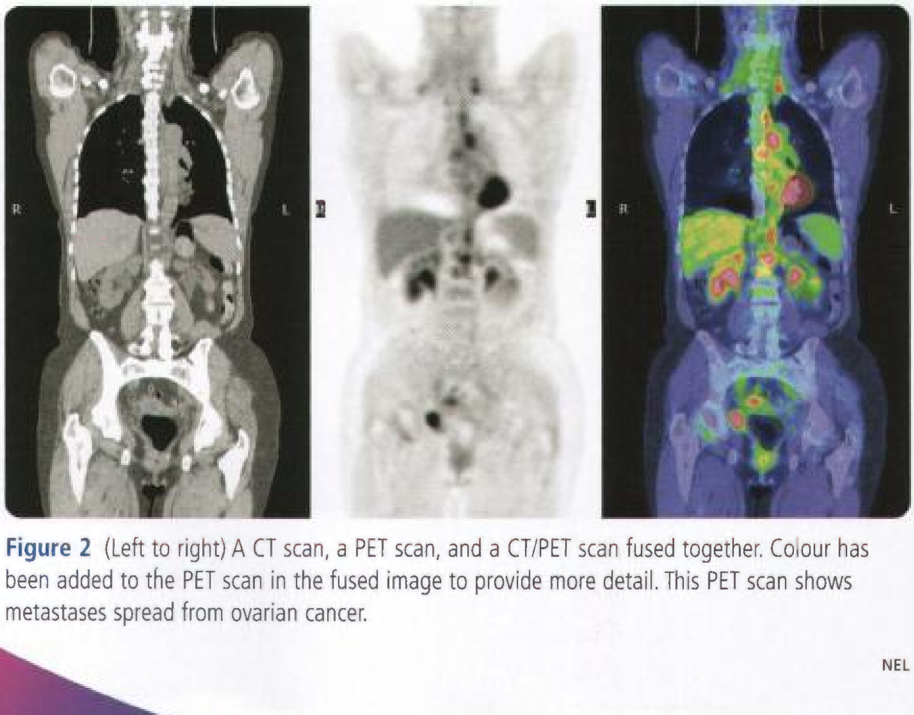

Figure 2 (Left to right) A CT scan, a PET scan, and a CT/PET scan fused together. Colour has been added to the PET scan in the fused image to provide more detail. This PET scan shows metastases spread from ovarian cancer.

11.2 Nuclear Reactions: Fission

Following Fermi's work in 1938, Otto Hahn, Lise Meitner, and Fritz Strassmann discovered that when neutrons bombarded uranium atoms, the reaction produced smaller nuclei that were about half the size of a uranium nucleus. Later, Meitner and Otto Frisch realized that after the uranium nucleus had absorbed a neutron, it split into two smaller nuclei. Until then, the only known nuclear processes involved a nucleus emitting a small fragment such as an alpha particle or a beta particle. This process of splitting a large nucleus into two smaller nuclei is called **nuclear fission**. Meitner and Frisch used the term because of the similarity to the process of cellular fission in biology.

Meitner and Frisch realized that, although the positively charged protons could exist side by side inside the nucleus, when the nucleus divided, there would be two positively charged nuclei very close to each other. These two nuclei would exert a very large electrostatic force of repulsion on each other and, therefore, would be driven apart with great speed. This means that the nuclei would have a great amount of kinetic energy. They concluded that a nuclear fission reaction would produce very large amounts of energy.

On Earth, uranium naturally occurs as three isotopes: 99.275 % is uranium-238, 0.720 % is uranium-235, and 0.005 % is uranium-234. Although all three isotopes are radioactive, they have very long half-lives and this type of decay is not significant for nuclear energy. Uranium-234 and uranium-238 do not undergo fission readily. However, if an atom of uranium-235 absorbs a neutron, it becomes uranium-236. The nuclear equation for this reaction is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{236}_{92}\text{U}$$

The uranium-236 nucleus is unstable and exists very briefly—for about a millionth of a millionth of a second—and then splits into two smaller nuclei (N_1 and N_2). The reaction releases a tremendous amount of energy. In addition, this process usually produces two or three neutrons. The nuclear fission reaction of uranium-235 can be written as

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{236}_{92}\text{U} \rightarrow N_1 + N_2 + \text{neutrons}$$

Several models have been proposed to describe how the nucleus splits into two parts. The liquid drop model treats the nucleus as if it were composed of a liquid. The protons and neutrons are like the molecules in a drop of water. The liquid nucleus is held together by cohesive forces that compete with repulsive electrostatic forces. The liquid drop model not only provides an

Did You KNOW?

Cheated out of a Nobel Prize?

Should Lise Meitner have been awarded the Nobel Prize? Meitner and Hahn worked together for 30 years in Germany. In 1917, they discovered the element protactinium. After she fled Nazi Germany at the end of 1938, Hahn and Strassmann analyzed the products formed when uranium was bombarded with neutrons and found that the elements were lighter than uranium. Hahn turned to Meitner to come up with the explanation. Within days, she and Otto Frisch had worked out a theoretical model of nuclear fission. Meanwhile, Hahn published his evidence of fission without listing Meitner as a contributor. Hahn won the 1944 Nobel Prize in Chemistry. Element 109 was named meitnerium after Meitner in 1994.

explanation of the splitting of a nucleus, but also provides a means of visualizing the process, as shown in Figure 1.

Note that the smaller nuclei (N_1 and N_2) are roughly half the original mass, but they are not equal in size. However, the total mass is about the same as the mass of the uranium-236 nucleus. Although there are many different possible nuclei produced, one possible nuclear fission equation is

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{141}_{56}\text{Ba} + ^{92}_{36}\text{Kr} + 3^{1}_{0}\text{n}$$

There are three neutrons produced in this fission reaction. The reaction follows the two rules for nuclear equations. First, the conservation of electric charge (atomic number) is obeyed since the total before (92 + 0) is the same as the total after (56 + 36 + 0). Second, the conservation of the total number of protons and neutrons (mass number) is obeyed since the total before (235 + 1) is the same as the total after (141 + 92 + 3(1)). Although the mass number is the same before and after, the mass is not. The mass of the products is slightly less since the fission reaction has converted a tiny amount of mass into energy. GO

To learn more about nuclear fission, go to www.science.nelson.com GO

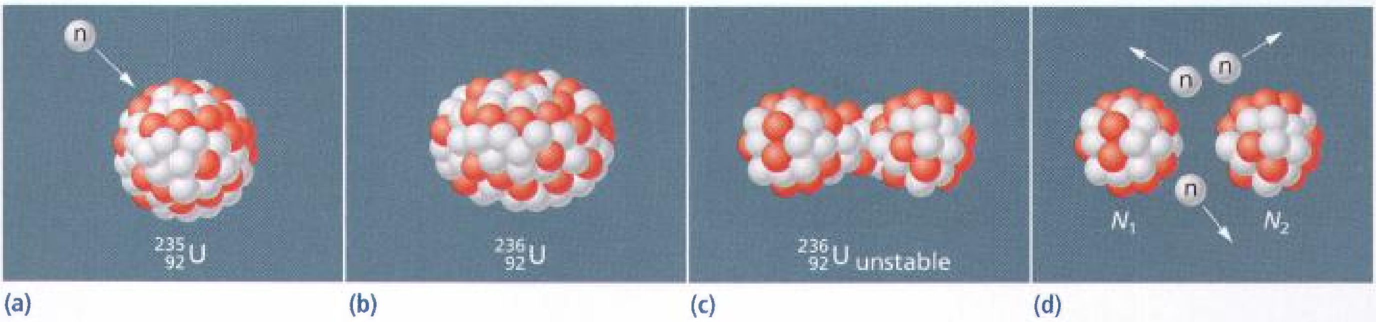

Figure 1 (a) The neutron penetrates the nucleus and transforms the uranium-235 into uranium-236. (b) The neutron changes the isotope and excites the nucleus. This causes the nucleus to become elongated. Since the two ends of the nucleus are both positively charged, they repel each other. (c) Because the force of repulsion is so strong, it causes the nucleus to split apart. (d) The fission of the nucleus is accompanied by the release of energy and three neutrons.

STUDY TIP

To help you recognize and solve similar problems on an exam, make a two-column chart of sample problems and methods of solution. In one column of the chart, write the problem. In the other column, write the steps to the solution. Reread the chart and try to picture the solution in your head.

SAMPLE PROBLEM

Determine the Missing Fragment

Consider the following nuclear equation:

$$^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{140}_{54}\text{Xe} + ? + 2^{1}_{0}\text{n}$$

(a) How many neutrons are produced by the reaction?

(b) Complete the nuclear equation.

Solution

(a) The large number 2 in front of the neutron indicates that there are 2 neutrons produced.

(b) Since the total of the atomic numbers on each side of the equation must be equal, the missing atomic number is 92 − 54 = 38. This means that the missing element is strontium. Since the total mass number on each side of the equation must be equal, the mass of the strontium must be (235 + 1) − (140 + 2(1)) = 94. Therefore, the missing isotope of the missing fragment is strontium-94 and the completed equation is

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{140}_{54}Xe + ^{94}_{38}Sr + 2^{1}_{0}n$$

Practice

Consider the following nuclear equation:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ? + ^{89}_{36}Kr + 3^{1}_{0}n$$

(a) How many neutrons are produced by the reaction?

(b) Complete the nuclear equation.

Both uranium-235 and uranium-238 occur in natural ores containing uranium. Since the isotopes of uranium are chemically very similar, they must be separated from each other using physical properties. Uranium-238 is slightly heavier (by one percent) than uranium-235. This difference in mass can be used to separate the isotopes. However, since the difference is very small, the separation is both difficult and costly.

Energy in Nuclear Fission Reactions

A tremendous amount of energy is produced in a nuclear fission reaction. Since the sum of the mass numbers before and after a nuclear fission is the same, how is it possible to get energy from nuclear fission? The answer is that a tiny amount of mass is converted to energy. We know this because there is a difference between the sum of the atomic masses before and after the reaction. To see exactly how much mass is converted into energy, we must convert the masses from accurate atomic mass units (u) into kilograms (kg). For example, let's look at the reaction

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3^{1}_{0}n$$

Tables 1 and 2 show the calculations for the masses of uranium-235 and neutrons before nuclear fission, and the isotopes and the neutrons produced after nuclear fission.

LEARNING TIP

Check your understanding of nuclear fission. Discuss the following analogy with a partner: Nuclear fission is to physics as cellular fission is to biology.

Table 1 Before Nuclear Fission

Isotope	Atomic mass unit (u)	Mass (kg)
uranium-235	235.04392	3.902999×10^{-25}
neutron	1.008665	1.674929×10^{-27}
total	236.05259	3.91975×10^{-25}

Table 2 After Nuclear Fission

Isotope	Atomic mass unit (u)	Mass (kg)
barium-141	140.91436	2.339940×10^{-25}
krypton-92	91.92627	1.526473×10^{-25}
neutrons (3)	3.025995	5.024786×10^{-27}
total	235.86663	3.916660×10^{-25}

Using Tables 1 and 2, we can see that the total mass converted as a result of nuclear fission is

$$m = 3.91975 \times 10^{-25}\ \text{kg} - 3.916660 \times 10^{-25}\ \text{kg} = 3.090 \times 10^{-28}\ \text{kg}$$

We can calculate the amount of energy produced using Einstein's equation (with a slightly more accurate number for the speed of light):

$$E = mc^2 = (3.090 \times 10^{-28}\ \text{kg})(2.997925 \times 10^8\ \text{m/s})^2$$
$$E = 2.777 \times 10^{-11}\ \text{J}$$

While this may seem like a tiny amount of energy, it is an enormous amount for a single atom to produce. By comparison, this is more than a million times more energy than a single molecule of carbon in a lump of coal releases when it reacts chemically. However, to produce a useful amount of energy using nuclear fission, a nuclear fission reactor is needed.

STUDY TIP

Reduce chapter test anxiety—start to study for a chapter test early. You cannot hope to cram three or four weeks of learning into a couple of days of studying!

Did You KNOW?

The Manhattan Project

Established just before the start of World War II in 1939, the Manhattan Project was the code name for the U.S. government's secret program to develop the first nuclear fission bomb. Enrico Fermi's successful production of a controlled nuclear fission reaction, in 1942, quickly led to the development of the first nuclear fission bombs. The first bomb was exploded at Los Alamos, New Mexico, on July 6, 1945. One month later, two nuclear weapons were exploded over Japan, at Hiroshima and Nagasaki. The Manhattan Project had taken fission from the laboratory to the battlefield.

Nuclear Fission Weapons

Once scientists understood that a fission reaction could produce great quantities of energy, their focus turned to creating nuclear weapons. A fission bomb, which is also called an atomic bomb, uses uranium or plutonium stored at a mass that is less than the critical mass. Critical mass is the mass of radioactive material required to initiate the reaction. When the material starts to undergo a reaction, the reaction proceeds at an increasing rate until all of the material is used. The nuclear material must be stored safely until needed, and then the goal is to use up all of the nuclear material before the bomb destroys itself. The simplest way to keep the mass less than critical mass is to keep the material in two sections and then force the pieces together. This is known as the "gun method." The bomb that was dropped on Hiroshima in Japan was a gun-type bomb.

Another way to detonate a nuclear weapon uses the "implosion" method. In this case, a chemical explosion compresses a single subcritical piece of nuclear material so that the nuclear material exceeds the critical mass. The bomb detonated over Nagasaki in Japan was an implosion-type bomb (Figure 2). GO

To learn more about nuclear fission weapons, go to **www.science.nelson.com** GO

Figure 2 The detonation of a nuclear fission bomb in Nagasaki caused immense damage from the intense heat of the explosion, the pressure of the shock wave from the blast, and radioactive fallout.

11.2 CHECK YOUR Understanding

1. Of the naturally occurring radioactive elements, which has the largest atomic number?
2. Write a definition of nuclear fission in your own words.
3. How is nuclear fission in physics similar to cellular fission in biology?
4. Nuclear fission produces two daughter nuclei that are driven apart with great speed. What causes the nuclei to be driven apart?
5. Compare radioactive decay and nuclear fission.
6. Describe the liquid drop model of nuclear fission in your own words.
7. Uranium-238 is the most common isotope of uranium on Earth. Would a 10 kg sample of uranium-238 be dangerous?
8. Uranium-236 is used in fission reactions to produce energy.
   (a) Why does uranium-236 not exist naturally on Earth?
   (b) How is uranium-236 produced for fission reactions?
9. When writing nuclear equations, you must follow two rules. Describe each rule.
10. Complete the following nuclear equations:
    (a) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{139}_{56}\text{Ba} + \textbf{?} + 3{}^{1}_{0}\text{n}$
    (b) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{132}_{50}\text{Sn} + \textbf{?} + 3{}^{1}_{0}\text{n}$
    (c) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow \textbf{?} + {}^{101}_{41}\text{Nb} + 3{}^{1}_{0}\text{n}$
    (d) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{141}_{56}\text{Ba} + \textbf{?} + 3{}^{1}_{0}\text{n}$
    (e) ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{90}_{37}\text{Rb} + {}^{144}_{55}\text{Cs} + \textbf{?}$
11. One possible outcome of the fission reaction of uranium is the production of strontium-90 and xenon-143 along with three neutrons and energy (Figure 3). Write the nuclear equation for this reaction beginning with the addition of a neutron to a uranium-235 nucleus.

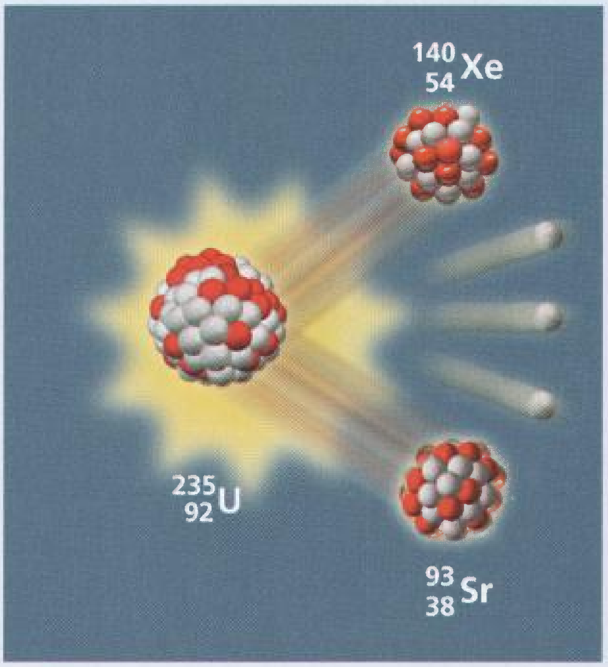

Figure 3

12. How does the total mass of the uranium-235 atom plus the neutron compare with the total mass of the products? Explain your answer.
13. If the mass of an electron ($9.10938188 \times 10^{-31}$ kg) were converted to energy, how much energy would it produce?
14. Uranium-235 is separated from the other two naturally occurring isotopes of uranium by physical means. Why is it not possible to use chemical means?
15. When an atom undergoes nuclear fission, it releases a relatively large amount of energy. Where does the energy come from?
16. What is meant by the term "critical mass"?

11.3 Nuclear Power Generation

For more information on chain reactions, go to www.science.nelson.com

LEARNING TIP
Visualization is a good way to remember things that are easy to picture. As you read the section on chain reaction, try to create a picture. Cover the section and recall your picture. Compare what you saw with the information in Figure 1. Did you leave out any important information?

The energy produced from individual nuclear fission reactions is very small. To produce a useful amount of energy, many fission reactions need to occur simultaneously. Physicists realized that the clue lay in the neutrons emitted as part of a nuclear fission reaction. When a neutron hits a uranium-235 atom to produce a uranium-236 atom, the uranium-236 undergoes fission and produces two or three neutrons. Those neutrons could then cause other nuclear fission reactions and continue the process in a **chain reaction**.

Figure 1 shows how a chain reaction could produce a large number of nuclear fission reactions. A single neutron begins the chain reaction. One event can cause three events, which can then cause nine events, and so on. This is exactly what is needed to produce the large number of reactions required to produce usable energy from nuclear fission, but the rapid increase in the number of fissions also clearly gives it the potential to run out of control.

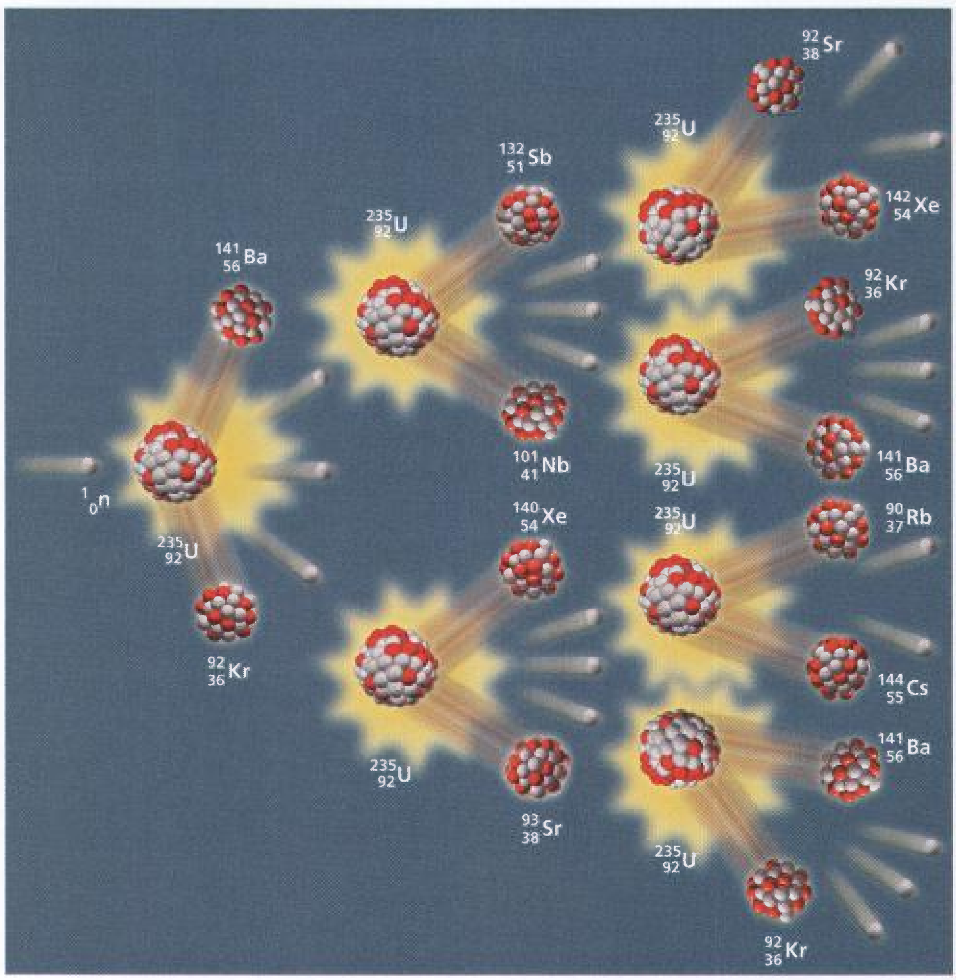

Figure 1 A self-propagating nuclear chain reaction initiated by a single neutron. The fission of uranium-235 produces a variety of products.

The Development of the Nuclear Fission Reactor

After the discovery of nuclear fission in 1939, Enrico Fermi began designing a way to create a self-sustaining chain reaction. Fermi and his team built the first nuclear fission reactor in Chicago (Figure 2).

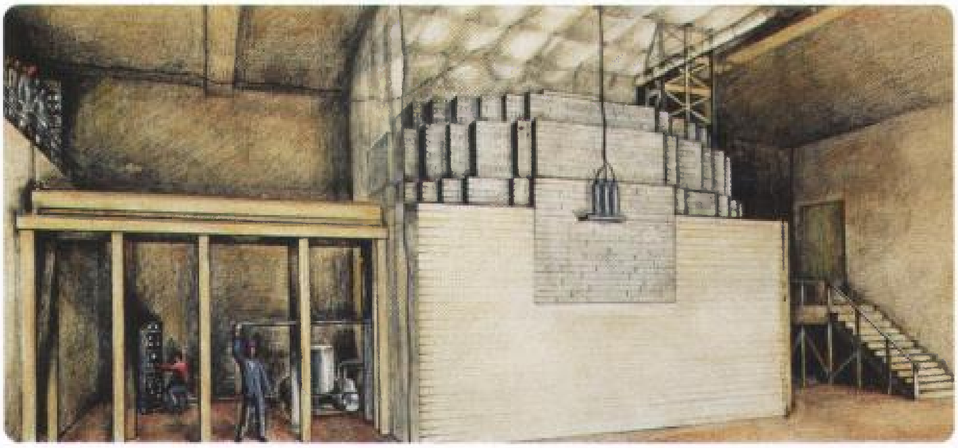

Figure 2 The world's first artificial nuclear reactor, Chicago Pile-1 (CP-1), was built on an old racquet court under the abandoned stands of Stagg Field stadium at the University of Chicago. The first artificial, self-sustaining nuclear fission reaction was initiated within CP-1 on December 2, 1942.

Before building the nuclear fission reactor, Fermi and his team of scientists had to solve five major problems. First, they had to determine which material would be used. Not every neutron produced as a result of fission is aimed at a uranium-235 atom. Rocks containing uranium are relatively common on Earth's surface, but do not form a chain reaction since the uranium atoms are spread relatively far apart. Even if the uranium is separated from the ore, over 99 % of the naturally occurring uranium is uranium-238, which absorbs neutrons without undergoing fission. The uranium had to be enriched to increase the proportion of uranium-235 atoms.

The second problem was that the neutrons that are emitted in a nuclear fission reaction have high speed. However, the uranium-235 nucleus will only absorb a slow moving neutron. To slow the neutrons down, scientists needed to find a moderator, which is a material that slows neutrons down as they move through it. Possible moderators considered were water (H_2O), heavy water (D_2O), and carbon. The hydrogen atoms in water tended to absorb the neutrons, so water could not be used. Heavy water is chemically identical to normal water except that the molecule is formed with deuterium atoms (^2_1H) rather than hydrogen atoms (^1_1H). It is called "heavy water" because deuterium atoms are twice as heavy as hydrogen atoms. Heavy water was scarce and expensive to produce so graphite, a form of carbon, was used as a moderator in the first nuclear fission reactor.

The third problem was that the neutrons would simply escape if there was not enough uranium fuel. The minimum mass of fuel needed to produce a reaction is called the critical mass. The critical mass depends on the isotope used. For example, the critical mass for uranium-235 is only several kilograms.

The fourth problem involved controlling the fission reaction. An uncontrolled chain reaction results in an explosion. To produce usable energy, the reaction must be controlled. Moveable control rods made of cadmium or boron were used to absorb neutrons. The rods were inserted

Did You KNOW?

Fermi: The Ultimate Physicist

Enrico Fermi was the last physicist whose accomplishments were in both theoretical and experimental physics. Not only could he solve abstract problems, but he could also build useful experimental tools. Fermi received the 1938 Nobel Prize in Physics for his discovery of new radioactive elements produced by neutron irradiation, and for the discovery of nuclear reactions brought about by slow neutrons. He was also a key figure in developing a nuclear fission reactor and, ultimately, the atomic bomb.

near the uranium-235 fuel to slow down, or withdrawn to speed up, the rate of nuclear fission reactions.

The fifth and final problem was dealing with the large amount of heat energy generated during the reaction. A coolant was used to remove the heat energy, which was then converted into electrical energy. Typically, the heat energy is used to boil water and produce steam that drives a turbine. The turbine is connected to a generator, which produces electricity.

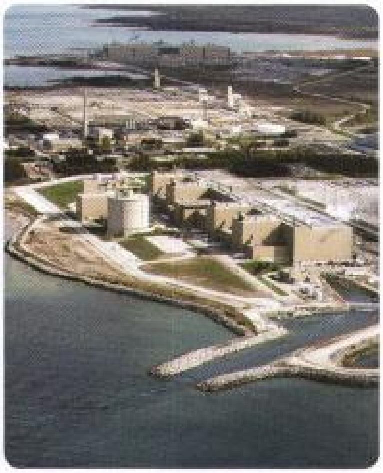

Figure 3 Bruce Nuclear Generating Stations A and B, on the eastern shore of Lake Huron, presently provide about 20 % of Ontario's electricity.

Nuclear Fission Reactors

There are over 440 nuclear reactors worldwide supplying 17 % of the world's electricity. There are different designs for nuclear fission reactors. They differ in the substances used for the moderator and the coolant.

The CANDU Reactors

CANDU reactors have been supplying electricity to Canadian consumers since 1962. Today there are 32 CANDU reactors around the world, including 18 in Canada (Figure 3). The name CANDU comes from three words: **CAN**adian, **D**euterium, and **U**ranium. The reactor was designed in Canada, uses heavy water (dideuterium oxide) as both a moderator and coolant, and natural uranium as the fuel (Figure 4). Natural uranium is cheaper, more easily available, and does not need enrichment facilities. Natural uranium only contains about 0.7 % uranium-235; the rest is uranium-238, which does not undergo fission readily. To increase the probability of fission, an excellent moderator, heavy water, is used to slow down the neutrons. GO

To learn more about the CANDU reactor, visit **www.science.nelson.com** GO

The CANDU reactor is known as a pressurized heavy water reactor (PHWR). Heavy water is an expensive moderator and coolant. Other types of reactors use cheaper moderators, such as water or graphite. However, cheaper moderators require the use of expensive enriched uranium.

The CANDU reactor also has control rods made of cadmium. By adjusting the amount the control rods are inserted, the rate of fissions and, therefore, the heat output is controlled.

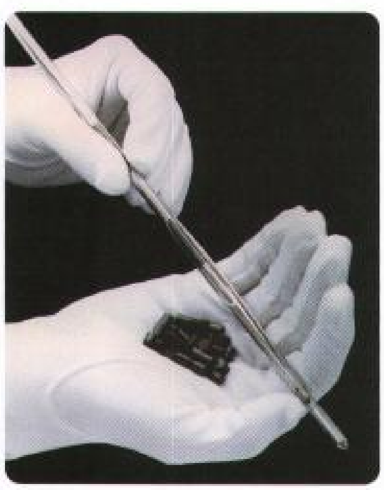

Figure 4 CANDU fuel pellets are made of crushed natural uranium. The pellets are placed in long metal rods that are sealed at both ends.

Although the fuel rods themselves are not radioactive, some of the fission products created are radioactive isotopes, which decay by producing alpha and beta particles, and gamma rays. While the alpha and beta particles produced can be easily stopped by solid materials, about a metre of concrete is required to stop the gamma rays. Since neutrons have no charge, they can penetrate solid walls. Neutrons are stopped by materials similar to those used for moderators and materials that contain hydrocarbons. For the safety of people working near the reactor, the core is contained in a series of shells that contain the radioactive by-products and protect workers from the radiation. In addition to shielding some of the operations that need to be done near the reactor, for added protection to workers, some operations are performed by remote control.

At the reactor, the nuclear energy is converted into heat energy. The heat energy still needs to be converted into electrical energy. Figure 5 shows a schematic for this process.

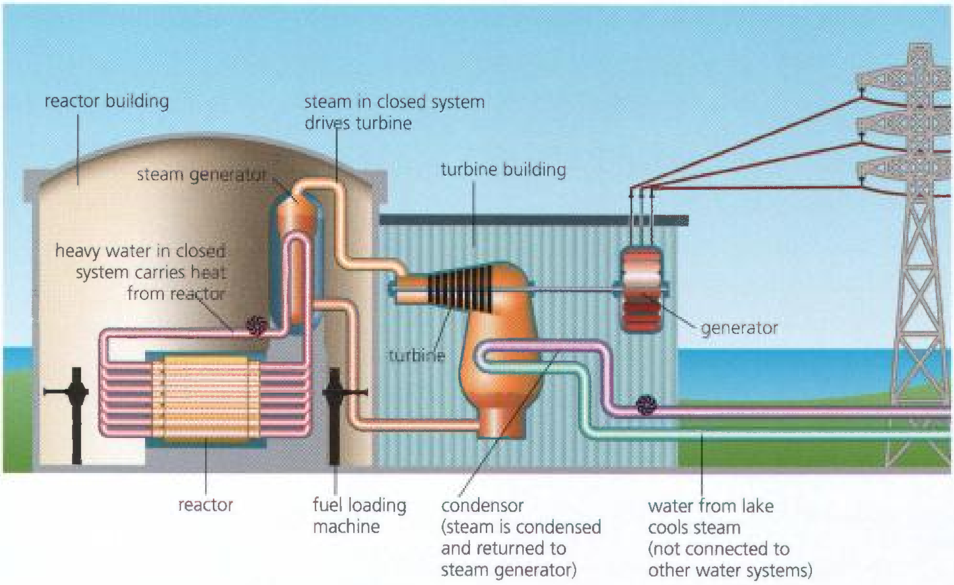

Figure 5 In a CANDU reactor, the water that produces the steam to drive the turbine and generator is completely separated from the heavy water that surrounds the nuclear fuel.

LEARNING TIP

A diagram such as Figure 5 helps illustrate how one piece of information is related to another. Each label has a purpose. Ask yourself, "How are the labels related to the diagram? How does this information relate to what I already know about a CANDU reactor?"

The heat is transported away from the reactor core by the heavy water coolant and transferred to fresh water. The fresh water boils and the steam turns a turbine, which causes a generator to produce electricity. The voltage of the electricity is raised by a transformer and transmitted down high voltage lines to consumers.

Pressurized Water Reactor

The most common nuclear fission reactor in the world is the pressurized water reactor (PWR). The PWR was originally developed to power nuclear submarines. This type of reactor uses normal water for the moderator and coolant. Since normal water absorbs neutrons, PWRs must use uranium fuel that has been enriched so that the percentage of uranium-235 in natural uranium is raised from 0.7 % to about 3 %. The coolant loop in the reactor is at high pressure and requires the use of high-strength materials, which increases the cost of the system.

A disadvantage of the PWR is that it must be shut down every 12 to 18 months for refuelling. There are no PWRs in Canada.

Did You KNOW?

Other Reactors

There are different types of reactors used by various countries around the world. The boiling water reactor (BWR) uses water as a coolant at lower pressures and to drive the turbine directly. Fast breeder reactors (FBR) do not use a moderator to slow down the neutrons. These reactors are designed to produce more nuclear fuel than they consume.

Nuclear Power

Regardless of the type of reactor used, there are both advantages and disadvantages of nuclear power. Using nuclear energy to generate electricity does not produce air pollution.

However, there are safety concerns associated with reactors. Although reactors have high levels of safety built into them, there is an inherent risk associated with the possibility of an accident. As reactors age, there is an increasing danger of minor failures of materials that may allow the release of

Figure 6 The international symbol for radiation appears wherever there are radioisotopes or machines that can produce radiation. This includes hospitals, nuclear research facilities, and nuclear power plants.

radioactive materials into the environment (Figure 6). The advantages and disadvantages of nuclear power are summarized below.

Advantages

- requires inexpensive fuel
- low levels of carbon dioxide produced
- produces large amounts of energy in a single plant
- fuel is easy to transport
- uranium is widely distributed around the world
- does not create acid precipitation or air pollution

Disadvantages

- requires large, expensive containment and waste storage facilities
- risk of accidents (although it is low)
- produces radioactive waste that requires long-term storage
- potential for waste products to be used in nuclear weapons
- limited supply of uranium on Earth
- perceived by the public as undesirable or too risky

STUDY TIP

Think about how you take notes. Compare your notes with the notes on this page. When you write point form notes, do you write only the words needed to record the ideas presented?

A major concern with nuclear reactors is the possibility of a meltdown where the heat generated by the nuclear process increases uncontrollably and melts the materials containing the reactor. This would result in an explosion or fire that releases large amounts of radioactive materials into the environment.

Nuclear power plants generate waste heat. In a nuclear power plant, the hot water used to drive the turbines often is dumped into a nearby lake or river. This can be avoided by recirculating water through large cooling towers. While these problems are of significant concern, the problem of nuclear waste products is both an immediate and long-term problem. Since the fission of uranium (or other nuclear fuel) produces a wide variety of fragments, there is a wide assortment of isotopes, many of which are radioactive. Some of the isotopes have short half-lives. For example, the half-life of iodine-131 is 8 days, while the half-life of krypton-85 is 11 years. However, the spent fuel rods also contain radioactive wastes that have very long half-lives. For example, the half-life of technetium-99 is 210 000 years.

To deal with the short half-lives, the spent fuel rods are stored in water for several years. However, isotopes with long half-lives will be a problem for a very long time. There is an increasing amount of nuclear waste currently stored in temporary facilities around the world waiting for a permanent solution (Figure 7). One solution is to bury the radioactive waste deep in the ground in storage containers. This solution requires that the ground be geologically stable. The Canadian Shield has been proposed as a suitable area. However, people may be opposed to living near areas where radioactive wastes are stored.

Figure 7 Nuclear waste is stored in temporary facilities.

11.3 CHECK YOUR Understanding

1. What makes a chain reaction possible in a nuclear reactor?
2. In a nuclear reaction, all of the emitted neutrons do not cause other nuclear fissions. If each nuclear fission in a particular chain reaction caused 1.5 further nuclear fissions, how many fission reactions would occur in the fifth step in the chain? How many would occur in the twentieth step?
3. Uranium-238 is a very common isotope of uranium. Why is it not possible to use this isotope for fuel in a nuclear reactor?
4. Uranium-235 does not undergo spontaneous nuclear fission. However, uranium-235 is used as a fuel in nuclear reactors. How is it used in a nuclear reactor?
5. What is the name given to a material that absorbs neutrons to control the rate of the reaction in a nuclear reactor? Give two examples of materials that are used for this purpose.
6. Why does a nuclear reactor require a moderator?
7. Why can heavy water be used as a moderator?
8. Since a nuclear reactor uses the heat of a nuclear fission reaction, why does a reactor require a coolant?
9. How does a nuclear reactor convert the thermal energy produced during a nuclear fission reaction into electrical energy?
10. Canada supplies the world with CANDU nuclear reactors. Explain the meaning behind the word CANDU.
11. What is the reason for the name "heavy water"?
12. CANDU nuclear reactors use heavy water as a moderator. Other reactor designs use either water or graphite as moderators. Discuss the advantages and the disadvantages of using water or graphite as moderators.
13. Are fuel rods radioactive? Explain your answer.
14. Why does the CANDU reactor use fresh water, rather than heavy water, to turn the turbine blades that produce electricity?
15. Pressurized water reactors require enriched uranium and are the most common reactors used in the world (Figure 8).
    (a) For what purpose were they originally designed?
    (b) What are their major disadvantages?

Figure 8

11.4 Explore an Issue

DECISION MAKING SKILLS

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

Nuclear Power

Figure 1 Coal and oil burning power plants emit nitrogen oxides, sulfur dioxide, and greenhouse gases into the atmosphere.

Humans have been burning fuels to produce heat and energy for a very long time. However, as populations have increased, society's need for energy has also increased. Unfortunately, the burning of fuels has led to air pollution, acid precipitation, and global warming. Building more nuclear power plants could reduce the amount of environmental damage from burning fossil fuels. However, the nuclear solution also has its own dangers. The choices that we make to meet our future energy needs require careful thought.

The Issue: Using Nuclear Energy to Produce Electricity

The demand for energy is increasing. While considerable efforts are being made to reduce energy requirements for many devices, the total use of energy is rising. Burning fossil fuels produces waste products that contribute to acid precipitation, global warming, and air pollution (Figure 1). In addition, extracting fossil fuels from Earth is becoming increasingly expensive and harmful.

Using nuclear energy could reduce some of the environmental cost of energy production. However, nuclear resources must also be mined, and their waste products pose significant problems. While it may be argued that nuclear fusion could be a very environmentally friendly solution, it is not an immediate solution.

Statement

As burning fossil fuels adversely affects the environment, thermal electric generation sites in British Columbia should be converted into nuclear fission power plants.

Background to the Issue

In parts of Canada, fossil fuels are the main energy source used to produce electricity. Burning fossil fuel releases energy to boil water, producing steam that drives a turbine to produce electrical energy. However, burning fuels releases carbon dioxide and sulfur dioxide, which contribute to global warming and acid precipitation, respectively.

Global warming is a term used to describe the increase in average temperature of the Earth's surface and oceans in recent decades. Most scientists agree that the increase is because of greenhouse gases. Since industrialization, the burning of fuels has increased the carbon dioxide emissions, which has increased the greenhouse effect and caused an increase in temperature. Although many countries around the world agree that global warming is a concern, there are scientific uncertainties about the exact impact of climatic change and the extent of the effects of burning fuels.

Nuclear reactors produce heat that is used to drive a turbine and produce electricity, similar to burning fuels. There are some advantages to using nuclear reactors; for example, no air pollution is produced in nuclear reactions. However, there are also some disadvantages. The public is so adverse to nuclear power that there has been a significant decrease in the building of nuclear power plants in the last few decades. Reactors are expensive to build, operate, maintain, insure against accidents, and, at the end of their lives, to decommission safely. These disadvantages will have to be considered before opting for the nuclear solution.

Although at the present time there are no nuclear power plants in B.C., there are 18 operating nuclear reactors in Canada. These reactors provide 15.5 % of Canada's electricity. The nuclear reactors are located in Quebec (1), Ontario (16), and New Brunswick (1) (Figure 2).

Figure 2 The Point Lepreau Generating Station in New Brunswick provides 30 % of the province's energy.

Make a Decision

1. Carefully read the statement and the background information.
2. The 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 nuclear power. You may find information in newspapers, a library periodical index or a CD-ROM directory, and on the Internet.

   www.science.nelson.com GO

4. Gather relevant information and prepare to defend your position in class. After the research is complete, your group will combine all information into a presentation.
5. You have been assigned to a side of the debate regardless of your initial opinion on the issue. Your research may reinforce or change your original position.

Communicate Your Decision

Your teacher will organize a classroom debate for both groups to give their presentation. Each group will have one member give their presentation and all class members should listen carefully to the debate.

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.

THE LEGACY OF CHERNOBYL

The worst nuclear accident occurred in Chernobyl over 20 years ago. What has happened to the area over the years? What does the future hold for the area?

Over 20 years ago, just after midnight on April 26, 1986, reactor number 4 at the Chernobyl nuclear power plant exploded causing the world's worst nuclear disaster (Figure 1). Reactor 4 had been shut down for maintenance. Various safety systems were bypassed so that engineers could perform an experiment on the cooling pumps. Two explosions caused flames and hot nuclear fuel and graphite to spew vast quantities of deadly radiation into the atmosphere. The fire burned for 10 days. The cloud of radiation spread different types of radioactive materials, especially iodine and cesium, across the Soviet Union, Central Europe, and beyond. Radioactive iodine-131 has a short half-life of 8 days and largely disintegrated within the first few weeks after the accident. Radioactive cesium-137 has a much longer half-life of 30 years, and is still found in soils and some foods in many parts of Europe.

Figure 1 Reactor number 4 was completely demolished during the explosion at Chernobyl.

Although news of the disaster was not immediately made public, the 50 000 people who lived in Pripyat, 3 km from the plant, were evacuated within 40 hours of the accident. An exclusion zone radiating 30 km outward from reactor 4 forced more than 100 000 people to abandon their homes. Most have never been allowed to return.

The effects of the radiation fallout on the people have been studied extensively. On the night of the explosion, about 600 plant workers worked with little or no protective gear to control the disaster. Within 3 months 28 of them died from acute radiation syndrome (ARS). A further 160 people died during the first year after the accident from ARS. The most dramatic health effect seen is the high incidence of thyroid cancer, especially in children. More than 4000 thyroid cancer cases were diagnosed from 1992 to 2006 in persons who were children or adolescents at the time of the accident. Most of these cases were successfully treated. There has also been a steady increase in reported birth defects. Currently, more than 7 million people receive or are entitled to receive special allowances because they have been affected by Chernobyl.

Today the town of Pripyat looks like a ghost town (Figure 2). Few people are allowed within the exclusion zone, although some of the older residents have returned. About 4000 scientists, geologists, and workers temporarily live in the less-irradiated buildings in Chernobyl. Visitors are allowed within the exclusion zone provided they have a special permit, an official government guide, and a handheld Geiger counter.

There is some hope in the exclusion zone. Because there are no agricultural or industrial activities in the exclusion zone, populations of animals and plants have expanded. Species of animals rarely seen in the area before the disaster are thriving in what is becoming a sanctuary (Figure 3).

It has been over 20 years since the disaster. But it may be over 100 years before the remaining reactors have been defuelled, decommissioned, and dismantled.

Figure 2 An abandoned classroom in a Pripyat school.

Figure 3 An elk runs in a forest in the 30 km exclusion zone around the Chernobyl nuclear reactor.

11.5 Nuclear Reactions: Fusion

Nuclear fusion reactions occur in the Sun and supply the energy needed to sustain life on Earth (Figure 1). **Nuclear fusion** is the fusing or joining of two small nuclei to make one larger nucleus. When two nuclei join together, the mass of the product nucleus is less than the sum of the masses of the original nuclei. The loss of mass is converted into energy and released.

To learn more about nuclear fusion, go to
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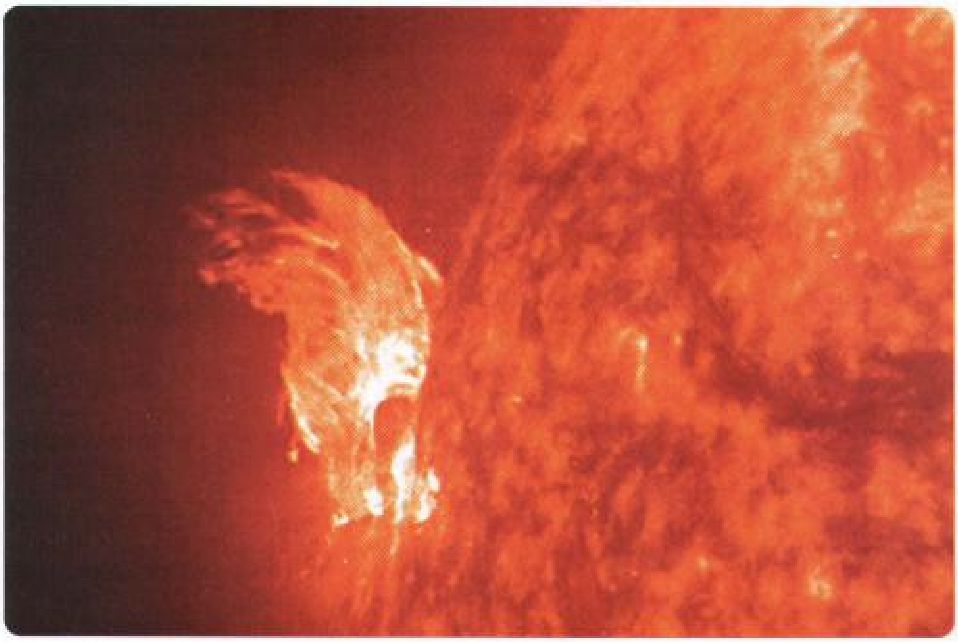


Figure 1 Nuclear fusion reactions take place in the Sun.

LEARNING TIP

Skim (read quickly) to get a general sense of Section 11.5. Examine the headings and figures, and scan for words in bold. Ask yourself, "What information is important here?"

For two nuclei to join together, their natural electrostatic repulsion needs to be overcome. To do this, the nuclei must collide at very high speeds. These high speeds can only occur at very high temperatures, such as in the Sun and other stars.

The simplest nuclear fusion is between two hydrogen nuclei (protons). This type of fusion reaction takes place in the Sun. This can be written as the nuclear equation

$$^{1}_{1}\text{H} + ^{1}_{1}\text{H} \rightarrow ^{2}_{2}\text{He}$$

As with other nuclear equations, the total of the atomic numbers and masses are the same before and after the fusion reaction. Because the $^{2}_{2}\text{He}$ is unstable, it decays immediately to a deuterium nucleus ($^{2}_{1}\text{H}$) by radioactive emission of a positron and a neutrino. A positron is identical to an electron except that it has a positive charge whereas an electron has a negative charge. A positron can be written as $^{0}_{1}\text{e}$. A neutrino is a particle that has energy, but no mass or charge. The nuclear equation for the reaction is

$$^{2}_{2}\text{He} \rightarrow ^{2}_{1}\text{H} + ^{0}_{1}\text{e} + \text{a neutrino}$$

Did You KNOW?

Antiparticles

For every type of particle in nature there is a corresponding antiparticle. For example, the antiparticle of a proton is an antiproton and the antiparticle of an electron is a positron. An antiproton is identical to a proton except that it has a negative charge. Similarly, the positron is identical to the electron except that it has a positive charge. When a particle collides with its matching antiparticle, they annihilate or destroy each other and release energy. The mystery is why the universe is populated with particles and not antiparticles.

That means that the fusion of two hydrogen nuclei (protons) results in the formation of a deuterium nucleus. This is followed by the fusion of deuterium with another hydrogen nucleus (proton) to produce helium-3:

$$^{2}_{1}H + ^{1}_{1}H \rightarrow ^{3}_{2}He + ^{0}_{0}\gamma$$

LEARNING TIP
When reading about nuclear equations, slow down your reading pace. Look back and forth between the equations and the related information in the text to help you understand the equations.

Note that a gamma ray (γ), which is electromagnetic radiation that has energy, but no mass or charge, is produced. The product of this reaction is then used to produce helium-4:

$$^{3}_{2}He + ^{3}_{2}He \rightarrow ^{4}_{2}He + 2^{1}_{1}H$$

This series of nuclear reactions produces one helium-4 atom from six hydrogen nuclei. In addition to producing helium, a vast amount of energy is also produced from nuclear reactions in the Sun.

Today, scientists are working to duplicate what is happening in the Sun in a controlled manner and to use it to create energy for use by society. Deuterium is readily available. Normal water contains two hydrogen atoms, and about 0.015 % of them are deuterium. Although this may seem like a small percentage, there is a vast amount of water available on Earth! The fusion of two deuterium atoms produces the following:

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{3}_{1}H + ^{1}_{1}H$$

Energy in Nuclear Fusion Reactions

The energy from fusion reactions comes from the conversion of mass, as with nuclear fission. Tables 1 and 2 show the calculations for the masses of deuterium before and after a fusion reaction.

Table 1 Before Nuclear Fission

Isotope	Atomic mass unit (u)	Mass (kg)
deuterium	2.014	3.344×10^{-27}
deuterium	2.014	3.344×10^{-27}
total	4.028	6.689×10^{-27}

Table 2 After Nuclear Fission

Isotope	Atomic mass unit (u)	Mass (kg)
hydrogen	1.008	1.674×10^{-27}
tritium	3.016	5.008×10^{-27}
total	4.024	6.682×10^{-27}

Using Tables 1 and 2, we can see that the total mass converted as a result of the nuclear fusion is

$$m = 6.689 \times 10^{-27}\ \text{kg} - 6.682 \times 10^{-27}\ \text{kg} = 7.0 \times 10^{-30}\ \text{kg}$$

We can calculate the amount of energy produced using Einstein's equation:

$$\begin{aligned} E &= mc^2 \\ &= (7.0 \times 10^{-30}\ \text{kg})(3.0 \times 10^{8}\ \text{m/s})^2 \\ E &= 6.3 \times 10^{-13}\ \text{J} \end{aligned}$$

While this may seem like a tiny amount of energy, it is an enormous amount for a single atom to produce—even by comparison with nuclear fission.

The goal of designing and building a nuclear fusion reactor has not yet been achieved. One of the advantages of using fusion to produce energy is that the process does not produce harmful waste products in the form of long-lived radioactive isotopes. The major difficulty is the very high temperatures needed to give the particles the high speeds they need to overcome their electrostatic repulsion. The high temperatures make it impossible to hold the material in any container. Nuclear scientists are experimenting with using magnetic fields to hold the material in place long enough for fusion to occur. Although experimental reactors have been made, not one is in commercial use at this time. The present reactors still require more energy than they are able to produce.

Nuclear Fusion Weapons

In the 1940s, scientists realized that the temperatures achieved in the explosion of a nuclear fission bomb were similar to the temperature of the Sun's core. This meant that a fission bomb using plutonium or enriched uranium could be used to start a fusion bomb, which is also called a thermonuclear or hydrogen bomb. The fusion bomb would be many times more powerful than a fission bomb. GO

To learn more about nuclear fusion weapons, go to
www.science.nelson.com GO

Although some scientists thought that a fusion bomb would be so powerful that it should not be developed, on November 1, 1952, the United States detonated the first fusion bomb (Figure 2). The resulting mushroom cloud was 150 km wide and 40 km high. The area was obliterated and the surrounding area was littered with radioactive debris. The bomb weighed about 65 tonnes and was an experimental device, not a weapon.

Figure 2 The first hydrogen bomb was detonated by the United States in 1952 on the Enewetak Atoll in the Marshall Islands in the Central Pacific Ocean.

In 1954, a second hydrogen bomb was exploded on Bikini Atoll, a ring of 23 islands in the Pacific Ocean. One island was completely vaporized and the radioactive fallout contaminated the surrounding area. Today, the people of Bikini live scattered around the Marshall Islands waiting for a complete radiological cleanup of the atoll.

In a hydrogen bomb, tritium ($^{3}_{1}H$) is used with deuterium. This produces more than four times the energy of using only deuterium. The fusion reaction is

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$$

Tritium is radioactive with a half-life of 12 years, which means that it is not very plentiful on Earth, whereas deuterium is plentiful.

Figure 3 Nebula NGC 604 is one of the largest known star-forming regions. The nebula contains more than 200 stars in a cloud that is nearly 1300 light years across.

Nuclear Processes in Stars

The nuclear processes that occur in stars (Figure 3) follow the stages in the life of the star and allow for different combinations. For example, in addition to the previously mentioned method of the formation of helium-4 from six hydrogen nuclei that takes place in our Sun, other routes are possible. For example, helium isotopes can produce beryllium, which is transmuted into lithium and turned back into two helium-4 nuclei. The stages involved in the process are

$$^{3}_{2}He + ^{4}_{2}He \rightarrow ^{7}_{4}Be + ^{0}_{0}\gamma$$

$$^{7}_{4}Be + ^{0}_{-1}e \rightarrow ^{7}_{3}Li \text{ and a neutrino}$$

$$^{7}_{3}Li + ^{1}_{1}H \rightarrow ^{4}_{2}He + ^{4}_{2}He$$

The nuclear process starts with one helium-4 nucleus and ends with the two helium-4 nuclei. The fusion reactions also release tremendous amounts of energy. The helium-4 nuclei are very important for the production of other elements. When all of the hydrogen is converted into helium-4, the temperature of the star rises, and then helium-4 begins to produce heavier elements. The production of carbon occurs in two steps:

$$^{4}_{2}He + ^{4}_{2}He \rightarrow ^{8}_{4}Be + ^{0}_{0}\gamma$$

$$^{4}_{2}He + ^{8}_{4}Be \rightarrow ^{12}_{6}C + ^{0}_{0}\gamma$$

Since the helium-4 nucleus is also called an alpha particle, this process is known as the triple-alpha process. Adding another alpha particle to the carbon-12 creates oxygen-16. Repeating the process with the oxygen-16 creates neon-20 and then magnesium-24. Each nuclear fusion reaction releases large amounts of energy. Different masses of stars follow different paths and produce different elements. Stars are the factories of the universe that make up all of the elements of the Periodic Table. Many heavy isotopes however, are only produced in the nuclear reactions in supernova explosions at the end of the life of some heavy stars.

STUDY TIP

A concept map can be used to map the stages involved in the nuclear processes that occur in stars. At the top of a study card, write "Stages of Nuclear Processes in Stars." Add words that are connected with lines or arrows. Write on the lines or arrows to explain the connections to the stages.

11.5

CHECK YOUR Understanding

1. Write a definition of nuclear fusion in your own words.
2. Why must two nuclei be moving at high speeds for nuclear fusion to occur?
3. Compare nuclear fission and fusion.
4. When two nuclei combine in fusion, does this reaction obey the law of conservation of mass? Explain your answer.
5. What is a neutrino? How is a neutrino produced?
6. Why is it not possible to use heavy elements, such as uranium, for nuclear fusion?
7. Jupiter is largely made of hydrogen in the same proportions as the Sun. Why do nuclear fusion reactions occur in the Sun, but not in Jupiter?
8. What is deuterium and why would it be a good fuel for a nuclear fusion reactor?
9. Compete the following nuclear fusion reactions:
   (a) ${}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + ?$
   (b) ${}^{3}_{2}He + {}^{3}_{2}He \rightarrow ? + 2{}^{1}_{1}H$
   (c) ${}^{3}_{2}He + {}^{3}_{2}He \rightarrow ? + {}^{1}_{1}H + {}^{1}_{1}H$
   (d) ${}^{2}_{1}H + ? \rightarrow {}^{3}_{1}H + {}^{1}_{1}H$
10. What are the major obstacles facing the development of a commercially successful nuclear fusion power plant?
11. What are the waste products produced by nuclear fusion? Are these products dangerous?
12. Why is tritium not plentiful on Earth?
13. Hydrogen bombs that have been exploded on Earth have radioactive waste products. How did the bomb produce these?
14. Why does a hydrogen bomb require a nuclear fission bomb?
15. What is the advantage of using tritium with deuterium in a hydrogen bomb?
16. Is it possible to store tritium for later use in a bomb? Explain your answer.
17. In the first part of a star's life, hydrogen is converted into helium-4. What happens to the star so that it converts helium-4 into other elements?
18. What elements can be made in stars using helium-4 building blocks?
19. Explain how stars produce carbon-12.
20. Stars produce the elements of the Periodic Table (Figure 4). Will our Sun produce all the elements on the Periodic Table at the end of its life?

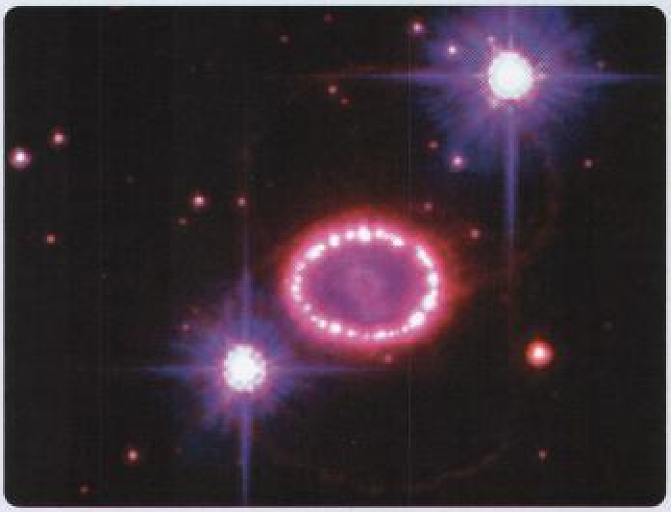


Figure 4

Atomic Energy

Vocabulary

nuclear fission, p. 313

chain reaction, p. 318

nuclear fusion, p. 327

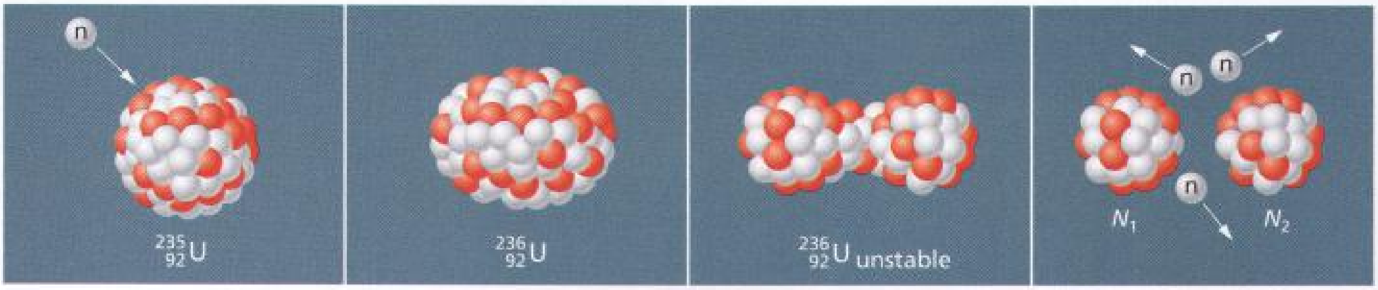
Key Ideas

Radioactive bombardment can change an isotope that is not radioactive into a radioisotope.

- Particles such as alpha particles or neutrons are aimed at the nucleus of an atom.
- If alpha particles are used, they need high speeds; however, neutrons can be used at slow speeds.
- This process, known as artificial radioactivity, can produce isotopes that do not occur naturally on Earth.

Nuclear fission occurs when a large nucleus splits into two smaller nuclei.

- The process of nuclear fission can be visualized by the water drop model.
- Although uranium-235 is stable, adding a neutron changes it to uranium-236, which is very unstable and undergoes fission.
- The process of nuclear fission usually produces some individual neutrons along with the two smaller nuclei.
- The total mass of the products produced by nuclear fission is smaller than the original mass.
- Nuclear reactions convert mass into energy.



Nuclear fusion occurs when two small nuclei are joined into one nucleus.

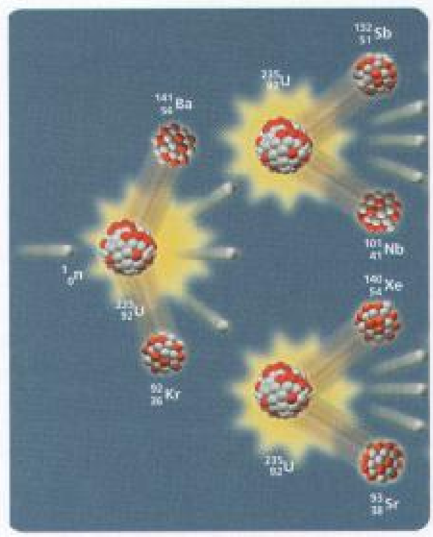
- When two nuclei fuse into a single nucleus, a small amount of mass is converted into energy.
- The simplest form of fusion occurs in the Sun where two hydrogen nuclei are joined together.
- The nuclear equation for the fusion of two hydrogen nuclei is

$$^{1}_{1}H + ^{1}_{1}H \rightarrow ^{2}_{2}He$$

- Stars use nuclear fusion to produce all of the elements of the Periodic Table.

Nuclear energy can be generated from the fission or fusion of atoms.

- A chain reaction occurs when the products of one reaction cause a further reaction.
- The neutrons released from nuclear fission can be used to create a chain reaction.
- If the rate of the chain reaction is controlled, it can be used in a nuclear reactor to produce thermal energy, which can be converted into electrical energy.
- Nuclear reactors require fuel, moderators, control rods, and coolants.
- Although nuclear reactors do not produce air pollution, their waste products pose a significant disposal problem.
- Stars use nuclear fusion to produce vast amounts of energy for billions of years.
- Although nuclear fusion reactors have been built, at this time, not one is capable of commercially producing electricity.



Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. In what form does the energy produced by a nuclear reaction appear?
   A. kinetic
   B. nuclear
   C. chemical
   D. electrical

2. When uranium-235 undergoes fission, how many neutrons usually are emitted?

K 3. What is the function of a control rod in a nuclear reactor?
   A. to raise the temperature of the nuclear fuel
   B. to slow down neutrons produced by fission
   C. to keep the mass of the fuel at the critical level
   D. to absorb neutrons produced by the fission process

4. Name two materials used for moderators in nuclear reactors.

5. What is heavy water? Why is heavy water used in some nuclear reactors?

6. Natural uranium contains two isotopes, uranium-235 and uranium-238.
   (a) Which isotope is more common?
   (b) Nuclear reactors use uranium-235. Why do reactors use this isotope and not uranium 238?

K 7. Which of the following statements would apply to a fusion nuclear reactor?
   A. Radioactive waste products are produced.
   B. There is a shortage of fuel required by the reactor.
   C. There is a substantial risk of a nuclear meltdown.
   D. The high temperatures required make it difficult to contain the fuel.

Use What You've Learned

U 8. The equation below represents the reaction in a nuclear reactor as uranium-235 undergoes fission.

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{x}_{50}Sn + ^{101}_{42}Mo + 3^{1}_{0}n$$

   What is the missing number x in the equation?
   A. 131
   B. 132
   C. 133
   D. 134

9. Uranium-238 nucleus decays to thorium-234 by alpha decay.
   (a) Write the nuclear equation.
   (b) Immediately after the decay, the daughter nucleus still has 92 electrons circling it. This means that there are two extra electrons. What do you think will happen to the two extra electrons?

10. Consider the following nuclear equation:

$$^{59}_{26}Fe \rightarrow ^{59}_{27}Co + ?$$

   (a) What is the missing term?
   (b) What type of decay process is this?

11. Some nuclear reactors use enriched uranium. What does the term "enriched" mean and why do reactors use enriched uranium?

12. Describe some of the safety measures that exist to prevent overheating in a CANDU reactor.

U 13. During nuclear fusion, atoms of hydrogen and deuterium react. What is the product of the nuclear reaction?

$$^{1}_{1}H + ^{2}_{1}H \rightarrow ?$$

   A. $^{3}_{1}H$
   B. $^{3}_{2}H$
   C. $^{2}_{2}He$
   D. $^{3}_{2}He$

14. What is nuclear waste? What should be done with nuclear waste?

15. The isotope tritium decays by beta emission into what nucleus?

U 16. How is the amount of thermal energy that is released in a nuclear reactor controlled?
A. by lowering the temperature
B. by limiting the number of neutrons released in each fission
C. by preventing daughter nuclei from undergoing fission
D. by limiting the number of neutrons, which stimulates additional fissions

17. Name and describe the three primary components of every nuclear reactor.

18. How does a thermal power plant produce electrical power? How is it different from a nuclear power plant?

Think Critically

19. What prevents a nuclear fission (atomic) bomb from going off accidentally while it is being stored?

20. Can a nuclear power plant be made perfectly safe? Why or why not?

21. What is the major obstacle to producing power with nuclear fusion?

HMP 22. Safety systems in commercial nuclear reactors prevent overheating and melting of the core. What prevents a nuclear explosion from occurring?
A. The uranium fuel is not pure enough.
B. Backup systems exist to prevent a nuclear explosion.
C. There is insufficient uranium fuel in the reactor core.
D. The fuel will not reach a high enough temperature.

HMP 23. Why are fission reactions unimportant in stars?
A. Neutrons are not moderated in stars.
B. There are few fissionable nuclei present.
C. The temperature in a star is too low to support fission.
D. Insignificant energy is released in each fission reaction.

24. Why is a "critical mass" needed before a chain reaction can occur? What happens if the critical mass is not achieved?

Use the following information to answer questions 25 and 26.

Oklo: Ancient Nuclear Reactors

In the 1970s, scientists realized that the uranium ore from the Oklo mine in Gabon, West Africa contained abnormally low amounts of U-235 compared with U-238. Many of the isotopes in the ore resembled those found in spent fuel at a nuclear reactor. These rich deposits of uranium ore have been dated to be about 1.7 billion years old. At that time, there may have been sufficient U-235 to support fission. Water seeping into the ore could have slowed the neutrons enough to cause fission and produce heat as is done in modern nuclear reactors. As the water heated and turned to steam, the neutrons would no longer be slowed, stopping fission and cooling the ore. Scientists believe these ancient nuclear reactors could have functioned on and off for millions of years.

HMP 25. What was the function of the water in the ancient nuclear reactors?
A. fuel
B. coolant
C. moderator
D. control rods

HMP 26. Why do scientists think the proportion of uranium-235 in the ore deposit became lower than expected?
A. It had undergone fission.
B. It was carried away by water.
C. It decayed to become uranium-238.
D. It decayed faster than uranium-238.

Reflect on Your Learning

27. What is your viewpoint on nuclear energy? Has studying this chapter changed your opinion?

28. Discuss how the course of history might have been changed if during World War II scientists had refused to work on developing a nuclear bomb. Do you think it would have been possible to avoid the building of such a bomb?

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UNIT C

Review

Radioactivity

Unit Summary

In this unit, you have learned about radiation, how it is produced, and how it is used. You have also looked at nuclear equations for nuclear fission and fusion reactions. Beginning with the word "radiation," add words and arrows to make a concept map that shows your understanding of radiation.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. What is the definition of atomic number?
   A. the number of protons found in the nucleus of an atom
   B. the number of neutrons found in the nucleus of an atom
   C. the number of electrons found in the nucleus of an atom
   D. the number of protons plus neutrons found in the nucleus of an atom

2. Which is most similar to an X-ray: an alpha particle, a beta particle, or a gamma ray? Why?

K 3. How many neutrons and protons are in the isotope $^{14}_{6}C$?

	Neutrons	Protons
A.	6	8
B.	6	14
C.	8	6
D.	14	6

K 4. Which of the following isotopes is represented by $^{27}_{11}Na$?
   A. sodium-11
   B. sodium-16
   C. sodium-27
   D. sodium-38

5. Fill in the missing particle or nucleus in the following nuclear decay equations.
   (a) $^{210}_{84}Po \rightarrow ^{206}_{82}Pb + ?$
   (b) $^{60}_{27}Co \rightarrow ^{60}_{28}Ni + ?$
   (c) $^{60}_{27}Co \rightarrow ^{?}_{?}? + ^{0}_{0}\gamma$
   (d) $^{12}_{7}N \rightarrow ^{12}_{6}C + ?$
   (e) $^{236}_{88}Ra \rightarrow ^{?}_{?}? + ^{4}_{2}He$

6. Copy Table 1 into your notebook, complete the nuclear equation, and identify the type of nuclear decay.

Table 1

Nuclear equation	Decay type
$^{66}_{29}Cu \rightarrow ^{66}_{30}Zn + ?$	
$^{121}_{50}Sn \rightarrow ? + ^{0}_{-1}e$	
$^{140}_{62}Sm \rightarrow ? + ^{4}_{2}He$	
$^{3}_{1}H \rightarrow ^{3}_{2}? + ?$	
$^{148}_{64}Gd \rightarrow ^{144}_{62}Sm + ?$	
$? \rightarrow ^{65}_{29}Cu + ^{0}_{-1}e$	
$^{189}_{78}? \rightarrow ? + ^{0}_{-1}?$	

K 7. Which of the following is not a source of natural background radiation?
   A. soil
   B. water
   C. human bodies
   D. dental X-rays

8. Tin-124 decays by emitting a beta particle with a half-life of almost 10 min.
   (a) Complete the nuclear equation
   $$^{124}_{50}\text{Sn} \rightarrow \textbf{?} + {}^{0}_{-1}\text{e}$$
   (b) A sample originally contained one million tin-124 atoms. Copy Table 2 into your notebook and complete the table.

Table 2

Time (min)	Expected number of tin-124 atoms	Expected number of decays	Activity (Bq)
0			
10			
20			
30			
40			
50			
60			

   (c) Draw a graph of the expected number of tin-124 atoms versus time, and a graph of the activity versus time.

Use What You've Learned

U 9. A sample of a material contained 4000 radioactive atoms of a particular isotope. How many atoms of the isotope would be left after four half-lives?
   A. 0
   B. 250
   C. 500
   D. 1000

10. Carbon-14 has a half-life of 5730 years. A skeleton was found that had only $\frac{1}{8}$ the amount of carbon-14 present compared with present-day bones. How old was the skeleton?

11. Complete the following nuclear equations:
   (a) $\text{n} + {}^{239}_{94}\text{Pu} \rightarrow {}^{141}_{54}\text{Xe} + {}^{97}_{40}\text{Zr} + \textbf{?}$
   (b) ${}^{2}_{1}\text{H} + {}^{2}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + \textbf{?}$

U 12. The isotope nickel-63 has a half-life of 100 years. If a sample contained 12 million atoms of nickel-63, how many atoms would have decayed after 400 years?
   A. 375 000
   B. 750 000
   C. 10 500 000
   D. 11 250 000

HMP 13. A nuclear fusion reactor does not produce radioactive waste. However, a hydrogen bomb produces radioactive fallout in the atmosphere. Which of the following explains this fact?
   A. The hydrogen bomb uses an atomic bomb to start the reaction.
   B. The fusion reactor consumes its own radioactive waste products.
   C. The fusion process in a bomb is different from the fusion process in a reactor.
   D. The hydrogen bomb explodes in the atmosphere, which introduces contamination to the process.

Think Critically

14. When you get an X-ray at the dentist's office, you are given a lead apron to wear.
   (a) Where is the lead apron placed on you?
   (b) Why is the lead apron used?

15. Research the impact or contributions that Canada has made toward the development of nuclear physics.

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Reflect on Your Learning

16. In this unit, you have learned how nuclear physics and radioactivity have been applied to areas such as medicine, research, energy, and weapons. Choose one area and explain how your understanding of this area changed as a result of studying this unit?

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UNIT D

MOTION

Unit Preview

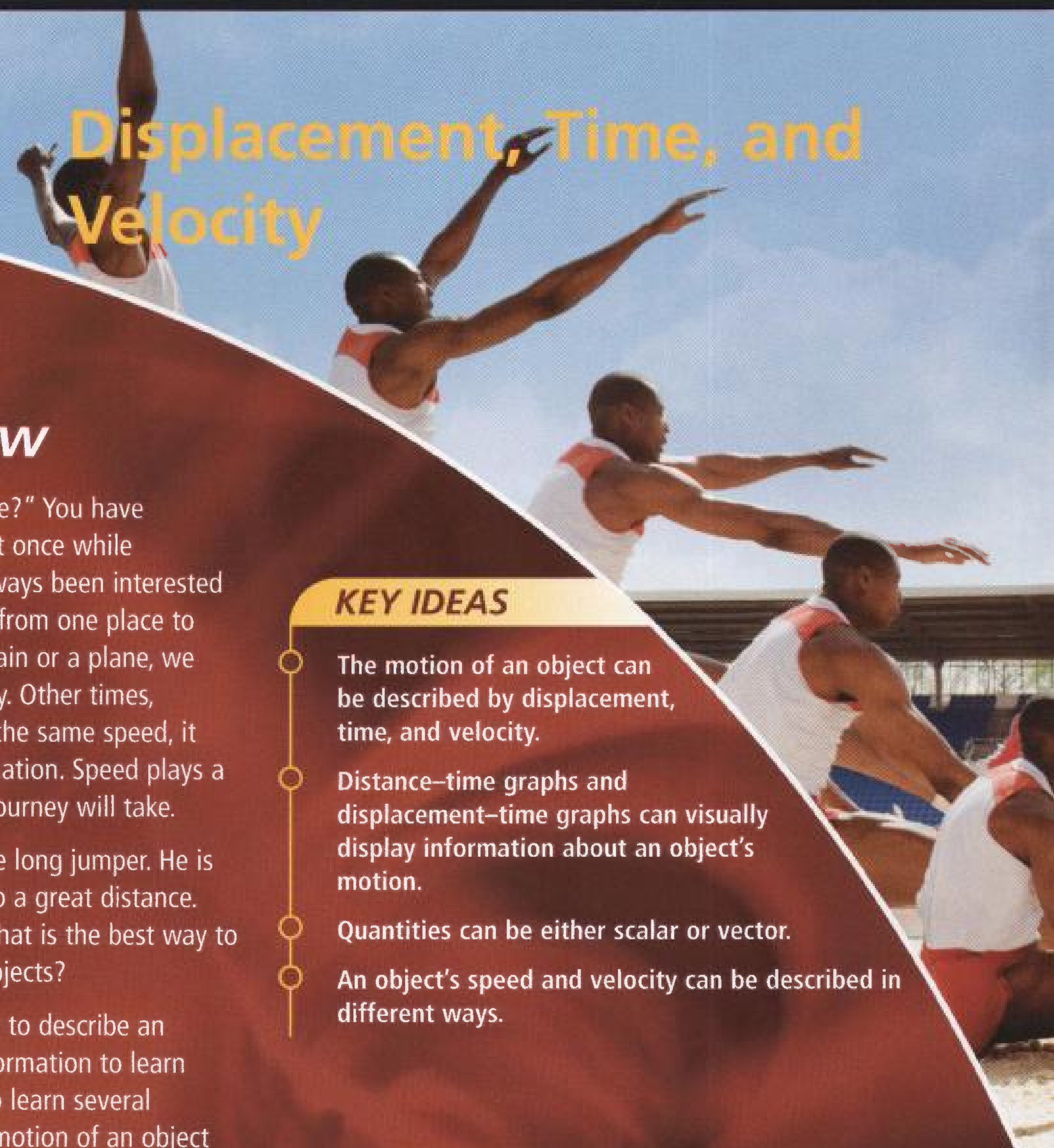
All around you, people are in motion. Whether they are walking to school, driving to work, flying to different cities around the world, or zooming around on a roller coaster—people are experiencing some type of motion. Earth is in constant motion around the Sun while rotating through space on its own axis. Even our solar system is in constant motion as it moves through space in the Milky Way Galaxy.

We use the study of motion to plan trips and to determine how long it will take to reach a particular destination. The study of motion helps scientists and engineers contribute to motion-related fields including transportation, sport science, or space science.

In this unit, we will look at and investigate the different types of motion, and look at how information about motion can be displayed on graphs.

CHAPTER 12

Displacement, Time, and Velocity



Chapter Preview

"How much longer until we get there?" You have probably asked that question at least once while travelling to a place. People have always been interested in knowing how long it takes to get from one place to another. Sometimes, if we are in a train or a plane, we arrive at our destination fairly quickly. Other times, because we do not always travel at the same speed, it takes a long time to reach our destination. Speed plays a big role in determining how long a journey will take.

Look at the series of photos of the long jumper. He is moving very fast so that he can jump a great distance. How can we describe his motion? What is the best way to display information about moving objects?

In this chapter, you will learn how to describe an object's motion. You will use this information to learn more about the motion. You will also learn several different methods of describing the motion of an object and apply these methods in different situations.

KEY IDEAS

- The motion of an object can be described by displacement, time, and velocity.
- Distance–time graphs and displacement–time graphs can visually display information about an object's motion.
- Quantities can be either scalar or vector.
- An object's speed and velocity can be described in different ways.

TRY THIS: Motion of a Table Tennis Ball

Skills Focus: observing, recording, communicating

In this activity, you will describe the motion of a table tennis ball.

Materials: table tennis table or rectangular table with masking tape across the middle, table tennis ball, two racquets

1. Position two people to play table tennis and position yourself in the middle beside the net.
2. The person on your right will serve the table tennis ball and the person on your left will receive the ball.
3. The server makes an easy serve with the table tennis ball. The receiver hits the ball to return it to the server. The server catches the ball and does not hit it.

A. Describe the position of the ball relative to you during the serve and return.

B. Describe the speed of the ball relative to you during the serve and return.

C. How did you indicate the direction that the ball was travelling relative to you in parts A and B?

12.1 Distance and Time

The concepts of distance and time are so commonplace that we take them for granted. We know the distances to different places (Figure 1) and we know the time that class begins and ends. We have units for distance and we have units for time. In addition, we have different needs for accuracy. A game of basketball with a bunch of friends ends when everyone wants to stop, while a championship game ends exactly when the buzzer goes!

LEARNING TIP

Skim (read quickly) to get a general sense of Chapter 12. Consider information gathered from the title, headings, figures, words in bold, and sample problems. What do you expect to learn in this chapter?

Figure 1 This signpost marks the distance from Canada Place in Vancouver to places all around the world.

Distance

The space between two points is the distance. Distances are commonly measured in units of metres. Historically, the metre was defined as one ten-millionth of the distance from the North Pole to the equator through Paris. Today, it is defined as the distance travelled by light in empty space during a time of 0.000 000 003 s. We use the metre to indicate not only the size of an object, but also how far the object travelled. For example, consider the situation shown in Figure 2. John wants to visit his grandmother who lives on the opposite side of the lake. He can either cross the lake using a boat, or he can walk along the shore.

Distances can vary greatly in size. For example, the distance between tracks on a CD is 1.6×10^{-6} m, or 1.6 μm. Although this seems small, the diameter of a hydrogen atom is about ten thousand times smaller: about 10^{-10} m. On the other extreme, the distance to the Sun is 1.5×10^{9} m. The distance to Proxima Centauri, the nearest star to our solar system, is 4.0×10^{16} m. The distances in space are so large that astronomers use units of light years to measure them. A light year is the distance that light travels in one year and is equal to 9.46×10^{15} m. This means that Proxima Centauri is 4.22 light years away from Earth.

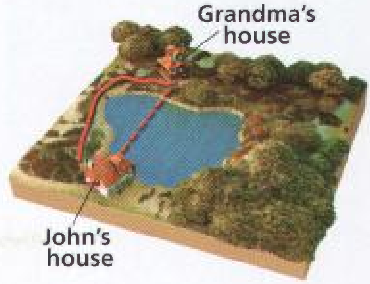


Figure 2 The distance to Grandma's house depends on the path that John takes.

TRY THIS: Standards of Measurement

Skills Focus: observing, predicting, analyzing, communicating

In this activity, you will measure lengths using commonplace objects.

Materials: a variety of objects (for example, desk, pencil, beaker, and classroom door), tickertape or string

1. Choose a commonplace object to be the basis for measuring distances. The width of the thumb at the base of the nail has already been chosen for the inch. However, you could use another part of your body (e.g., finger width/length, arm length, etc.) or another object (this textbook, your pen, a dime, a hockey stick, etc.).
2. Create a name for the base unit of your measuring system. For example, the thumb width is called the inch. However, the name of the base and the unit could be the same. For example, the Swedish word "tum" and the French word "pouce" both mean inch and thumb.
3. Use your measuring object to measure the lengths of other objects. For convenience, you may transfer the length of your base unit to tickertape or string for measuring. If the object is smaller than your base unit, you will have to devise a means to measure or estimate fractional units.

A. Which length was the easiest to measure? Why?

B. Which length was the most difficult to measure? Why?

C. Compare your measurements for the length of each object on the list with your classmates. For each object, decide which base unit created by the class was most suitable.

D. What was the basis for choosing the most suitable unit?

E. How could you measure the width of a page of this text using your unit?

Figure 3 The Gastown Steam Clock in Vancouver was built in 1977, and is the world's only steam powered clock.

Time

Most people have an intuitive understanding of time. We speak of how soon an event will take place compared with the present time or how much time has passed since an event occurred. Time can also mean the reading on a clock (Figure 3) or the difference between two clock readings. Time is measured in different units including years, days, hours, minutes, and seconds. In general, time is the duration of an event.

To emphasize that time is a duration, it is often referred to as a **time interval** and given the symbol Δt. The symbol Δ is the Greek letter *delta*, and represents change. Therefore, the symbol Δt combines the symbols for change (Δ) and time (t) together to mean "change in time."

Time and Distance

Time and distance are fundamental to our understanding of the natural world around us. These quantities can be used by themselves, for example, in using distance measurements to determine area or volume. By combining time and distance we can determine speed. Often we combine them with other quantities, such as mass, to describe quantities such as density, force, or energy.

Period and Frequency

One of the early proposals for defining distance was to make the base unit equal to the length of a pendulum that had a period of one second. A period (T) is the time interval between two repeating events. For example, the period of a pendulum is the time interval needed for a complete swing (both back-and-forth swings, or one cycle). The period of a pendulum does not depend on the mass of the bob or on the amplitude (the amount the pendulum is pulled to the side) if the amplitude is small. A period is measured in units of time.

Frequency is related to period. Frequency (f) is the number of cycles that occur in a specific time interval. For example, the frequency of a pendulum might be 15 cycles per minute. The SI unit for frequency is the hertz (Hz), which is equal to one cycle per second.

Since frequency is the number of occurrences per second, and period is the time per occurrence, they are reciprocals of each other, which can be written as

$$T = \frac{1}{f} \quad \text{or} \quad f = \frac{1}{T}$$

where T is the period (in s) and f is the frequency (in Hz). The occurrence or event that is repeating is often circular so frequency is often referred to as revolutions per second or cycles per second. Therefore, three cycles per second is equal to 3 Hz and 45 revolutions per second is 45 Hz. GO

SAMPLE PROBLEM 1

Determine Period and Frequency

Ann counted 7 pulses in her wrist in 6 s. What are the period and frequency of her heart beat?

Solution

Determine the period.

$$T = \frac{6\text{ s}}{7\text{ pulses}} = 0.86\text{ s}$$

There are two possible methods to determine the frequency.

Method A

$$f = \frac{7\text{ pulses}}{6\text{ s}}$$

$$f = 1.2\text{ Hz}$$

Method B

$$T = \frac{1}{f}$$

$$f = \frac{1}{T} = \frac{1}{0.86\text{ s}}$$

$$f = 1.2\text{ Hz}$$

The period is 0.86 s and the frequency is 1.2 Hz.

Practice

Five waves wash up on shore in 60 s. Determine their period and frequency.

Did You KNOW?

The Father of Standard Time

Can you imagine what life would be like if every city followed its own time—for example, if Vancouver was about ten minutes later than Victoria? This is what it would be like if Canadian engineer Sir Sandford Fleming (1827–1915) had not invented the system of standard time. His idea divided the world into 24 time zones measured against the time set in Greenwich, England. Fleming's standard time revolutionized travel and is still used today.

To learn more about period and frequency, go to **www.science.nelson.com** GO

STUDY TIP

There are many ways to improve your chances of remembering new material. One way is to plan an immediate review after each class and to build a review into each study session.

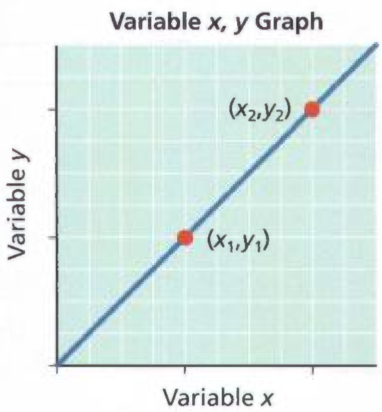


Figure 4 Graphing two variables that are directly related produces a straight line, which can then be used to calculate the slope.

Graphs and the Slope of a Line

Many quantities, including distance and time, and period and frequency, have mathematical relationships. If we graph two quantities that are directly related, such as x and y, we will get a straight line (Figure 4). The angle, or steepness, of the line is known as the **slope** of the line. In science, the x-axis is very often time. Therefore, the slope tells us what happens to the y variable as a function of time.

To calculate the slope, we divide the rise (along the y-axis) by the run (along the x-axis) using any two points on the line (x_1, y_1) and (x_2, y_2).

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{y_2 - y_1}{x_2 - x_1}$$

In the following activity, you will use a graph and the slope of the line to see how the period of a pendulum is related to its length. In section 12.3, we will look at how graphs can help us understand the relationship between distance and time.

TRY THIS: Length of a Pendulum with a Period of One Second

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

In this activity, you will determine the length of a pendulum with a period of one second.

Materials: pendulum (string, bob, retort stand, and clamp), stopwatch or clock with a second hand

1. Make a pendulum with a length of 1 m. Using a small amplitude swing, measure the time interval needed for 10 cycles (complete swings) of the pendulum (Figure 5).

Figure 5

2. Copy Table 1 into your notebook and record the time. Divide the time by 10 to determine the period of the pendulum and record it in the table.

Table 1 Data Table

Length (cm)	Time (s)	Period (s)	Square root of length ($\sqrt{cm}$)
100	10		
80			
60			

3. Repeat step 2 for different pendulum lengths.
4. Although the period of a pendulum increases with the length of the pendulum, it is not a direct relationship. The period is related to the square root of the length of the pendulum. The last column of your table is for the square root of the length of the pendulum ($\sqrt{cm}$).

A. Estimate what pendulum length would have a period of 1 s.

B. Plot the data on a graph with period as a function of length. Draw a line through the data. Use the graph to estimate the length of a pendulum with a period of 1 s.

C. Plot a graph with period as a function of the square root of the length. Draw a line of best fit. Use the graph to estimate the length of a pendulum with a period of 1 s.

D. Why would this last estimate of length be more accurate than either of the first two estimates?

E. Calculate the slope of the line of the graph made in part C.

12.1 CHECK YOUR Understanding

1. There are different units used to measure time. Which unit would most commonly be used to measure the following?
   (a) your age
   (b) the duration of a Grade 10 Science class
   (c) the time an Olympic athlete needs to run 100 m
   (d) the time needed to fly from Vancouver to Paris
   (e) the duration of the summer holiday from school
2. Write a definition of distance in your own words.
3. The metre was originally defined as a fraction of the distance from the North Pole to the equator. What problems would this definition of the metre create for people?
4. A rectangular field is 1.5 km long and 700 m wide (Figure 6). An asphalt road goes around the outside of the field and a dirt path cuts across the field. A student wants to go from A to B on the field. Path *x* goes along the road and is shown in red; path *y* is shown in blue. Which path has the shorter distance? By how much is this path shorter?

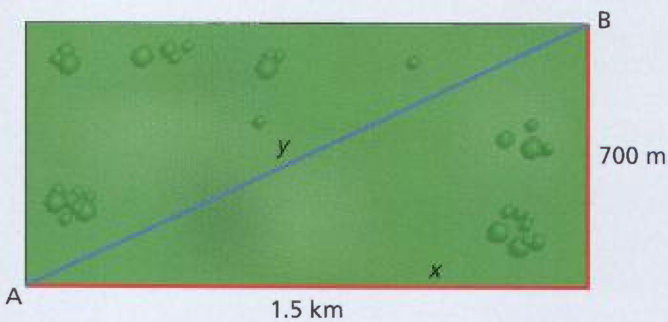


Figure 6

5. Why is time often referred to as a time interval in science?
6. Grandpa Adams took a nap from 2:32 p.m. until 3:19 p.m. How many seconds was Grandpa asleep?
7. Two points or locations are needed to measure distance. What two things are needed to measure a time interval?
8. A woodpecker taps 8 times on a tree in 2 s. What are the period and the frequency of the tapping?
9. Two children are playing on a teeter-totter (seesaw) in a park. They each move up and down 9 times in 25 s. Determine the period and frequency of their movement on the teeter-totter.
10. A bee's wings beat with a frequency of 200 Hz (Figure 7). What is the period of a beat of the bee's wings?

Figure 7

12.2 Speed

Everyone has seen the road signs "Maximum 90 km/h" (Figure 1). The **speed** of an object is equal to the distance an object travels divided by the time interval. In other words, speed is the rate at which the object is travelling. The equation that we use to calculate speed is

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{\Delta d}{\Delta t}$$

where Δd is the change in distance, and Δt is the change in time.

Figure 1 Road signs tell us the maximum speed at which we are allowed to drive.

LEARNING TIP

Note that in an equation where the variables have a delta symbol in both the numerator and the denominator, the symbols cannot be cancelled. Recall that the delta symbol (Δ) represents "change in."

For example, if a bus takes 10 min to travel from the bus stop to a beach that is 6 km away, we could say the bus is travelling at 0.6 km/min. However, this is not a typical unit for measuring the speed of motor vehicles. Instead we could say that, at that rate, in 1 h the bus would have gone 36 km. Therefore, the speed of the bus was 36 km/h.

It is not likely that a bus would travel all the time at 36 km/h. In other words, the speed of 36 km/h would be an average speed for the trip to the beach.

Average Speed

The speed of an object is calculated by dividing the distance travelled by the time taken. The **average speed** of an object is the total distance the object travelled divided by the total time taken. The equation for calculating average speed is

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{d_f - d_i}{t_f - t_i}$$

where v_{av} is the average speed, d_f is the final position, d_i is the initial position, t_f is the final time, and t_i is the initial time. In this equation, the motion started at time t_i at a position of d_i and ended at time t_f at a position of d_f. This way of writing the equation for average speed is useful when the initial location or time is not considered to be zero.

Did You KNOW?

Mach Speed

The speed of aircraft is given in Mach number, which measures the speed of an object relative to the speed of sound (332 m/s or 1195 km/h). Mach 1 equals the speed of sound. The fastest airplane, the Lockheed SR-71 Blackbird, can travel at Mach 3.

SAMPLE PROBLEM 1

Determine Average Speed

A student saw a spider walking along a metre stick. When the spider crossed the 15 cm mark, the student started a stopwatch. When the spider reached the 60 cm mark, the student stopped the stopwatch. It took the spider 84 s. Calculate the average speed of the spider in cm/s.

Solution

Substitute the values into the average speed equation. In this case, the initial time was 0 s.

$$v_{av} = \frac{d_f - d_i}{t_f - t_i}$$

$$= \frac{60\ \text{cm} - 15\ \text{cm}}{84\ \text{s} - 0\ \text{s}}$$

$$v_{av} = 0.54\ \text{cm/s}$$

The average speed of the spider was 0.54 cm/s.

Practice

A dog was seen walking down a marked track by a student with a stopwatch. The student started the stopwatch when the dog was at the 20 m line. The stopwatch read 37 s when the dog crossed the 45 m line. Determine the average speed of the dog in m/s.

The average speed equation can be used to solve motion problems. In addition to solving for average speed, we can rearrange the equation to solve for time or distance. Note that all distances need to be in the same units, and all time measurements must also be in the same units. For example, if the distance is in metres (m) and the speed is in km/h, then one of the units must be changed to reflect the same distance unit (m and m/h, or km and km/h). GO

To learn more about different units for measuring speed and how they are related, go to **www.science.nelson.com** GO

SAMPLE PROBLEM 2

Determine Average Speed

A person walks 8.5 km in 2.2 h. What was the person's average speed?

Solution

Substitute the values into the average speed equation.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$= \frac{8.5\ \text{km}}{2.2\ \text{h}}$$

$$v_{av} = 3.9\ \text{km/h}$$

The person's average speed was 3.9 km/h.

Practice

A racing pigeon flew a distance of 52 km in 1.7 h. What was the average speed of the racing pigeon?

Did You KNOW?

Breaking the Sound Barrier

Although American pilot Chuck Yeager experienced queasiness the first time he ever flew an airplane, he was the first pilot to fly faster than the speed of sound. On October 14, 1947, days after cracking several ribs in a horseback riding accident, he broke the sound barrier flying the rocket-powered Bell X-1 at Mach 1.06.

SAMPLE PROBLEM 3

Determine the Time

A small plane flies 84 km from Nanaimo to Victoria. The average speed of the plane when flying is 280 km/h. Determine the plane's flying time.

Solution

Change the form of the average speed equation to solve for Δt. Then, substitute the values into the equation and solve.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta t = \frac{\Delta d}{v_{av}}$$

$$= \frac{84 \text{ km}}{280 \text{ km/h}}$$

$$\Delta t = 0.3 \text{ h}$$

The plane's flying time will be about 0.3 h.

Practice

A bowler rolls a bowling ball at 7 m/s down a bowling alley. The pin is 18.5 m away. How long will it take for the ball to reach the pin?

STUDY TIP

Don't delay! As soon as you have read the sample problem, do the practice problem right away. The experience of solving a problem will increase your chances of remembering the new material.

SAMPLE PROBLEM 4

Determine Distance

Sunlight takes about 500 s to reach Earth. Light travels at 3.0×10^8 m/s. How far is the Sun from Earth? (Refer to Appendix B2 for tips on the appropriate use of scientific calculators with scientific notation.)

Solution

Change the form of the average speed equation to solve for Δd. Then, substitute the values into the equation and solve.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta d = v_{av} \Delta t$$

$$= (3.0 \times 10^8 \text{ m/s})(500 \text{ s})$$

$$\Delta d = 1.5 \times 10^{11} \text{ m}$$

The Sun is 1.5×10^{11} m from Earth.

Practice

A speed skater is skating at 13.2 m/s. How far will he skate in 37.9 s?

SAMPLE PROBLEM 5

Determine the Distance

The driver of a car travelling at 50 km/h sees a deer crossing the road ahead. It takes the driver 1.2 s to react and start to apply the brakes. How far did the car travel before the driver hit the brakes?

Solution

In this case, the answer will be most useful in metres. Therefore, the speed will have to be changed from km/h to m/s.

$$\left(\frac{50\ \cancel{\text{km}}}{1\ \cancel{\text{h}}}\right)\left(\frac{1000\ \text{m}}{1\ \cancel{\text{km}}}\right)\left(\frac{1\ \cancel{\text{h}}}{3600\ \text{s}}\right) = 13.9\ \text{m/s}$$

Rearrange the average speed equation, and then substitute the values into the equation.

$$v_{av} = \frac{\Delta d}{\Delta t}$$

$$\Delta d = v_{av}\,\Delta t$$

$$= (13.9\ \text{m/s})(1.2\ \text{s})$$

$$\Delta d = 17\ \text{m}$$

The car travelled 17 m.

Practice

A person is riding a bicycle at 9.2 m/s. How far, in kilometres, will the person travel in 2.6 h?

Instantaneous Speed

Often we want to know how fast an object is going at a particular instant in time. The speedometer of the car indicates the current speed at which the car is moving (Figure 2). **Instantaneous speed** is the speed of an object at a particular instant in time. When a driver gets a speeding ticket, it is because the instantaneous speed of the car, as indicated by the police officer's speed detector, exceeds the maximum speed limit. GO

Figure 2 A speedometer tells you how fast you are travelling at a particular instant in time.

To learn about the world's fastest airplane, boat, and car, go to www.science.nelson.com GO

Constant Speed

Vehicles, such as buses and cars, often change speeds to pass other cars, to slow down for pedestrians, or to obey traffic signals. However, some objects, such as light travelling from a star, travel at a constant speed. If the speed of an object is constant (does not change), then its average speed will be the same as its instantaneous speed. Therefore, an object has constant speed if its instantaneous speed is not changing.

12.2 CHECK YOUR Understanding

1. A freestyle swimmer was timed every 10 m as she swam a 50 m race. The times and distances are shown in Table 1.

Table 1 Motion of a Swimmer

Distance (m)	0	10	20	30	40	50
Time (s)	0	5.9	17.9	28.2	43.0	61.2

   (a) What is the average speed of the swimmer for the first 10 m?
   (b) What is the average speed of the swimmer for the last 10 m?
   (c) What was her average speed for the entire race?

2. A driver travelled 22 km in 15 min, then stopped for lunch for 25 min, and then drove another 34 km in 20 min. What was the average speed for the trip? What was the average speed while the car was moving?

3. Greyhounds can race faster than any other breed of dog (Figure 3). A greyhound ran 250 m in a time of 13.1 s. What was its average speed?

Figure 3

4. A large clock has a second hand that is 18 cm long.
   (a) What distance does the tip of the second hand travel in 1 min?
   (b) What is the speed of the tip of the second hand?
   (c) Is the speed constant? Explain your answer.

5. A golf ball landed 75 m away from the tee. The golf ball travelled with an average speed of 43 m/s. How long was the golf ball in the air?

6. The speed of sound is 343 m/s at 20 °C. A baseball fan is sitting 150 m from home plate. How much longer will it take for the sound of the batter hitting the ball to be heard by the fan than the umpire?

7. A nerve impulse travels with a speed of 90 m/s. How long would it take for an impulse to go a distance of 55 cm?

8. A wheelchair athlete can travel at 6.1 m/s. How far can the athlete travel in 65 s?

9. A family travels from Squamish to Kelowna in 4 h 38 min, not including rest stops, at an average speed of 82 km/h. What is the distance between the two cities?

10. A river is flowing at 2.5 m/s. How long will it take a log floating in the river to travel 1 km?

11. A motorcycle is being designed to be the fastest in the world. The target speed on a trial ride was 540 km/h. How far would the motorcycle travel in 15 s?

12. The space shuttle travels at 7800 m/s in an orbit with a radius of 6700 km about Earth.
   (a) What is the distance the shuttle travels in one complete orbit?
   (b) How long does it take to complete an orbit?

13. One object had an average speed of 36 km/h while another object had a constant speed of 36 km/h. Explain how these two speeds could be different.

14. A train had a constant speed of 65 km/h travelling beside a highway for 10 min. What was the instantaneous speed of the train at the 5 min mark?

Awesome
SCIENCE

THE TORTOISE, THE HARE, AND THE HUMAN

If a hare and tortoise were to race, the hare would easily beat the tortoise. But how would the hare do against a human or a horse? Different animals travel at different speeds.

Everyone knows that in the story of the hare and the tortoise, the tortoise won the race because it ran at a steady speed, while the hare ran fast, but took many rest stops (Figure 1). In truth, the desert tortoise has been clocked at speeds of 0.21 to 0.48 km/h while the snowshoe hare races past at speeds of 45 km/h. While the tortoise would not actually win a race against a hare, what would the outcome be if people and other animals joined in?

Many people run for fun, for exercise, or competitively. However, the running speed of humans depends on the length of the race. The fastest time recorded for a 100 m sprint is 9.74 s, which means that the current record holder ran at 37 km/h. The fastest time recorded for a marathon (42 km) is currently 2:04:26, which means that the person ran at 20 km/h (or about half the speed of the sprint runner). While the hare can run past the fastest sprinter, it would have a hard time maintaining a speed of 45 km/h for 42 km to stay ahead of the marathon runner.

The cheetah, recognized as the world's fastest land animal, can hit a top speed of over 110 km/h (Figure 2). However, a cheetah would not be able to maintain that speed for more than 1500 m because it would overheat. The fastest land animal in North America has much more stamina for speed than the cheetah. The pronghorn antelope travels at an average speed of 55 km/h for distances as great as 43 km.

How would animals, such as racehorses and greyhounds that are bred to race, fare in the race against the hare? The famous racing horse, Secretariat, has held the record for the Kentucky Derby since 1973 when he raced the 2 km track at an average speed of 60 km/h. In 2000, the world's fastest greyhound, Be My Bubba, ran a 500 m track at an average speed of 61 km/h. Both the racehorse and the greyhound can go faster than the hare, but the horse can hold the speed for much longer than the greyhound.

What would the outcome of the race be if flying and swimming competitors were allowed to participate? The ruby-throated hummingbird darts from flower to flower at speeds of 97 km/h. The peregrine falcon flies at average speeds of 105 km/h, but has been measured at diving speeds of 282 km/h. Swimming competitors are equally fast. The sailfish is the fastest fish swimming at 110 km/h. Dolphins are the fastest swimming mammals reaching speeds of 60 km/h. The fastest human swimmers reach speeds of 8 km/h.

Clearly, different animals have adaptations that allow them to run at speeds that ensure their survival. Herbivores, such as hares, antelopes, and horses, are able to run at speeds that allow them to escape predators. Carnivores, such as cheetahs, run at speeds to help them catch their prey. Fast swimmers have a streamlined shape to allow them to move quickly through the water. And the slow and steady tortoise, which may not be able to win any races, can always retreat into its shell.

Figure 1 Would the tortoise really win a race against a hare?

Figure 2 The cheetah is the fastest land animal.

12.3 Graphing Distance and Time

If you were walking down the sidewalk and a passing motorist stopped and asked for directions to the nearest gas station, you could give the directions in a variety of ways. You could give the directions including distances or, if you had a map of the area, you could highlight the path the motorist should follow to get to the gas station.

There are different ways that we can analyze an object's motion. For example, we can record the motion with a video camera, write a description of the object's motion, look at the position and time data for the object in a data table, or look at the data organized into a graph. No method is appropriate for all uses and each method has its advantages. In this section, we will explore these methods. Think about how you could redo the Try This Activity at the start of the chapter investigating the motion of a table tennis ball and describe the motion differently.

TRY THIS: Graphing the Motion of a Trotting Cat

Skills Focus: recording, analyzing, communicating

In this activity, you will use a graph to communicate the motion of a trotting cat. Before motion pictures and video cameras existed, British photographer Eadweard Muybridge developed a machine that was able to take pictures in rapid succession. Your handout shows Muybridge's photos, taken in 1887, showing the motion of a trotting cat. Lines were added every 0.5 m in the background to help study the motion. There are 20 pictures in the sequence. However, the time between pictures is not known.

Materials: handout of Muybridge's moving cat photos, ruler, graph paper

1. Look at the pictures of the cat on your handout. Write a brief description of the cat's motion.
2. Copy Table 1 in your notebook. Although the time between pictures is not known, we will assume that the pictures were taken every 0.1 s.
3. The picture is not life-sized. Distances, as measured on the picture, need to be scaled to know the actual distances. To determine the scale of the photograph, measure the distance (in mm) between the 0 m line and the 0.5 m line. Then, divide the 0.5 by the distance (in mm). This is the scale factor, which will be used to convert distances measured on the picture (in mm) into the real distances of the cat (in m).

Table 1

Picture (cm)	Time (s)	Picture distance (mm)	Real distance (m)
1	0		
2	0.1		
3	0.2		

4. Choose a point on the cat to represent the position of the cat. The tip of the nose is a good choice. That means that the distance of the cat in the first picture can be read from the picture and is 0.5 m.
5. Determine the distance of the cat in the second picture by measuring the distance (in mm), from the 0.5 m line to the tip of the cat's nose. This is the picture distance. Multiply the picture distance by the scale factor. This is the real distance.
6. Repeat step 5 for the remaining pictures.

A. Draw a graph of the real distance of the cat's nose as a function of time.

B. What happens to the slope of the graph over the time of the motion? How does this relate to the motion of the cat?

C. What does the slope of the line of a distance–time graph indicate about motion?

When you look at a distance–time graph, you can see how the distance of an object varies with time by the steepness of the slope. Recall from page 344 that we can calculate the slope of a line by dividing the rise (change in distance) by the run (change in time). Therefore, the equation is

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta d}{\Delta t}$$

This is the same equation that we use to calculate speed. This means that the slope of a line on a distance–time graph is equal to speed. You saw this when you observed the slope of the line you drew in the Try This activity. Note that if the distances were measured in metres and the time in seconds, then the units for the slope would be metres/second (m/s), which is a unit of speed. If the distances were measured in kilometres and the time in hours, the units for the slope would be kilometres/hour (km/h), which is also a unit for speed. GO

To learn more about graphing and slopes, go to
www.science.nelson.com GO

Graphing Constant Speed

What does the distance–time graph of an object moving at a constant speed look like? Suppose that a jogger is moving toward the start of a 100 m track. If she was moving at a constant speed of 3 m/s when she crossed the start line, in 1 s her distance on the track would be 3 m, at 2 s her distance would be 6 m, at 3 s her distance would be 9 m, and so on. The information for the first 10 s is shown in Table 2. Figure 1 shows the graph of the time and distance.

LEARNING TIP

When graphing distance and time, time is always on the *x*-axis (horizontal). You may remember this from your Grades 9 and 10 math classes.

Table 2 Distance of a Jogger

Time (s)	Distance (m)
0	0
1	3
2	6
3	9
4	12
5	15
6	18
7	21
8	24
9	27
10	30

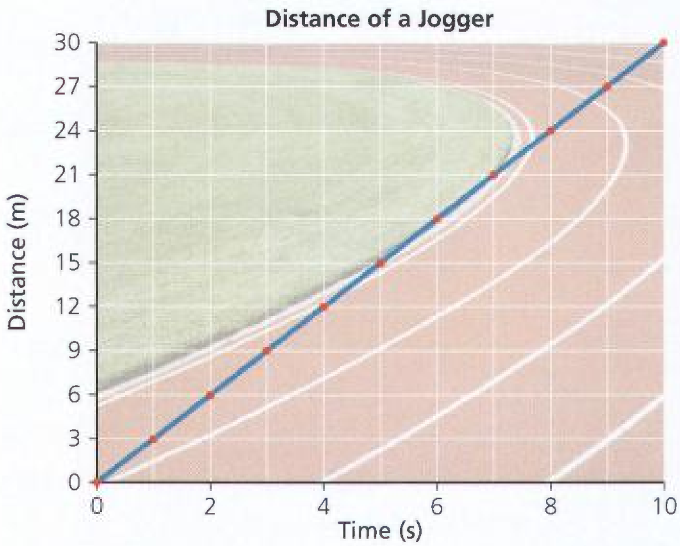


Figure 1 Distance–time graph for a jogger

How can we determine the average speed of the jogger using the graph? We can calculate the slope of the line for the graph using the following equation:

$$\text{slope} = \frac{d_f - d_i}{t_f - t_i} = \frac{\Delta d}{\Delta t}$$

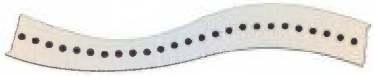


Figure 2 The spacing of the dots on the tickertape indicates the rate of motion.

We can conclude that the slope of a line on a distance–time graph is equal to average speed. We can calculate the slope of the line in Figure 1 to determine the average speed of the jogger as follows:

$$\text{slope} = v_{av} = \frac{\Delta d}{\Delta t} = \frac{30\text{ m} - 0\text{ m}}{10\text{ s} - 0\text{ s}} = 3\text{ m/s}$$

Therefore, for a distance–time graph of constant speed, the slope of the line is equal to the average speed.

Scientists use different techniques to investigate motion. One technique involves using a recording timer. As the paper tape is pulled through the timer, dots are recorded on tickertape paper. Figure 2 shows an illustration of tickertape that has been pulled through a timer. For example, Table 3 shows how far a student pulled tickertape through the timer in 1.2 s at a constant speed. Figure 3 shows the graph of the data with a line of best fit. (See Appendix B5 for information on a line of best fit.)

Table 3 Motion of Tickertape

Time (s)	Distance (cm)
0	0
0.10	3.1
0.20	5.8
0.30	7.7
0.40	9.2
0.50	13.3
0.60	15.7
0.70	17.3
0.80	18.8
0.90	21.1
1.00	23.7
1.10	26.0
1.20	28.2

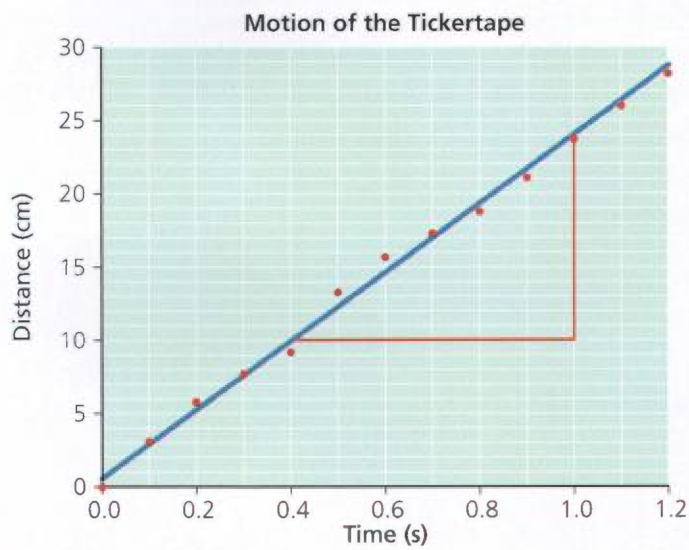


Figure 3 Distance–time graph showing line of best fit

We can calculate the slope of the line as

$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{24\text{ cm} - 10\text{ cm}}{1.0\text{ s} - 0.4\text{ s}} = 23.3\text{ cm/s}$$

Therefore, we can conclude that the tickertape was pulled at an average speed of 23 cm/s.

We can also use the average speed equation to calculate average speed:

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{28.2\text{ cm} - 0\text{ cm}}{1.20\text{ s} - 0\text{ s}} = 23.5\text{ cm/s}$$

There is a slight difference between the two calculations of average speed. Can you think of an explanation for this difference?

LEARNING TIP

When working through calculations such as the ones found here, it helps to work with a partner. Can you think of a reason for the slight difference between the two calculations of average speed?

Let's look at another example. Table 4 shows the time and distance for a bicycle. Figure 4 shows the graph of the bicycle's motion.

Table 4 Motion of a Bicycle

Time (s)	Distance (m)
0	0
2	5
4	26
6	62
8	106
10	141
12	185
14	225

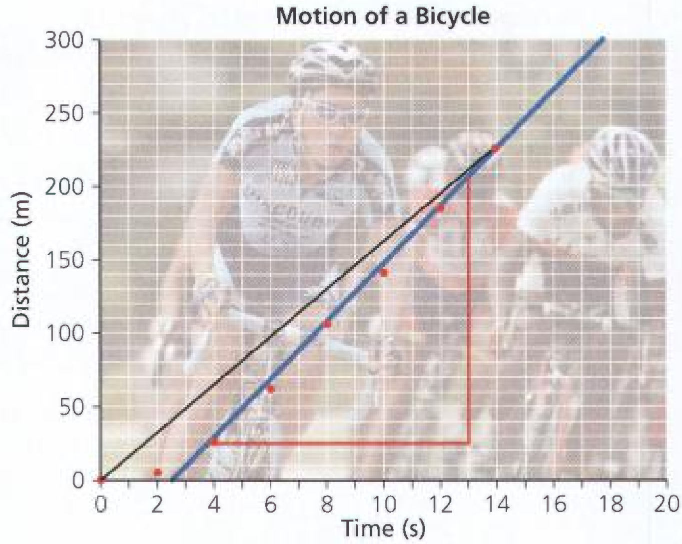


Figure 4 Distance–time graph. The black line is the average speed. The blue line is the line of best fit after 3 s.

From the graph, we can see that the bicycle started slowly, and then travelled at a constant speed. The blue line shows that the speed is almost constant after 3 s. We can determine the average speed for the entire trip:

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{225 \text{ m} - 0 \text{ m}}{14 \text{ s} - 0 \text{ s}} = 16.1 \text{ m/s}$$

The average speed is shown as the black line on the distance–time graph.

We can calculate the slope of the blue line to determine the average constant speed. To do this, we pick two points, shown here as two red lines, which form a triangle with the line of best fit. The advantage of the triangle is that it makes it easy to see the points on the graph. The larger the triangle, the easier it is to read the values, thereby reducing the error. The triangle is attached to the line of best fit and not to observed data points.

$$\text{slope} = v_{av} = \frac{\Delta d}{\Delta t} = \frac{205 \text{ m} - 25 \text{ m}}{13 \text{ s} - 4 \text{ s}} = 20.0 \text{ m/s}$$

This shows us that, once the bicycle was travelling at a constant speed (after 3 s), the average speed was 20 m/s. What do we do if we only want to know the speed at a particular instant in time on a graph?

Sometimes objects travel at a constant slow speed and then at a constant faster speed. For example, a car could travel at 50 km/h on city streets and then increase speed to 80 km/h on a highway. What do you think this type of motion would look like on a graph? You will investigate this type of motion in Investigation 12A. 12A *Investigation*

12A *Investigation*

Motion With Two Speeds

To perform this investigation, turn to page 366.

In this investigation, you will investigate the motion of an object.

Did You KNOW?

Sonic Booms

An airplane travelling faster than the speed of sound (supersonic speed) produces a sonic boom. This is because, as the airplane increases its speed, it pushes air molecules out of its way. At supersonic speeds, the airplane causes the air pressure waves to build up and compress, producing shock waves. When the shock waves reach your ears, you hear a sonic boom.

Determining Instantaneous Speed

How could you graph the motion of a car that does not travel at a constant speed: for example, a car that travels at 36 km/h (10 m/s) and then increases its speed to 108 km/h (30 m/s)? Note that such a change would not happen instantly. If the change in speed took 5 s, we can graph the motion as shown in Figure 5.

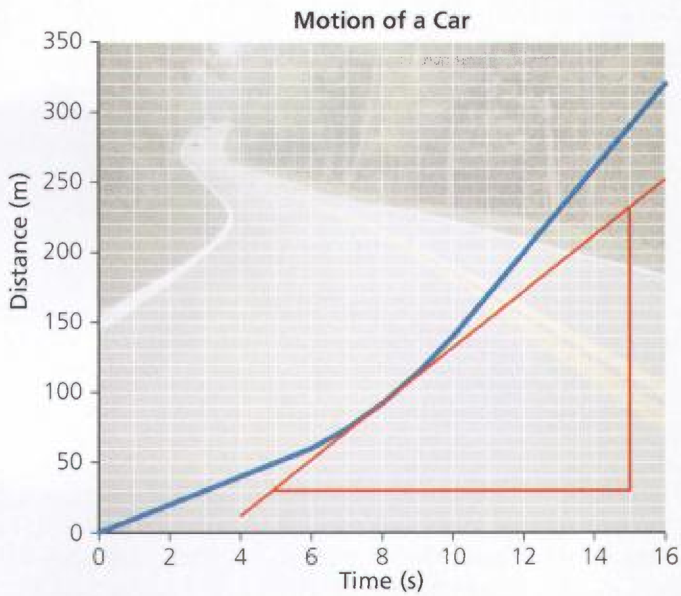


Figure 5 Distance–time graph. The red line is the tangent at 8 s.

We can see from the graph that the car had a constant speed of 10 m/s for the first 6 s and that it had a constant speed of 30 m/s for the last 6 s. However, between 6 s and 10 s, the car was changing speed. We can determine the speed of the car at any particular time using the slope of the line on the graph. For example, if we want to know the speed of the car at exactly 8 s, we would find the slope of the line at 8 s. To do this, we draw a tangent to the line at 8 s. The tangent to the line is the direction that the line is pointing at that time, and can be drawn by aligning a ruler with the line at that point on the curve. Note that drawing a tangent to the line requires a little practice and different people will draw slightly different lines. However, if all the students in your class drew tangents to the same line, their slopes would all be very similar.

We can calculate the slope of the tangent to determine the instantaneous speed at 8 s:

$$\text{slope} = v = \frac{230\text{ m} - 30\text{ m}}{15\text{ s} - 5\text{ s}} = 20\text{ m/s}$$

The instantaneous speed of the car at 8 s was 20 m/s. We can calculate the instantaneous speed of an object (that does not have constant speed) at a particular time by calculating the slope of the tangent to the line of the distance–time graph of the object's motion.

Using Distance–Time Graphs

So far, we have used distance–time data to construct a graph. However, it is possible to start with a graph and derive information from it. For example, look at the graph in Figure 6.

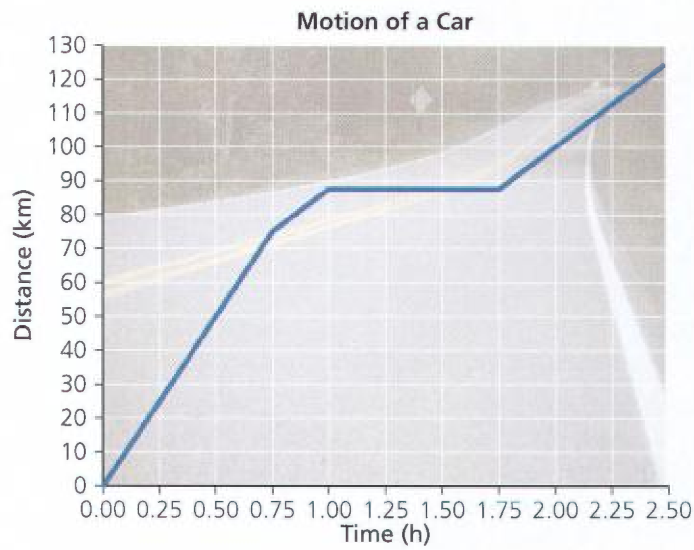


Figure 6 The distance–time graph of the motion of a car.

> ***LEARNING TIP***
> Adopt a questioning attitude when you are interpreting a graph such as Figure 6. What type of graph is it? What does the title tell you? What is represented on the vertical and horizontal axes? What does the plotted line tell you?

We can see that the car was travelling at a constant speed for the first 45 min (0.75 h) since the slope of the graph is constant. We can calculate the speed the car was travelling during this time by noticing that the car travelled 50 km in the first 30 min (0.50 h) and would, therefore, travel 100 km in 1 h. This is an informal way of calculating the slope. The car then slowed down for 15 min (0.25 h) and travelled 12 km. Its speed was therefore 48 km/h. The car then stopped for 45 min before travelling for 45 min at a constant speed. We can determine the speed at which the car was travelling during this time by calculating the slope:

$$\text{slope} = v = \frac{125\text{ km} - 87\text{ km}}{2.5\text{ h} - 1.75\text{ h}} = 51\text{ km/h}$$

Therefore, the car travelled at 100 km/h for 45 min, 48 km/h for 15 min, stopped for 45 min, and then travelled at 51 km/h for 45 min. We can see, from the graph, the distance the car travelled at different times. For example, at 30 min, the car travelled 50 km. At 45 min, the distance is about 75 km. The total distance the car travelled is about 125 km. Although it looks as though the speed of the car changed instantly from one constant speed to a different constant speed, we can assume that the change of speed was more gradual. However, the graph does not show enough detail.

12.3 CHECK YOUR Understanding

1. The position of a dog running down a soccer field for 7 s is given in Table 1.

Table 1 The Motion of a Dog

Time (s)	0	1	2	3	4	5	6	7
Distance (m)	0	2	5	9	18	22	25	31

   (a) Draw a distance–time graph for the dog.
   (b) What was the average speed for the dog?
   (c) What was the speed of the dog when $t = 6$ s?
   (d) During which second was the dog running the slowest?
   (e) During which second was the dog running the fastest?

2. A bowling ball is rolling down the alley with a constant speed. What would the distance–time graph look like? Sketch the graph.

3. The distance a car travelled was recorded every 6 min (0.1 h) and plotted on a graph (Figure 6). The car started the journey in town for 30 min (0.5 h) and then continued on the highway.

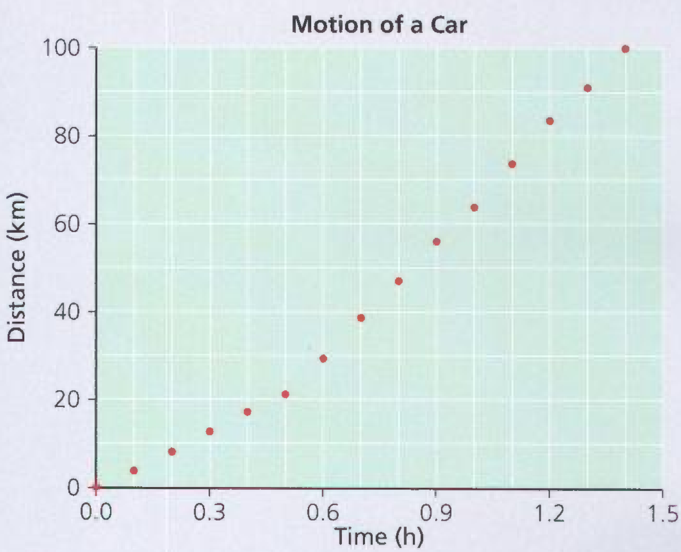


Figure 6

   (a) What was the car's average speed in town?
   (b) What was the car's average speed on the highway?
   (c) Did the car travel at a constant speed on the highway? How do you know?

4. Write a description of how to determine instantaneous speed from a distance–time graph.

5. Figure 7 shows the distance–time graph for the flight of a butterfly.

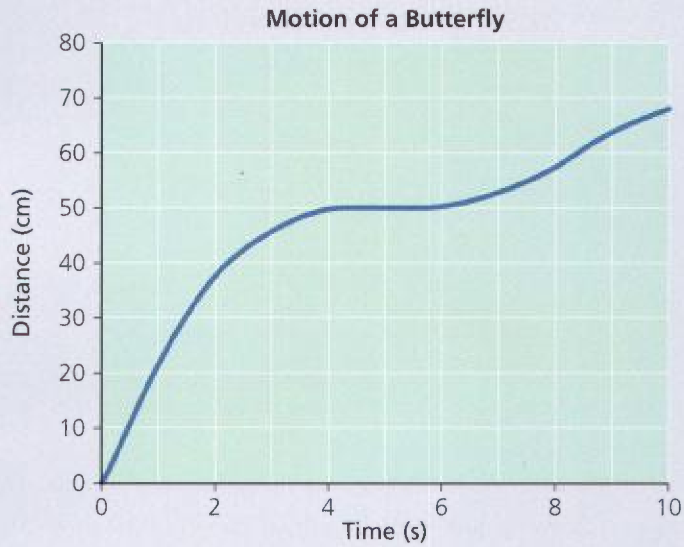


Figure 7

   (a) Using the graph, write a short description of the butterfly's motion.
   (b) What was the average speed of the butterfly for the 10 s?
   (c) What was the instantaneous speed of the butterfly at the following times: 2 s, 5.5 s, and 9 s?

12.4 Displacement and Velocity

In the study of motion, it is sometimes important to know the direction so that you can describe the position of a place in relation to a reference point. For example, Kamloops is located 300 km northeast of Nanaimo. In some situations, it is necessary to know not only the speed at which a vehicle is moving, but also the direction. For example, the Thalys high-speed train travels from Brussels, Belgium southwest to Paris, France at 300 km/h. Both displacement and velocity are quantities that require direction.

STUDY TIP

There are many new vocabulary words in this section. As you read, make a study card for each term. You can use these cards later to study for a chapter exam.

Displacement

Distance is a scalar quantity. A **scalar quantity** has a number and a unit. A quantity that has both a number and a unit is called a magnitude. The distance to an object tells you how far away it is, but does not indicate the direction. For example, a student's home is a distance of 500 m from the school. Figure 1 shows a map of the student's home in relation to the school. You can see that the student's home is actually 500 m north of the school. This is known as the displacement of the student's home from the school.

The **displacement** of an object is defined as the change in position of the object. Displacement is a vector quantity. A **vector quantity** has both magnitude and direction. We use the letter d to represent both distance and displacement. To distinguish between the two quantities, we put a small arrow over the vector symbol. An example of each is shown below.

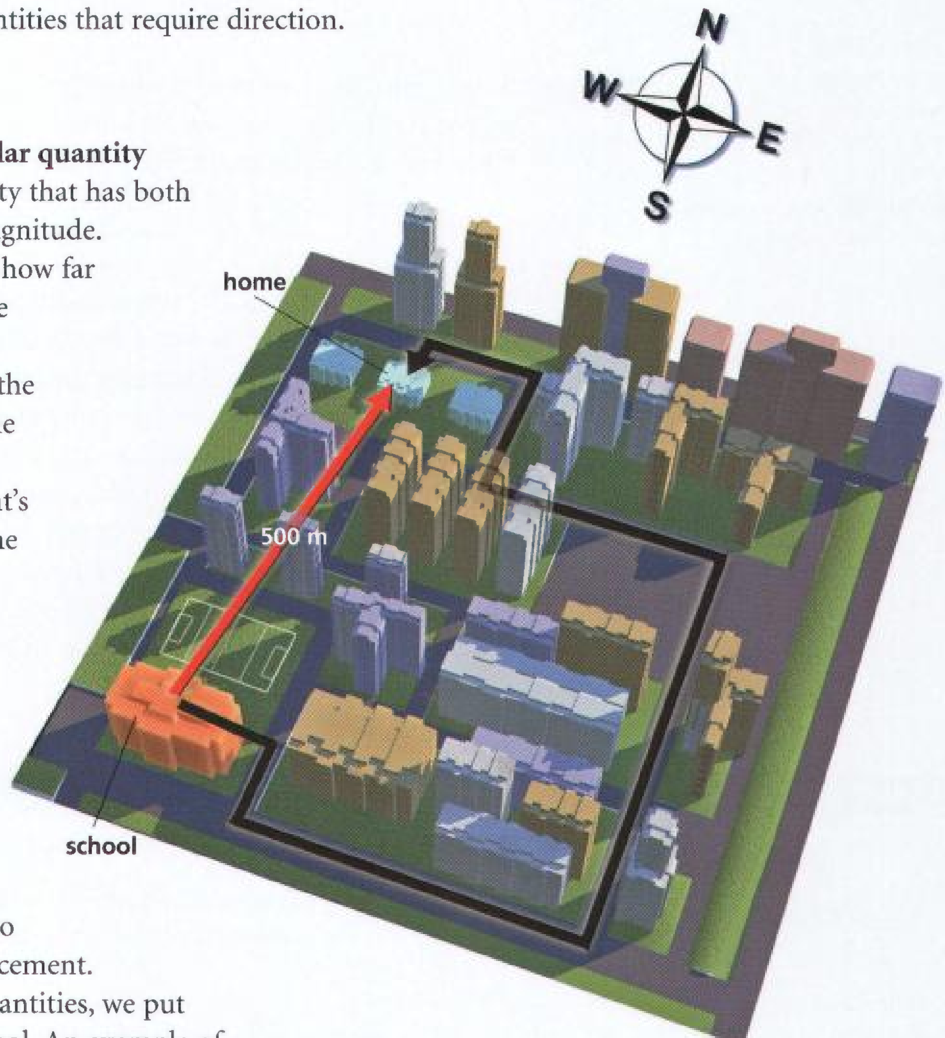
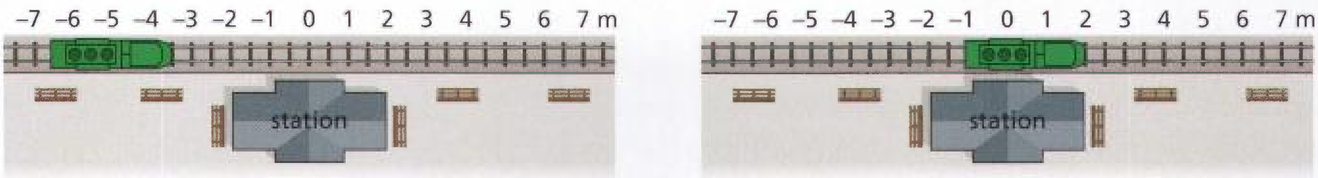


Figure 1 The student's home is 500 m [N] from the school.

$$\text{distance} = \Delta d = 1.5 \text{ km}$$
$$\text{displacement} = \Delta\vec{d} = 312 \text{ m [E]}$$

Note that the symbol for displacement is $\Delta\vec{d}$, which means "change in position."

To calculate the displacement of an object, we need to know its position relative to a reference point. We calculate a change in position by subtracting the initial position, $\vec{d}_i$, from the final position, $\vec{d}_f$. For example, look at Figure 2(a).



(a) (b)

Figure 2 (a) A train is 3.5 units to the left of the train station. We can also indicate the direction by saying −3.5 units. (b) The train moves so that it is 2.0 units to the right of the train station. We can also indicate the direction as +2.0 units.

If the train moves from its position 3.5 units left of the station as shown in Figure 2(a) to a position of 2.0 units right of the station as shown in Figure 2(b), then its displacement from its original position can be calculated as

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i = 2.0 \text{ m} - (-3.5 \text{ m}) = 5.5 \text{ m}$$

This means that the displacement of the train was 5.5 m to the right.

Direction is important when determining displacement. We calculate changes in position by subtracting the initial position from the final position. In addition, all positions must be relative to the same point. For example, in Figure 2, all positions of the train are relative to the train station. Directions can be left/right, forward/backward, north/south, east/west, or up/down. Remember that we choose one direction to be the reference direction, which will be a positive number, and that the opposite direction will be a negative number. For example, if up is the positive direction, then down will be negative. In Figure 2, right of the train station was positive and left was negative.

SAMPLE PROBLEM 1

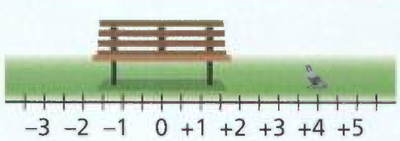


Figure 3 A pigeon stands 4 m right of a bench.

Determine Displacement

A pigeon standing 4 m to the right of a bench walks (Figure 3) to a position 2.5 m to the left of the bench. What is the displacement of the pigeon?

Solution

Let the direction right be positive. Substitute the values into the displacement equation.

$$\begin{aligned}\Delta\vec{d} &= \vec{d}_f - \vec{d}_i \\ &= -2.5 \text{ m} - (+4.0 \text{ m}) \\ \Delta\vec{d} &= -6.5 \text{ m}\end{aligned}$$

The displacement of the pigeon is −6.5 m, or 6.5 m left.

Practice

A dog is sitting 1.5 m to the left of a bench. The dog walks so that it is 3.5 m right of the bench. What was the dog's displacement?

Velocity

Speed is the rate of change of distance. As with distance, speed (v) is a scalar quantity because it only has magnitude. **Velocity** ($\vec{v}$) is the rate of change of displacement. Velocity is a vector quantity because it has a magnitude and a direction. The symbol has an arrow over it, in the same way that displacement ($\vec{d}$) does, to indicate that it is a vector quantity. The differences in the equations of speed and velocity are shown below.

$$\text{speed} = v = \frac{\text{distance}}{\text{time}} = \frac{\Delta d}{\Delta t}$$

$$\text{velocity} = \vec{v} = \frac{\text{displacement}}{\text{time}} = \frac{\Delta \vec{d}}{\Delta t}$$

Distance and speed depend on the path taken. Displacement and velocity only depend on the initial and final positions, not the path taken. The following examples illustrate this point. GO

To learn more about the concepts of scalar and vector, go to **www.science.nelson.com** GO

SAMPLE PROBLEM 2

Determine Average Speed and Average Velocity

A cyclist trains on the circular track shown in Figure 4. The track has a radius of 100 m and the circumference is 628 m. The cyclist goes 3.5 times around the track in 91.6 s.

(a) What was the average speed of the cyclist?

(b) What was the average velocity of the cyclist?

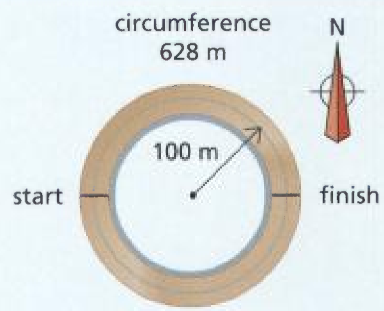


Figure 4 A circular bicycle training track

Solutions

(a) Substitute the values into the average speed equation.

$$v_{av} = \frac{\Delta d}{\Delta t} = \frac{3.5\ (628\ \text{m})}{91.6\ \text{s}}$$

$$v_{av} = 24.0\ \text{m/s}$$

The average speed of the cyclist was 24.0 m/s.

(b) First, find the displacement of the cyclist.

$$\Delta\vec{d} = \vec{d}_f - \vec{d}_i = 200\ \text{m [E]} - 0\ \text{m [E]}$$

$$\Delta\vec{d} = 200\ \text{m [E]}$$

Now, substitute the values into the average velocity equation.

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t} = \frac{200\ \text{m [E]}}{91.6\ \text{s}}$$

$$\vec{v}_{av} = 2.18\ \text{m/s [E]}$$

The average velocity of the cyclist was 2.18 m/s [E].

Practice

A swimming pool is 50 m long. A swimmer completes 150 m in a time of 83 s. The swimmer begins at the south end of the pool and finishes at the north end.

(a) What was the average speed of the swimmer?

(b) What was the average velocity of the swimmer?

Graphing Displacement and Velocity

Displacements can be plotted on a graph in the same way that distances can be plotted. While the slope of the line of a distance–time graph is equal to the speed, the slope of the line of a displacement–time graph is equal to the velocity of the object. The major difference is that displacements have a direction.

Table 1 shows the displacement of a hiker going on a walk. A graph of the data is shown in Figure 5.

Table 1 Displacement of a Hiker

Time (min)	Displacement (m south)
0	0
5	275
10	615
15	865
20	1200
25	1200
30	1200
35	720
40	450

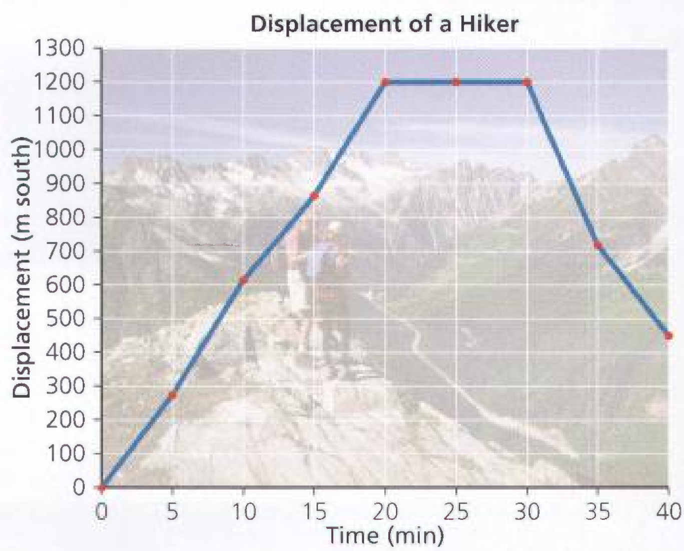


Figure 5 Displacement–time graph

We can see from the graph that after 20 min, the displacement of the hiker is 1200 m south. We can calculate the average velocity of the hiker for that time using the equation

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t} = \frac{1200 \text{ m [S]}}{20 \text{ min}} = 60 \text{ m/min [S]}$$

This is an average velocity of 60 m/min [S].

While speeds are always positive, velocities, because they are vector quantities, can be positive or negative with reference to a given direction. For example, the slope of the line between 30 and 35 min is –100 m/min or 100 m/min north.

A car travelling down a twisty road at 60 km/h has a constant speed. However, since the direction of the car is constantly changing, the velocity is constantly changing. If an object is travelling at a constant speed in a constant direction, then the object has constant velocity. This is known as **uniform motion**. A child riding a merry-go-round is travelling at constant speed. However, the child does not have uniform motion because the direction of motion is constantly changing.

To learn more about uniform motion, go to **www.science.nelson.com**

Although vectors have both magnitude and direction, sometimes we only need part of a vector quantity. For example, we may only need to know the direction of the displacement from the origin.

SAMPLE PROBLEM 3

Determine the Magnitude of Average Velocity

A bird flies 300 m [S] in 43 s, lands on a tree branch, and sits for 28 s. Then, the bird turns and flies north 500 m in 62 s. Which of the following is the magnitude of the velocity of the bird?

A. 1.5 m/s

B. 1.9 m/s

C. 6.0 m/s

D. 7.6 m/s

Solution

Let the direction south be positive. The initial position is 0 m. We know that the final position is 300 m + (−500 m) = −200 m, which is the same as 200 m [N]. Substitute the values into the velocity equation.

$$\vec{v}_{av} = \frac{\Delta\vec{d}}{\Delta t} = \frac{\vec{d}_f - \vec{d}_i}{\Delta t} = \frac{-200\text{ m} - 0\text{ m}}{43\text{ s} + 28\text{ s} + 62\text{ s}}$$

$$\vec{v}_{av} = -1.5\text{ m/s}$$

Therefore, the velocity of the bird is −1.5 m/s, or 1.5 m/s [N]. However, since we only need the magnitude of the velocity, we do not need to include the direction. The best answer is A. 1.5 m/s.

Practice

A car travels east at 50 km/h and travels 100 km in 2 h. The driver stops for 1 h to have lunch. The driver then continues to travel east 50 km in 1 h. What is the magnitude of the average velocity of the car for this trip?

A. 12 km/h

B. 38 km/h

C. 50 km/h

D. 75 km/h

12.4 CHECK YOUR Understanding

1. Write a definition of magnitude in your own words.
2. Which of the following are vector quantities?
   (a) displacement
   (b) speed
   (c) time
   (d) velocity
3. (a) What is the difference between position and distance?
   (b) What is the difference between position and displacement?
4. Give two examples each of speed and velocity. Use your examples to explain the difference between speed and velocity.
5. A bicycle messenger rides a bicycle around a square city block that has sides that are 100 m long (Figure 6). The messenger begins the ride at corner A.
   (a) When the messenger reaches corner C, what is the distance and the displacement?
   (b) When the messenger returns back to corner A, what is the distance and displacement?

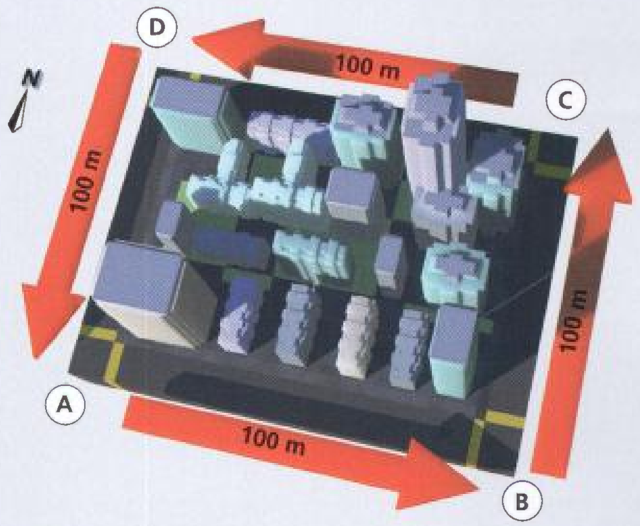


Figure 6

6. A turtle moves 3.5 m [E] in 136 s and then moves 1.7 m [W] in 88 s.
   (a) What is the average speed of the turtle?
   (b) What is the average velocity of the turtle?
7. A cyclist rode a bicycle for a little over 4 min. Her displacement was recorded and a displacement–time graph for the cyclist is shown in Figure 7.

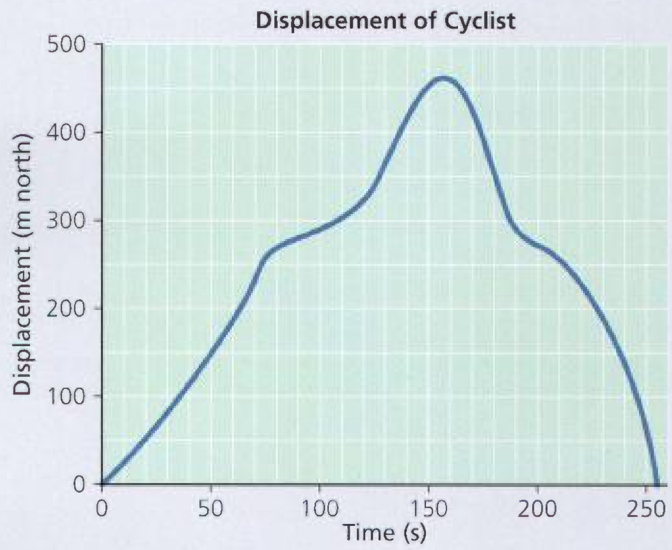


Figure 7

   (a) When was the cyclist's velocity the greatest?
   (b) When was the cyclist's speed the greatest?
   (c) When was the cyclist's displacement 300 m north?
   (d) What was the cyclist's average velocity for the first 70 s?
   (e) What was the cyclist's average speed for the entire trip?
   (f) What was the cyclist's instantaneous velocity at 240 s?
   (g) Did the cyclist stop at any time during the ride? If so, at what time?
   (h) What was the cyclist's average velocity for the first 200 s?
   (i) What was the cyclist's average velocity for the entire trip?

Tech CONNECT

DETECTING SPEED

In Canada, there were about 3000 fatalities in traffic collisions in 2005. About 17 % of these fatalities were because of inappropriate or excessive speeds. Radar and laser speed guns are used by police to detect speeds.

Speed limits on roads are set to identify a reasonable limit that will ensure public safety (Figure 1). However, most drivers (a staggering 85 %) have no idea how fast they are going at a particular time. To enforce speed limits, police use radar and laser speed guns to catch speeding drivers.

Figure 1 Speeding is the leading cause of accidents.

Radar, which stands for RAdio Detection And Ranging, was developed in World War II. A radar speed gun is basically a radio transmitter, which produces radio waves, and a receiver (Figure 2). The device sends out a radio wave that has a particular frequency and waits for the reflection of the signal to bounce off a vehicle. If the radar gun and a car are both standing still, the reflected signal will have the same wave frequency as the original signal. If the car is moving away from the radar gun, the first part of the radio wave has to travel a shorter distance to reach the car than the second part of the wave, which changes the frequency. Depending on how much the frequency changes, a radar gun can determine how quickly a car is moving toward or away from it. Police officers have been catching speeders this way for more than 50 years.

Many police departments are now using a speed detector that uses light instead of radio waves. A laser (or LIDAR for LIght Detection And Ranging) speed gun shoots many bursts of infrared laser light, and then measures the time for the light to reach a car and reflect back (Figure 3). By multiplying this time by the speed of light, the laser gun determines how far away the object is. Because it sends out many laser bursts of light, it can collect multiple distances. By comparing these different distances, it can calculate the speed of the car. A laser gun can be used to target a specific vehicle and is very accurate.

The use of radar and LIDAR guns to catch and deter speeders is a controversial topic. There are many radar detectors available to the speeding public that make it possible to pick up the radio signal emitted by the radar gun. Light sensitive detectors are used to detect the beams from LIDAR guns. However, the use of these detectors may have a benefit besides possibly avoiding a speeding ticket. Detectors alert motorists to the speed at which they are driving. Being aware of speed and slowing down may save lives.

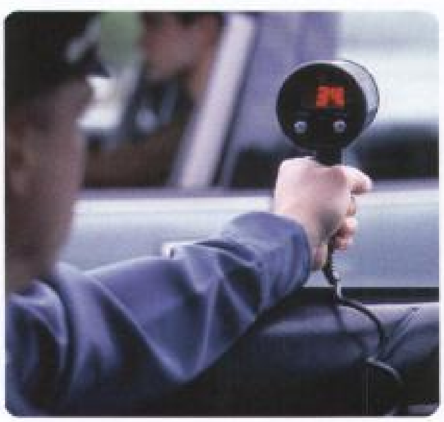


Figure 2 A police officer using a radar gun.

Figure 3 A LIDAR gun

Motion With Two Speeds

INQUIRY SKILLS

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

The motion of an object can be observed, and its distance and time recorded. The information about the motion can be described in words, in a data table, or with a graph. What information can the graph give in an efficient manner?

Scientists use a variety of different instruments to investigate motion. One instrument is a recording timer (Figure 1). In this investigation, you will use a recording timer to obtain data. You will then draw and analyze the distance–time graph.

Figure 1 A recording timer can be used to time motion.

Question

How are two different speeds shown on a distance–time graph?

Experimental Design

The tickertape recording timer uses electricity from an outlet that has a frequency of 60 Hz. That means that the time interval between dots is $\frac{1}{60}$ of a second or 0.0167 s. This is an awkward number for graphing. However, if we put a line through the first dot, which is at line number zero, and then put another line through the sixth dot after that one (the seventh dot), it will be $\frac{6}{60}$ of a second later (Figure 2). This is equal to 0.1 s and is much easier to graph.

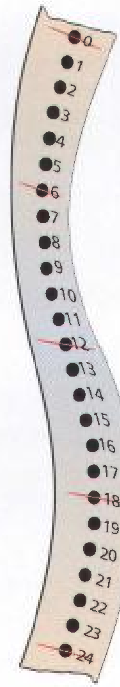


Figure 2 Sometimes it is more convenient to use time intervals of six dots rather than using every dot.

Doing this will also reduce the number of data points produced from a length of tickertape. If you find that using every sixth dot produces too many data points from a length of tickertape, then use every twelfth dot.

Materials

- tickertape
- recording timer

Procedure

1. Thread 1–2 m of tape into the recording timer.
2. Turn on the timer and begin to pull the tape at a constant speed through the timer (Figure 3). After pulling half the tape through the timer, double the speed of the tape (without stopping) and pull the rest of the tape through the timer. It is not necessary to exactly double the speed—the speed just needs to be a faster constant speed.

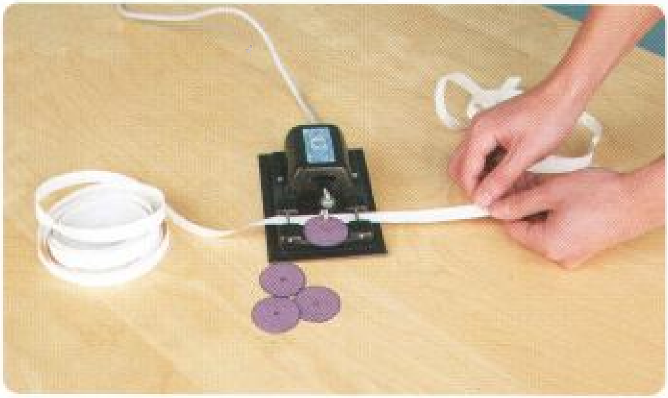


Figure 3

3. Using a convenient time interval, mark your tape into the data points you will use. Determine how many data points you will use.
4. Copy Table 1 into your notebook and add enough rows for your data.

Table 1

Time (s)	Distance (m)
0	0

5. Record the time and the distance travelled by the tape in your table. The distance travelled is the distance from the starting point each time, not just the distance travelled during the time interval.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Draw a distance–time graph for your data. Draw a line of best fit for the first half of the tape and a line of best fit for the second half of the tape.

(b) Determine the slopes of the two lines of best fit. What do these lines represent?

(c) Draw a line joining the first dot on your graph to the last dot. Determine the slope of the line. What does this slope represent?

(d) How are constant speeds shown on a distance–time graph?

(e) How are different constant speeds shown on a distance–time graph?

(f) Draw a line of best fit for all of the data on your graph.

Evaluation

(g) What happened to the slope of the line when you were increasing the speed of the tape?

Synthesis

(h) If you repeated the experiment and pulled the tickertape quickly and then slowed down, what changes would this make to your graph? Draw a sketch of the graph.

CHAPTER 12

Review

Displacement, Time, and Velocity

Key Ideas

The motion of an object can be described by displacement, time, and velocity.

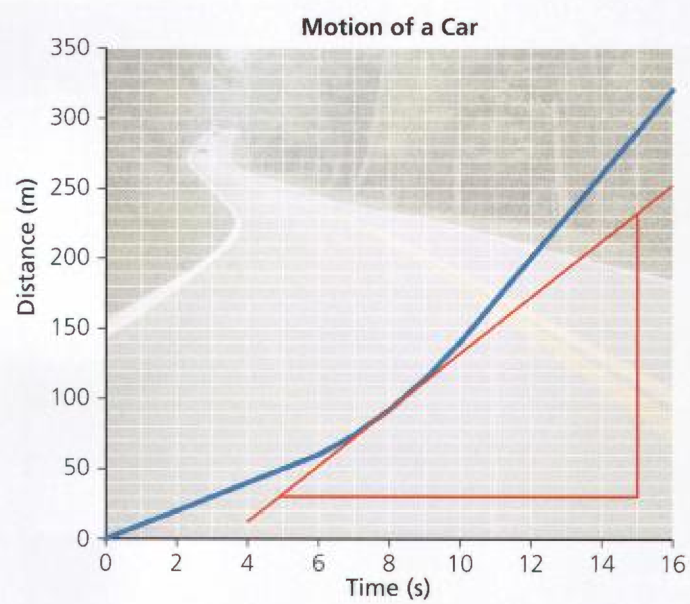
- Distance and displacement are similar, but not identical concepts in science. Speed and velocity are also similar, but not identical concepts.
- The displacement of an object is its change in position in relation to a point of reference, and the time interval for the change is how long the object took to get to the final position from the initial position.
- Velocity is the rate of change of displacement and is given by the equation

$$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$$

- If an object is travelling at a constant velocity, neither the magnitude nor the direction of its velocity changes.

Distance–time graphs and displacement–time graphs can visually display information about an object's motion.

- If the line of best fit of a distance–time graph or a displacement–time graph is a straight line, the object is travelling at constant speed or velocity.
- The slope of the line is equal to the speed or velocity of the object.
- If the slope of the line is changing, the speed or velocity is not constant (it is changing).
- Distance and displacement are always on the vertical axis and time is always on the horizontal axis.
- If the forward direction is defined as positive, then a negative velocity implies the object is moving in a backwards direction. The same is true for displacement.



Vocabulary

time interval, p. 342

slope, p. 344

speed, p. 346

average speed, p. 346

instantaneous speed, p. 349

scalar quantity, p. 359

displacement, p. 359

vector quantity, p. 359

velocity, p. 361

uniform motion, p. 363

Quantities can be either scalar or vector.

- Scalar quantities only have magnitude, which is a number with a unit.
- Vector quantities have both a magnitude and a direction.
- Time, distance, and speed are scalar quantities.
- Displacement and velocity are vector quantities.
- Vector quantities are indicated by an arrow over the symbol. For example speed is v, whereas velocity is $\vec{v}$.

Table 1 Summary of Quantities

Quantity	Symbol	Scalar or vector
time	t	scalar
distance	d	scalar
displacement	$\vec{d}$	vector
speed	v	scalar
velocity	$\vec{v}$	vector

An object's speed and velocity can be described in different ways.

- The average velocity of an object is the total displacement divided by the total time, regardless of changes in motion.
- The instantaneous speed of an object is its speed at a specific time.
- An object in uniform motion has a constant velocity.
- For an object in uniform motion, its average speed is equal to its instantaneous speed at any time.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. Use an example to explain the difference between distance and displacement.
2. Write a definition of "period" in your own words.

K 3. What does the slope of a distance–time graph determine?
   A. time
   B. speed
   C. distance
   D. direction

Use What You've Learned

U 4. A student uses the pulse in her wrist to measure her heart rate. She counts 72 beats in 1 min. What are the period and frequency of her heartbeat?

	Period	Frequency
A.	0.014 s	72 Hz
B.	0.83 s	1.2 Hz
C.	1.2 s	0.83 Hz
D.	72 s	0.014 Hz

U 5. A jet plane travels at an average speed of 800 km/h. How much time, in hours, is required for the plane to travel from Vancouver to Winnipeg, a distance of 2400 km?
   A. 0.25
   B. 0.33
   C. 1.0
   D. 3.0

U 6. Devon is riding his bicycle at 15 m/s. How far will he travel in 12 s?
   A. 1.2 m
   B. 3.0 m
   C. 27 m
   D. 180 m

7. An ant was sitting on the 50 cm mark of a metre stick. The ant then started to move. Table 1 gives the position of the ant over 28 s.

Table 1 Position of an Ant

Time (s)	Position (cm)
0	50
4	50
8	10
12	10
16	75
20	75
24	30
28	30

   (a) What distance did the ant travel?
   (b) What was the average speed of the ant?
   (c) What was the average velocity of the ant?

8. A stroboscopic light was used to illuminate a moving golf club in a dark room while a camera recorded the golf club's motion (Figure 1).

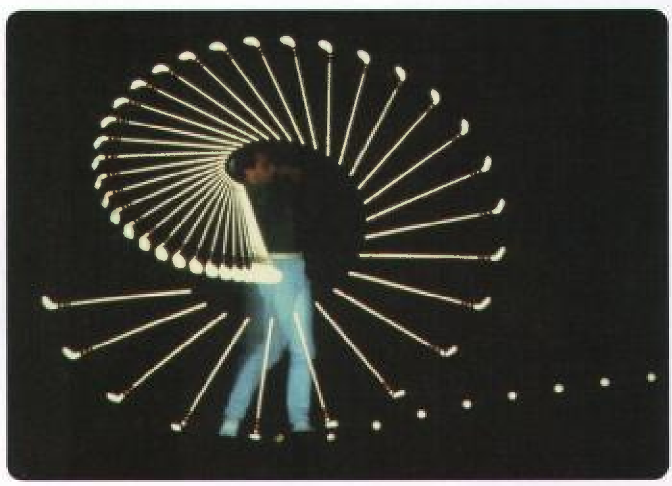


Figure 1

   (a) Is the golf club moving with a uniform speed?
   (b) At which part of the swing is the club moving the fastest?
   (c) At which part of the swing is the club moving the slowest?

9. Drivers in a Volkswagen and a Cadillac take the same 140 km trip. The Volkswagen travels at 80 km/h for the entire trip. The Cadillac starts at the same time, driving at 100 km/h, but the driver stops for 10 min to fill the gas tank. Which car has the higher average speed? Which car arrives first at the destination? How many minutes separate the arrival times of the cars?

10. A hiker leaves a campsite and travels by car for 45 min at an average speed of 60 km/h, and then hikes for 1.5 h at 4.2 m/s.
    (a) How far did the hiker drive?
    (b) How far did the hiker walk?
    (c) What total distance did the hiker travel?
    (d) What was the hiker's average speed for the trip?

Use Figure 2 to answer questions 11 and 12.

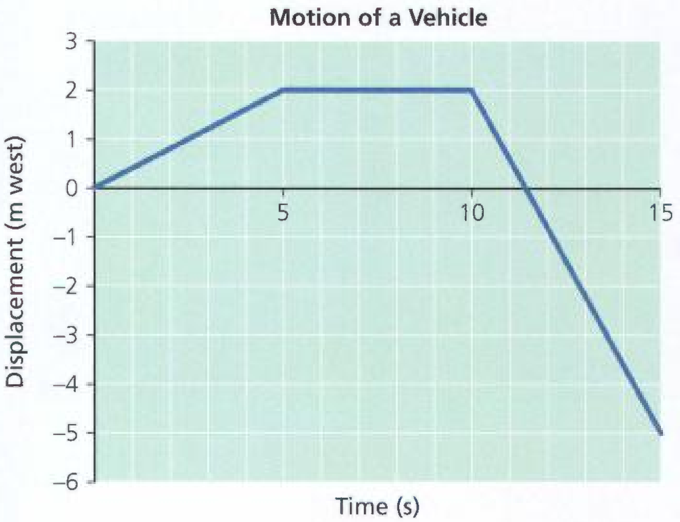


Figure 2

U **11.** At what time was the displacement closest to 1 m [E]?
A. 2.4 s
B. 12.1 s
C. 2.4 s and 10.7 s
D. 10.7 s and 12.1 s

U **12.** What was the average velocity from 1 s to 15 s?
A. 0.33 m/s [E]
B. 0.33 m/s [W]
C. 0.6 m/s [E]
D. 0.6 m/s [W]

13. A bird's flight along the side of an office building was recorded on a video camera that also recorded the time. The distance was estimated using the size of the office building windows. Table 2 shows the data for the bird's flight.

Table 2 Distance of a Bird

Time (s)	1.2	1.7	2.1	2.7	2.9	3.3	3.7	4.1
Distance (m)	2.9	6.2	9.2	14.9	18.2	24.0	29.7	33.1

(a) Use the data to make a distance–time graph.
(b) What was the average speed of the bird along the building?
(c) What was the instantaneous speed of the bird at 3.0 s?

U **14.** A car travels 3 km [W], 4 km [E], and 1 km [W]. What is the displacement of the car?
A. 0 km
B. 4 km
C. 7 km
D. 8 km

Think Critically

HMP **15.** Why is distance usually on the vertical axis even if distance is the independent variable?
A. It is a convention.
B. Distance is a scalar quantity.
C. It is used to calculate speed.
D. Time cannot be controlled as a variable.

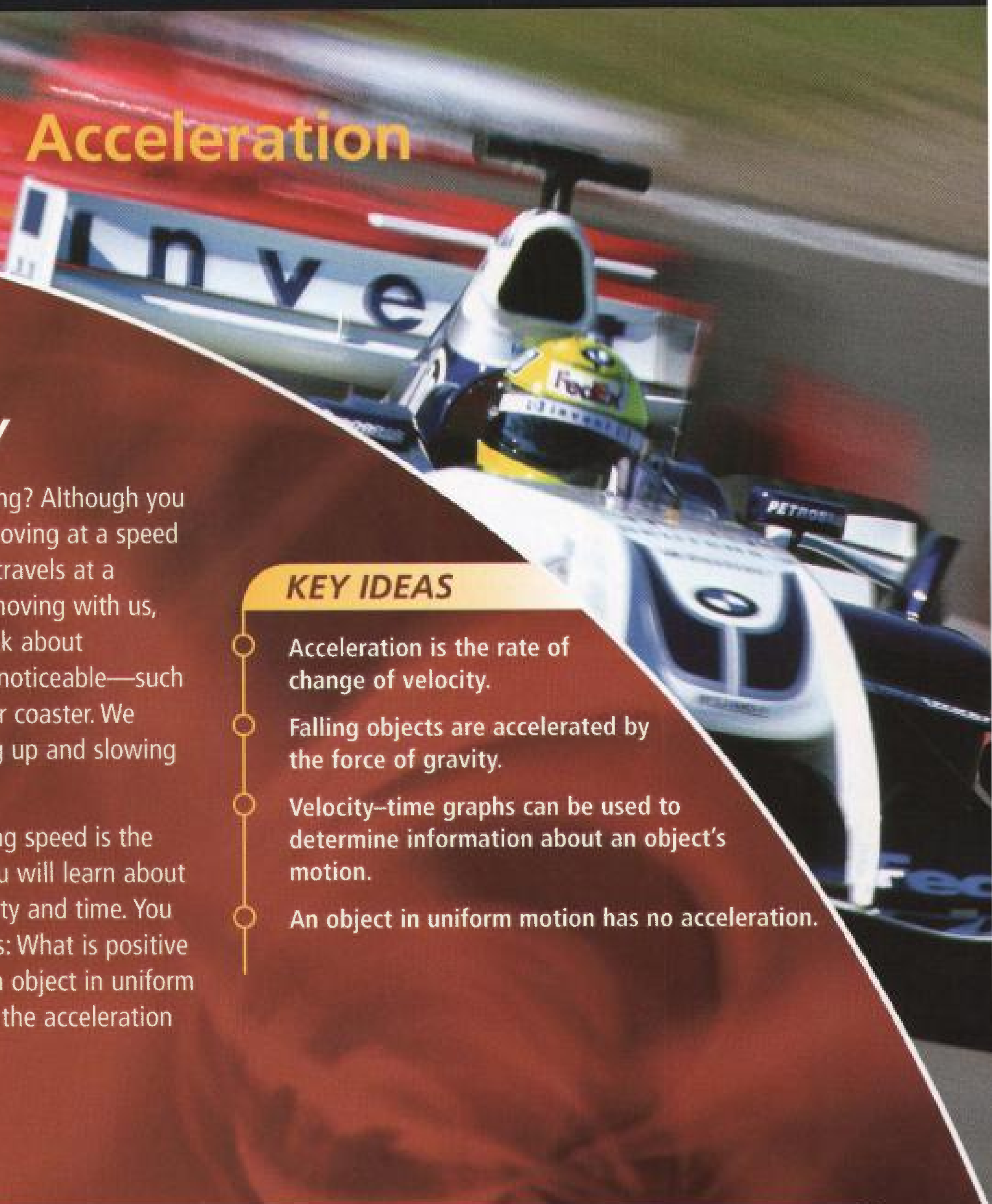
16. An object undergoes motion. Is it possible for the magnitude of the displacement to be the same as the distance? Explain your answer (you should use an example to support your answer).

Reflect on Your Learning

17. What have you learned about graphing and interpreting graphs that has helped you understand the concepts presented in this chapter?

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

CHAPTER 13 Acceleration



Chapter Preview

Did you know that you are always moving? Although you may not feel it, everything on Earth is moving at a speed of 30 km/s around the Sun. Since Earth travels at a constant speed, and because the air is moving with us, we do not feel as if we are moving. Think about experiences in which movement is very noticeable—such as in a fast-moving racecar or on a roller coaster. We usually associate the feeling of speeding up and slowing down with changes in motion.

The study of increasing and decreasing speed is the study of acceleration. In this chapter, you will learn about acceleration and how it relates to velocity and time. You will be able to answer questions such as: What is positive and negative acceleration? Why does an object in uniform motion have zero acceleration? What is the acceleration of a falling object?

KEY IDEAS

- Acceleration is the rate of change of velocity.
- Falling objects are accelerated by the force of gravity.
- Velocity–time graphs can be used to determine information about an object's motion.
- An object in uniform motion has no acceleration.

TRY THIS: Motion of Objects in Free Fall

Skills Focus: predicting, conducting, observing, recording, analyzing, communicating

In this activity, you will observe the falling motion of different objects.

Materials: set of masses, sponge ball, table tennis ball

> Do not drop the masses from too high as they could be damaged or cause injury if they hit someone. A soft landing pad, such as a pillow, will protect this equipment and the floor.

1. Hold a 10 g mass in one hand and a 200 g mass in the other hand so that they are at the same height. Predict what would happen if you dropped the masses at the same time. Record your prediction.
2. Drop the masses and note which mass lands first.
3. Repeat steps 1 and 2 using the 10 g mass and the sponge ball, and then with the 10 g mass and the table tennis ball.

A. Write an explanation for your observations.

B. Did your observations support your prediction? Explain.

C. Would your results be different if heavier masses had been used?

D. What factors determine how long an object takes to fall to the ground?

E. How could you devise an experiment that would investigate one of the factors listed in C?

13.1 Accelerating Objects

As you learned in Chapter 12, when you are travelling at a constant speed in a straight line, you have uniform motion. However, most objects do not travel at constant speed in a straight line so they do not have uniform motion. For example, a cyclist speeds up, changes direction, or does both while riding a bicycle (Figure 1). When an object changes speed or direction, it is changing its velocity. **Acceleration** is defined as the rate of change of velocity. Acceleration is a vector quantity similar to displacement and velocity. It therefore has both a magnitude and direction. The average acceleration is the change of velocity divided by the time interval taken for the change. This is written as the equation

$$\vec{a}_{av} = \frac{\text{change of velocity}}{\text{time interval}} = \frac{\Delta\vec{v}}{\Delta t}$$

where $\vec{a}_{av}$ is the average acceleration in m/s^2, $\Delta\vec{v}$ is the change in velocity in m/s, and Δt is the time in s. Note that the unit for acceleration is metres per second per second (m/s/s), which is abbreviated to metres per second squared (m/s^2).

Since acceleration is the change in velocity, which is calculated by subtracting the initial velocity ($\vec{v}_i$) from the final velocity ($\vec{v}_f$), we can also write the equation as

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

LEARNING TIP

Preview Chapter 13 to get an overall impression of the content. Skim the headings, tables, figures, and sample problems. Review the key ideas and chapter preview. What information will be new to you? What topics do you need to focus your attention on?

To learn more about how changes in velocity relate to acceleration, watch the animation at **www.science.nelson.com**

Figure 1 These cyclists in the Tour de France are travelling at a constant speed, however, their motion is accelerated.

STUDY TIP

Develop the study skill of planning ahead. Plan to read each section before it is discussed in class. Doing this will help you understand the material that is presented in class at a deeper level.

SAMPLE PROBLEM 1

Determine Acceleration

A baseball is thrown toward a batter with a velocity of 30 m/s. The batter hits the ball with the bat so that the ball flies away at a velocity of 25 m/s. The ball was in contact with the bat for 0.003 s. What is the average acceleration of the ball while being hit?

Solution

Let the direction away from the batter be positive (and the direction toward the batter be negative). Substitute the values into the acceleration equation.

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

$$= \frac{25 \text{ m/s} - (-30 \text{ m/s})}{0.003 \text{ s}}$$

$$\vec{a}_{av} = 18\ 000 \text{ m/s}^2$$

The average acceleration of the baseball while being hit is + 18 000 m/s^2, or 18 000 m/s^2 away from the batter.

Practice

A helicopter was travelling east at 14 m/s (50 km/h) observing traffic. The helicopter turned, and 35 s later it was travelling west at 14 m/s. What was the average acceleration of the helicopter during this period?

An object in uniform motion that is travelling at a constant velocity (speed and direction are not changing) has no acceleration. For example, a car travelling along a straight road at a constant speed has an acceleration of zero. However, an object that is travelling in a circle at a constant speed is continuously changing its direction and, therefore, is undergoing acceleration. Planets, Ferris wheels, and merry-go-rounds, have motion like this. Since it is so common, this type of motion is called uniform circular motion. You will study uniform circular motion in senior physics courses.

Acceleration from Rest

An article in the newspaper states that a car can go from zero to 100 km/h in 3.2 s. This is a measure of acceleration. This could be written as

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{100 \text{ km/h} - 0 \text{ km/h}}{3.2 \text{ s}} = 31 \text{ km/h/s}$$

We read this as thirty-one kilometres per hour per second. In other words, the velocity forward increases by 31 km/h each second. Therefore, although the base metric unit for acceleration is m/s^2, it is possible to use other units to express the rate of change of velocity.

How can you determine the acceleration of an object in the laboratory? Using a ramp and a recording timer, you can investigate the motion of an accelerating object. 13A *Investigation*

13A *Investigation*

Analysis of an Object Moving at Constant Acceleration

To perform this investigation, turn to page 393.

In this investigation, you will examine and analyze the motion of an object as it accelerates from rest.

Falling Objects: Acceleration Due to Gravity

In the Try This activity at the beginning of this chapter, you compared the rates at which different objects fall to the ground. Objects fall because the force of gravity attracts them to Earth (Figure 2). For objects such as marbles and books, we can assume that the effect of air resistance is negligible. When air resistance is negligible, the motion is known as free fall.

Figure 2 This bungee jumper enjoys a brief moment of free fall before the elastic cord causes the jumper to rebound upwards.

For example, let's look at an experiment that studied the displacement and time of a falling marble. The marble was videotaped as it fell beside a metre stick. The data given in Table 1 was recorded by watching the video in slow motion. Figure 3 shows the displacement–time graph.

Table 1 Displacement of a Falling Marble

Time (s)	Displacement (cm down)
0.00	0
0.05	1
0.10	5
0.15	10
0.20	20
0.25	30
0.30	45
0.35	60
0.40	80
0.45	100

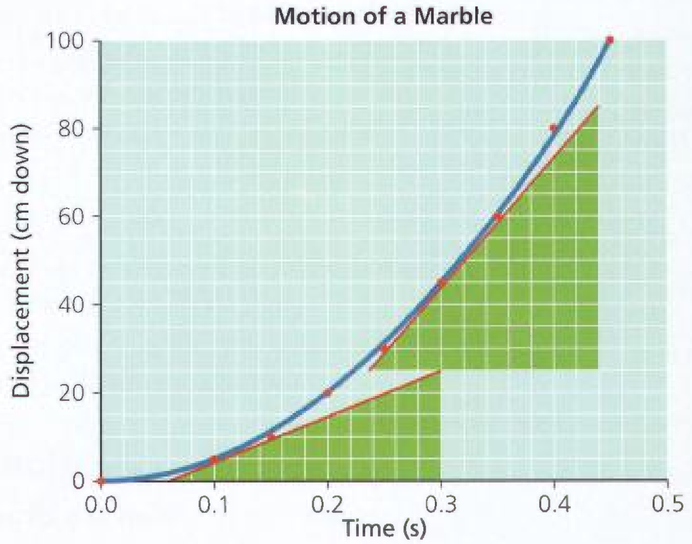


Figure 3 Displacement–time graph for the motion of a falling marble

You have learned that the slope of a line on a displacement–time graph equals velocity. We can calculate the slopes of the two tangents to the graph to determine the instantaneous velocity of the marble at 0.1 s and 0.3 s:

$$\vec{v}_{0.1\text{ s}} = \frac{\text{rise}}{\text{run}} = \frac{25\text{ cm} - 0\text{ cm}}{0.3\text{ s} - 0.06\text{ s}} = 104\text{ cm/s down}$$

$$\vec{v}_{0.3\text{ s}} = \frac{\text{rise}}{\text{run}} = \frac{85\text{ cm} - 25\text{ cm}}{0.44\text{ s} - 0.24\text{ s}} = 300\text{ cm/s down}$$

Table 2 shows the results if the instantaneous velocity is calculated for other times. A graph of velocity–time is shown in Figure 4.

Table 2 Velocity of a Falling Marble

Time (s)	Velocity (cm/s down)
0	0
0.1	104
0.2	190
0.3	300
0.4	395
0.5	491

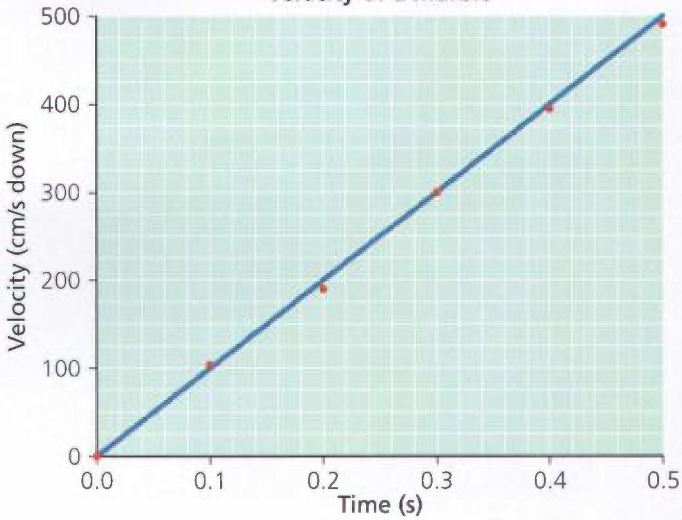


Figure 4 Velocity–time graph for a falling marble

Did You KNOW?

Acceleration of Gravity in Space

The acceleration of gravity on the surface of the Moon is 1.6 m/s^2 (about one-sixth of that on Earth) and on Mars is 3.7 m/s^2 (about one-third). The gravity on Neptune is 14.1 m/s^2, which means that it generates an acceleration of gravity that is almost 1.5 times greater than that of Earth.

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

We can see from Figure 4 that the velocity of the marble increased with time. By drawing the line of best fit, we can see that the velocity increased at a constant rate, although the increments were not equal because there were slight errors in the data. The rate that the marble's velocity increased is the acceleration of the marble and is caused by the force of gravity. Since we know that the acceleration of gravity is fairly constant, we know that the acceleration of the marble is also constant. Using this definition, we can calculate the free fall acceleration of the marble as

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{491 \text{ cm/s} - 0 \text{ cm/s}}{0.5 \text{ s}} = 982 \text{ cm/s}^2 \text{ down}$$

This value is the acceleration caused by the force of gravity. The force of gravity changes slightly from one location on Earth to another. The average value of acceleration of gravity on Earth is 9.8 m/s^2 down. Note that this value does not apply to objects that are affected by air resistance. GO

Negative Acceleration

Acceleration is defined as a change in velocity over time. The change in velocity can be either an increase or a decrease. An object that undergoes a decrease in velocity, that is, the final velocity is less than the initial velocity, has **negative acceleration.** This means that the change in velocity will be a negative number. For example, a car is travelling west (let this be the positive direction) and its velocity is decreasing. If we know that the magnitude of the acceleration is 5.6 m/s^2, then we know that the acceleration is negative (-5.6 m/s^2, or 5.6 m/s^2 [E]). When you are using vector quantities in equations, you must be careful when indicating directions. The following problems illustrate this.

SAMPLE PROBLEM 2

Determine the Time Interval

A golf ball rolled across the green with an acceleration of -1.4 m/s^2. If the initial velocity was $+2.8$ m/s, for how many seconds did the golf ball roll before stopping?

Solution

Since the acceleration is given as -1.4 m/s^2, we know that the direction forward must be positive. Substitute the values into the acceleration equation.

$$\vec{a}_{\text{av}} = \frac{\vec{v}_{\text{f}} - \vec{v}_{\text{i}}}{\Delta t}$$

$$\Delta t = \frac{\vec{v}_{\text{f}} - \vec{v}_{\text{i}}}{\vec{a}_{\text{av}}}$$

$$= \frac{0 \text{ m/s} - 2.8 \text{ m/s}}{-1.4 \text{ m/s}^2}$$

$$\Delta t = 2.0 \text{ s}$$

The golf ball rolled for 2.0 s before stopping.

Practice

A skier travelling at a velocity of 18 m/s stops with an acceleration of -4.9 m/s^2. Over what time interval did the skier stop?

As you can see, if the acceleration in Sample Problem 2 had not been negative, the change in time would have been calculated to be a negative number, which would mean that time went backwards! GO

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

Solving Problems for Velocity

There are two different ways of writing the equation for acceleration:

$$\vec{a}_{\text{av}} = \frac{\Delta \vec{v}}{\Delta t} \quad \text{and} \quad \vec{a}_{\text{av}} = \frac{\vec{v}_{\text{f}} - \vec{v}_{\text{i}}}{\Delta t}$$

We can use either equation to solve for average acceleration. We can also rearrange the equations to solve problems for final velocity as shown:

$$\vec{a}_{\text{av}} = \frac{\vec{v}_{\text{f}} - \vec{v}_{\text{i}}}{\Delta t}$$

$$\vec{v}_{\text{f}} - \vec{v}_{\text{i}} = \vec{a}_{\text{av}} \Delta t$$

$$\vec{v}_{\text{f}} = \vec{v}_{\text{i}} + \vec{a}_{\text{av}} \Delta t$$

This equation is much more convenient for finding the final velocity without doing the algebra every time!

STUDY TIP

Once you have completed a sample problem, try this handy trick for remembering it for an exam: On one side of a study card, write the category of the problem (e.g., finding average acceleration). On the other side, write out the problem and solve it.

SAMPLE PROBLEM 3

Determine the Final Velocity

A baseball is thrown upward with an initial velocity of 15 m/s. What will the baseball's velocity be after 2 s? The acceleration of gravity is 9.8 m/s^2 down.

Solution

Let upward be positive. Substitute the values into the final velocity equation.

$$\vec{v}_f = \vec{v}_i + \vec{a}_{av}\Delta t = +15 \text{ m/s} + (-9.8 \text{ m/s}^2 \times 2 \text{ s})$$
$$\vec{v}_f = -4.6 \text{ m/s}$$

The velocity will be −4.6 m/s, or 4.6 m/s downward.

Practice

A slingshot shoots a marble upward with an initial velocity of 20 m/s. What is the speed of the marble after 1.5 s? The acceleration of gravity is 9.8 m/s^2 down.

SAMPLE PROBLEM 4

Determine the Initial Velocity

After accelerating at 4.5 m/s^2 [E] for 1.4 s, a car's velocity was 15 m/s [W]. What was the initial velocity of the car?

Solution

Let the direction west be positive. Substitute the values into the final velocity equation.

$$\vec{v}_f = \vec{v}_i + \vec{a}_{av}\Delta t$$
$$\vec{v}_i = \vec{v}_f - \vec{a}_{av}\Delta t = 15 \text{ m/s} - (-4.5 \text{ m/s}^2 \times 1.4 \text{ s})$$
$$\vec{v}_i = 21 \text{ m/s}$$

The car's initial velocity was +21 m/s, or 21 m/s [W].

Practice

A rocket was travelling upward when the second stage fired. The second stage gave the rocket an average acceleration of +19 m/s^2 for 4.5 s. If the final velocity of the rocket was +125 m/s, what was the rocket's velocity before the second stage fired?

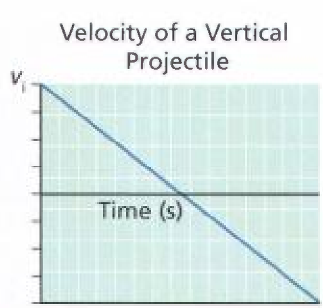


Figure 5 Velocity–time graph for a vertical projectile

Graphing the Velocity of Vertical Projectiles

If an object is thrown upward with an initial velocity (v_i), the object will rise upward and its velocity will decrease until the object stops at some time, *t*. This is shown in Figure 5. After the object stops briefly, it begins to fall. The object will speed up as it falls, but as you can see in the graph, the velocity of the object continues to decrease. Therefore, the acceleration is negative and constant. Note that the slope of the line is negative. For objects on Earth, the acceleration of gravity is −9.8 m/s^2 (the negative sign indicates that the acceleration is down).

13.1 CHECK YOUR Understanding

1. Write a definition of acceleration in your own words.
2. Two students get in an elevator on the ground floor and ride the elevator up to the fifth floor.
   (a) Describe what happens to their velocity and acceleration during the trip.
   (b) Sketch a velocity–time graph for the trip. What do you think an acceleration–time graph for the trip would look like? Sketch your idea.
3. Which of the following are possible units for acceleration?

   A. $\frac{\text{cm/s}}{\text{s}}$

   B. $\frac{\text{m} \times \text{s}}{\text{s}}$

   C. km/h/s

   D. $\frac{\text{min}}{\text{min/km}}$
4. What happens to the velocity of an object as it falls if the only force acting on the object is gravity? What happens to the acceleration of the object?
5. A cyclist starts from rest and reaches a velocity of 18 m/s [SW] in 3.8 s. What was the cyclist's acceleration?
6. A UFO is flying at a velocity of 45 m/s [E]. If 5.9 s later its velocity was 35 m/s [W], what was its acceleration? What assumption did you make?
7. A motorcycle and rider start from rest and reach a velocity of 52 km/h [E] in 2.7 s. What was the acceleration of the motorcycle in m/s^2?
8. A sprinter finishes a race with a velocity of +8.9 m/s. The sprinter accelerated to a stop at a rate of -2.7 m/s^2. How long did it take the sprinter to come to a stop?
9. A small rock was dropped and its displacement recorded in time intervals of 0.1 s. The data is shown in Table 3.

Table 3 Motion of a Rock

Time (s)	Displacement (cm down)	Average velocity (cm/s down)	Average acceleration (cm/s^2 down)
0	0		
0.1	0.20		
0.2	0.51		
0.3	0.90		
0.4	1.38		
0.5	1.97		
0.6	2.67		
0.7	3.46		
0.8	4.33		
0.9	5.33		
1.0	6.41		

   (a) Draw a displacement–time graph.
   (b) What happens to the slope of the line as time increases?
   (c) What happens to the velocity of the rock as time increases?
   (d) Determine the average velocity for each time interval.
   (e) Why is there one less average velocity value than the number of time or displacement values?
   (f) Draw a velocity–time graph for your values. Draw a line of best fit for your data.
   (g) What is the slope of the line for the velocity–time graph?
   (h) Why do you think that the initial velocity did not equal to 0 cm/s?
   (i) Determine the average acceleration for each time interval.

13.2 Graphing Accelerated Motion

STUDY TIP

Having notes, study cards, and past exams organized and handy will help you prepare for future exams. An effective organization system is to put all your notes, cards, and past exams in a file folder for each chapter.

As we saw in Chapter 12 for displacement, time, and velocity, graphing information is often a very effective means of communicating information about motion. For example, we used displacement–time graphs to obtain information about velocity. What information can we obtain from velocity–time graphs and acceleration–time graphs?

Constant Acceleration

As we saw in the previous section, objects accelerated by gravity have a constant acceleration if other forces are negligible. In addition to falling objects, there are other situations where there is constant acceleration. In these situations, the velocity changes at a constant rate, and the resulting velocity–time graph is a straight line.

For example, the simulated emergency braking of a motorcycle on a test track was observed during an experiment. The initial velocity of the motorcycle was just under 90 km/h forward (25 m/s), and the velocity of the motorcycle was recorded every 0.2 s. The velocity was converted into m/s and the data is shown in Table 1. Figure 1 shows a graph of the data.

Table 1 Motion of a Motorcycle

Time (s)	Velocity (m/s forward)
0	24.0
0.5	20.4
1.0	17.7
1.5	12.7
2.0	8.7
2.5	4.9
3.0	1.3

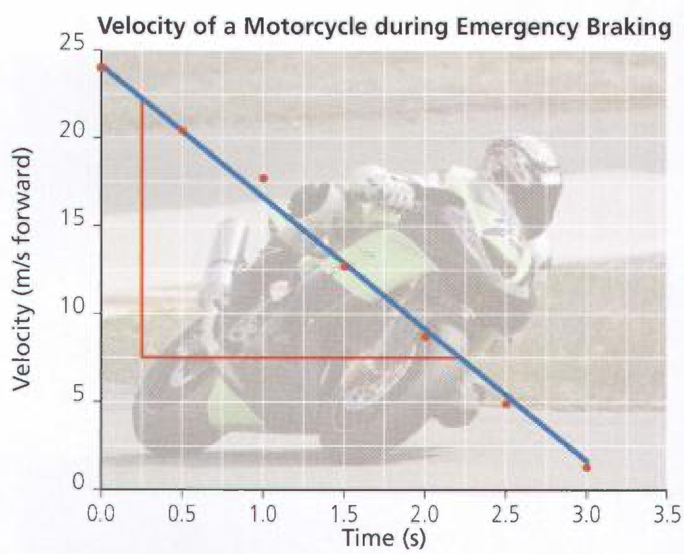


Figure 1 Velocity–time graph for the emergency braking of a motorcycle on a test track.

A line of best fit was drawn through the data. The slope of the line is equal to the acceleration of the motorcycle. In this case, since the slope is downward, the acceleration is negative while the motorcycle brakes. A negative acceleration means that the velocity is decreasing. Since the line of best fit is straight, we can see that the acceleration was constant.

If we define the forward direction of the motorcycle as positive, we can determine the acceleration of the motorcycle by calculating the slope of the line:

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{7.5 \text{ m/s} - 22.5 \text{ m/s}}{2.25 \text{ s} - 0.25 \text{ s}} = -7.5 \text{ m/s}^2$$

In addition to being able to determine the acceleration from the graph, we can also see that, if we extend the line of best fit to zero velocity, the motorcycle stopped in just under 3.2 s.

This example shows that we can use the slope of the line of a velocity–time graph to determine the acceleration of an object. If the object has a constant acceleration, the line will be straight and have a constant slope. A positive slope indicates that the object has a positive acceleration (increasing velocity). A negative slope indicates that the object has a negative acceleration (decreasing velocity). What significance does the area under the line have?

LEARNING TIP

Check your understanding. Explain to a partner why objects travelling at constant velocity have zero acceleration. Refer to Figure 2.

Area Under a Velocity–Time Graph

If an object is travelling at a constant velocity, then its acceleration is zero. That means the slope of the line on the velocity–time graph will also be zero. Figure 2 shows the velocity–time graph for a bicycle travelling at a constant velocity of 8 m/s [E] for 20 s. Since the velocity is constant, we know that the bicycle has no acceleration and, therefore, the line is horizontal with a slope of 0 m/s^2.

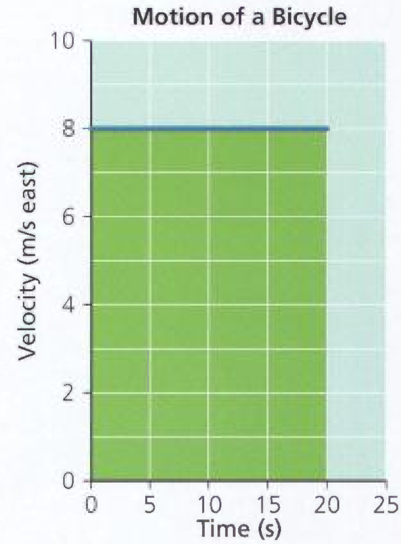


Figure 2 The area under the line is shown as a green rectangle.

We can determine the area of a rectangle using the equation

$$\text{area} = lw$$

where l is length and w is width. We can, therefore, calculate the area under the line in Figure 2 as

$$\text{area} = 8 \text{ m/s [E]} \times 20 \text{ s} = 160 \text{ m [E]}$$

The area under the line represents a displacement. Recall that in Chapter 12 we found that displacement could be calculated using the equation

$$\Delta\vec{d} = \vec{v}_{av}\Delta t$$

We can see from Figure 2 that the bicycle was travelling at 8 m/s at 0 s. However, the bicycle obviously started from rest at some earlier time.

What if the bicycle accelerated at a constant 1 m/s^2 from rest for 10 s? Figure 3 shows the graph for this situation. The area under the line is a triangle. The equation for the area of a triangle is

$$\text{area} = \frac{1}{2}hb$$

where h is height and b is base. In this case, we can calculate the area:

$$\text{area} = \frac{1}{2}hb = \frac{1}{2}(8 \text{ m/s})(10 \text{ s}) = 40 \text{ m}$$

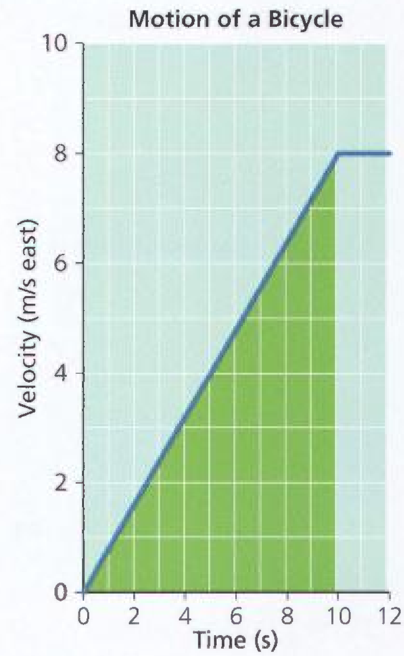


Figure 3 The area under the line is shown as a green triangle.

Just as in Figure 2, the area under the line is a measure of a displacement. How does this compare with the displacement equation ($\Delta\vec{d} = \vec{v}\Delta t$)? When acceleration is constant, one half of the height is the same as the average velocity and the base is the change in time. Therefore, we can expect that the area under the line of a velocity–time graph is equal to the displacement during that time interval.

SAMPLE PROBLEM 1

Determine Displacement

A car was travelling at a constant velocity of 15 m/s [N] (54 km/h). Use Figure 4 to determine the displacement the car travelled between 3 s and 7 s.

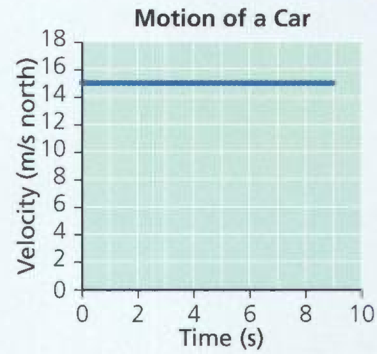


Figure 4 Velocity–time graph

Solution

The displacement is equal to the area under the line.

area = lw $\quad \Delta\vec{d} = \vec{v}\Delta t$

$\Delta\vec{d} = (15 \text{ m/s})(4 \text{ s}) = 60 \text{ m [N]}$

The displacement of the car was 60 m [N].

Practice

An ant was crawling across a picnic table carrying a breadcrumb. The ant was crawling at +6 cm/s. Use Figure 5 to calculate the displacement between 5 s and 12 s.

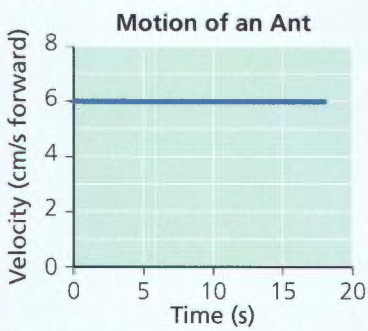


Figure 5 Velocity–time graph

SAMPLE PROBLEM 2

Determine Displacement

A golf ball was putted at 4 m/s [E] on the green. The ball stopped in 2.5 s. Use Figure 6 to determine how far the golf ball rolled while stopping.

Figure 6 Velocity–time graph

Solution

The displacement is equal to the area under the line.

area = $\frac{1}{2}hb$

$\Delta\vec{d} = \frac{(4 \text{ m/s})(2.5 \text{ s})}{2} = 5 \text{ m [E]}$

The golf ball rolled 5 m [E] while stopping.

Practice

A plane starts from rest and reaches a velocity of 90 m/s [W] in 22 s during take-off as shown in Figure 7. Determine the displacement travelled by the plane during the 22 s.

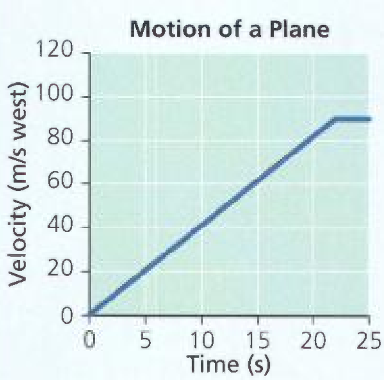


Figure 7 Velocity–time graph

What happens to the displacement if an object has a negative velocity? For example, Figure 8 shows the graph of the velocity of a dog as it chases a ball and brings the ball back. You can see from the graph that the dog travels east for 3 s to get the ball at a constant velocity of 4 m/s, stops for 2 s to pick the ball up, and then runs back at 3 m/s. As shown in the graph, east is positive. The displacement of the dog as it ran to get the ball is the area under the line (4 m/s [E] × 3 s), which is 12 m [E]. However, because the dog had a negative velocity when it ran back, we can represent the velocity as either −3 m/s, or 3 m/s [W]. We can then calculate the displacement as the area under the line: −3 m/s × 4 s = −12 m, or 12 m [W]. The total displacement for the round trip is calculated by adding the two parts:

$$\Delta\vec{d} = 12\text{ m} + (-12\text{ m}) = 0\text{ m}$$

This is what we would expect the displacement to be for a round trip.

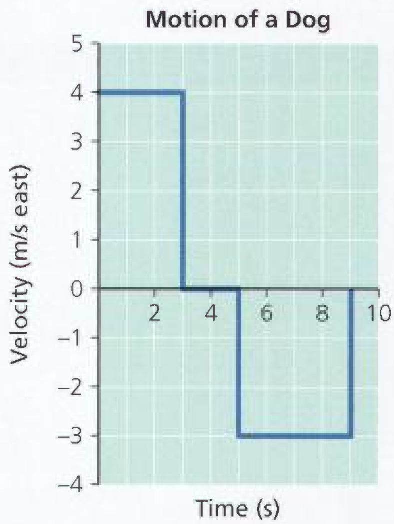


Figure 8 Velocity–time graph

Instantaneous Acceleration

Velocities do not change at a constant rate. In fact, velocities usually change with varying rates rather than at a constant rate. Just as we saw with instantaneous speed, **instantaneous acceleration** is the acceleration of an object at a particular instant in time. We can determine instantaneous acceleration by calculating the slope of the tangent to the line of a velocity–time graph.

Let's look at an example of an elevator going from the ground floor to the sixth floor. The elevator starts from rest and accelerates briefly to a constant velocity, and then slows down (undergoes negative acceleration) until it stops when it reaches the sixth floor. The motion might look something like that shown in Figure 9.

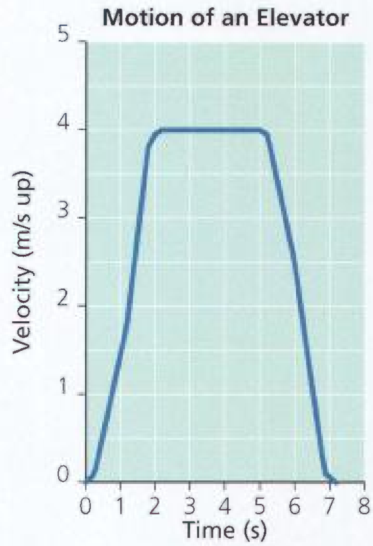


Figure 9 Velocity–time graph

We can see that when the elevator was starting, it did not have a constant acceleration. In fact, the acceleration of the elevator started at 0 m/s^2, reached a maximum acceleration, and then returned to 0 m/s^2 when the elevator reached a constant velocity of 4 m/s up. We know that the maximum acceleration occurred a little after 1.5 s since that is where the slope of the line is the steepest.

We can determine the maximum acceleration by finding the slope of the tangent to the line at 1.6 s. This would be the instantaneous acceleration at 1.6 s. Figure 10 shows the tangent to the line at 1.6 s. We can calculate the instantaneous acceleration at 1.6 s:

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{4.5\text{ m/s up} - 0.5\text{ m/s up}}{2.0\text{ s} - 1.0\text{ s}} = 4\text{ m/s}^2\text{ up}$$

Therefore, we can determine the instantaneous acceleration of an object by finding the slope of the tangent to the line of a velocity–time graph.

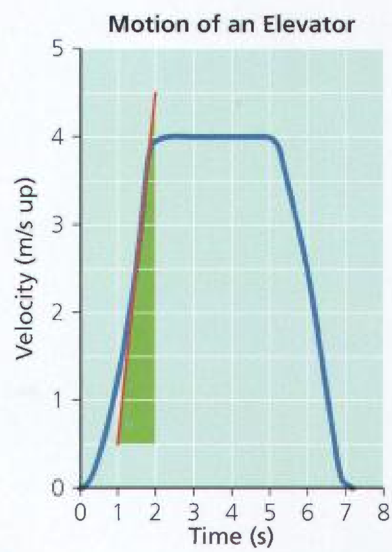


Figure 10 Velocity–time graph with a tangent to the line drawn at 1.6 s

SAMPLE PROBLEM 3

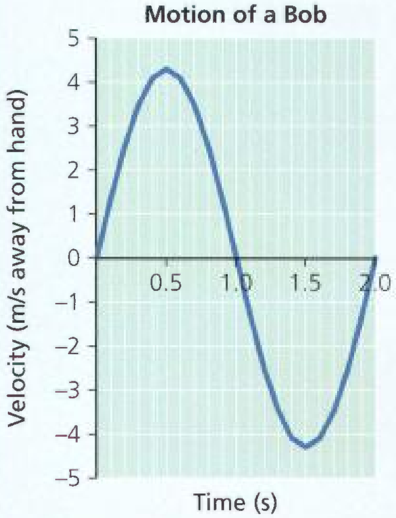


Figure 11 Velocity–time graph

Determine Instantaneous Acceleration

A student holds the bob of a pendulum to one side and then lets the bob swing. Figure 11 shows how the velocity changed with time during one complete period (a period is the time that the bob swings away from the student's hand and then returns). Determine the instantaneous acceleration of the bob at 1.3 s.

Solution

Figure 12 shows the tangent to the line at 1.3 s. We can determine the instantaneous acceleration at 1.3 s by calculating the slope of the tangent. Let the direction away from the student's hand be positive.

$$\text{slope} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

$$\vec{a} = \frac{2.5 \text{ m/s} - (-3.5 \text{ m/s})}{0.4 \text{ s} - 1.3 \text{ s}}$$

$$\vec{a} = -6.7 \text{ m/s}^2$$

The acceleration is -6.7 m/s^2, or 6.7 m/s^2 toward the student's hand.

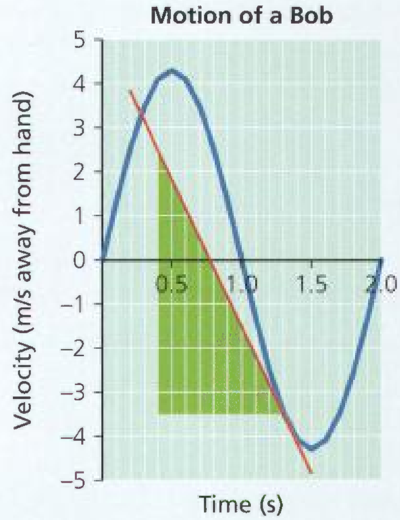


Figure 12 Velocity–time graph with a tangent to the line drawn at 1.3 s

Practice

A student was learning to drive a car with a standard transmission. The student reached 7 m/s (25 km/h) in first gear, and then had trouble shifting into second gear. After shifting, the student accelerated the car to 14 m/s (50 km/h). Figure 13 shows the velocity–time graph for the car. Use the graph to determine the instantaneous acceleration at 4 s.

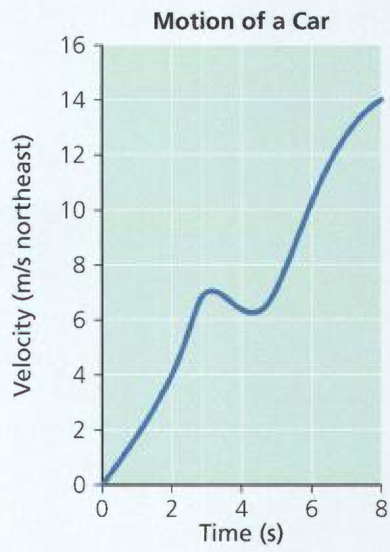


Figure 13 Velocity–time graph

13.2

CHECK YOUR Understanding

1. Why can a graph be more useful than other means of giving information about the motion of an object?
2. What does the slope of a velocity–time graph represent?
3. The line of best fit on a velocity–time graph for a boat travelling on a lake is a straight line. What can we say about the acceleration of the boat?
4. Figure 14 shows the velocity–time graph for an object.

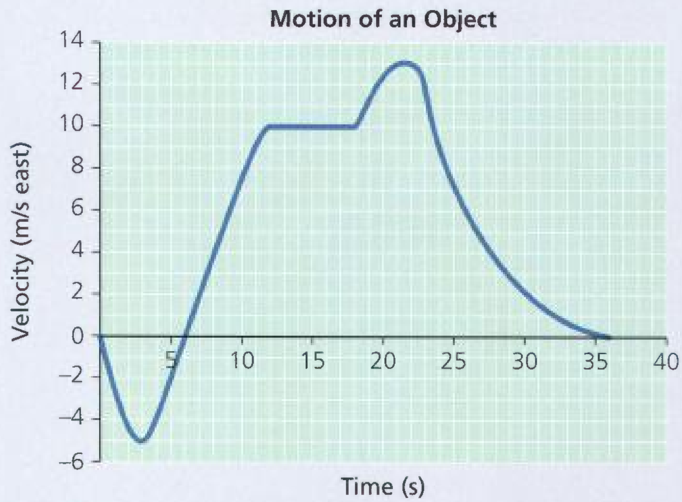


Figure 14

   (a) When did the object have negative acceleration?
   (b) When was the object's acceleration 0 m/s^2?
   (c) When did the object have a constant negative acceleration?
   (d) When was the object's acceleration the greatest?

5. A car accelerates from rest at a constant rate and then travels at a constant velocity. Sketch a velocity–time graph that shows this information.
6. How can you determine the displacement of an object from a velocity–time graph?
7. Figure 15 shows the velocity of a bicycle in a time trial.

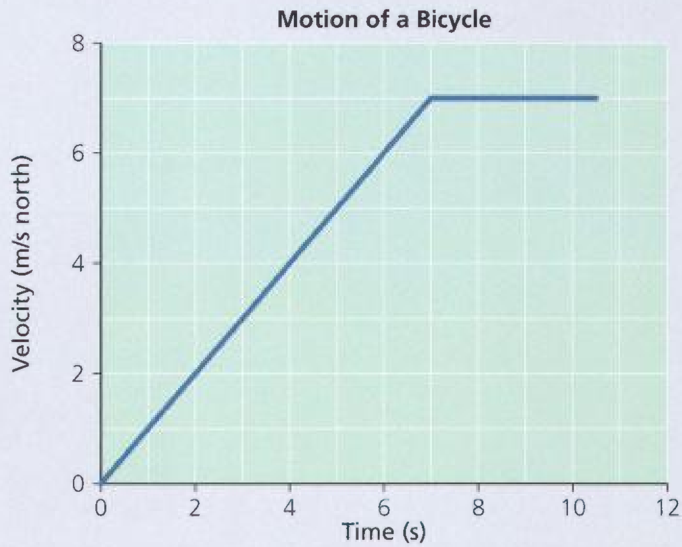


Figure 15

   (a) What was the acceleration of the bicycle during the first 5 s?
   (b) What was the bicycle's displacement while accelerating?
   (c) What was the bicycle's displacement while travelling at a constant velocity?
   (d) What was the total displacement the bicycle travelled?
   (e) What was the bicycle's average velocity?

13.3 Explore an Issue

DECISION MAKING SKILLS

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

Greyhound Racing

LEARNING TIP
Before beginning the Explore an Issue, skim the headings and subheadings to get an overall impression of the different parts of the activity.

People have always been interested in contests. Who can jump the farthest? Who can jump the highest? Who can lift the most weight? Who can eat the most pancakes? And, who is the fastest?

Racing, whether it involves people, horses, or dogs, is probably one of the most popular events. People race on foot, in vehicles, in wheelchairs, in dogsleds, and in sailboats. Racing animals, such as horses and dogs, is also a very popular spectator sport. Different breeds of dogs are raced, including whippets, dachshunds, and greyhounds (Figure 1).

Figure 1 Greyhound racing is a very popular type of dog racing.

The Issue: A Local Greyhound Racing Track

A sports consortium wants to build a greyhound racing track in your community. The consortium has applied to the local city council to begin construction of the racing track. In addition to dog racing, the track will provide additional attractions that will appeal to all ages and will promote family entertainment. The consortium also believes that the track will bring economic benefit to the area.

However, a group representing animal rights is opposed to the greyhound racing track. They believe that the dogs used in the racing industry are mistreated and are not treated in a humane manner. In addition, the group believes that there is a danger posed to society by the betting that is associated with racing.

Statement

The city council should support the sports consortium's application to begin construction of a greyhound racing track.

Background to the Issue

Many people mistakenly believe that greyhound racing is illegal in Canada. Although greyhound racing is not illegal, there is no legislation regarding the racing of greyhounds.

In the United States, while greyhound racing is a multibillion-dollar business, it is illegal in 34 states and legal in just 16 states. Greyhound racing is popular in countries around the world.

Greyhounds begin racing when they are about 1.5 years old after six months of training. They race for about three years; however, a few are still racing when they are six years old. Retired greyhounds can be adopted by families (Figure 2), are used for breeding, or are euthanized. There are many organizations that provide adoption programs for retired greyhounds.

The greyhounds used in racing are raised in breeding farms. However, since not all dogs produced are suitable for racing, the farms produce more dogs than are needed for racing. The racing industry is self-regulated by dog racing organizations. In addition, animal welfare laws are applicable to racing dogs.

Figure 2 Retired racing greyhounds make wonderful family pets and can live for 12–14 years.

Make a Decision

1. Carefully read the statement and the background information.
2. The class will be divided into two groups. One group will support the statement while the other group will oppose the statement.
3. Search for information in newspapers, a library periodical index or a CD-ROM directory, or on the Internet.

   www.science.nelson.com GO
4. Gather relevant information, and prepare to defend your position in a class debate.

Communicate Your Decision

Your teacher will organize a classroom debate for both groups to present their arguments. One member of each group will deliver the presentation and debate the issue on behalf of their group.

After the debate, the class will vote on the issue. You should vote for the position with the most convincing arguments. Your teacher will conduct the vote and announce the results.

13.4 Objects in Motion

When an object is in motion its acceleration and velocity both depend on how its displacement is changing. In other words, we could use a displacement–time graph of the object to produce both a velocity–time graph and an acceleration–time graph. In addition, we could use a single graph to compare the motions of two different objects or to show two or more different types of motion.

Motion Graphs

LEARNING TIP

Check your understanding of the three types of motion graphs by explaining to a partner how they are related to each other. Refer to Figures 1 to 3 in your explanation.

There are three different types of motion graphs: displacement–time ($\vec{d}-t$ graph) (Figure 1), velocity–time ($\vec{v}-t$ graph) (Figure 2), and acceleration–time ($\vec{a}-t$ graph) (Figure 3). Since these graphs are for the motion of the same object, the graphs are all related to each other.

The slope of the displacement–time graph produces a velocity–time graph, and the slope of the velocity–time graph produces an acceleration–time graph. Can you see the relationships between these three graphs?

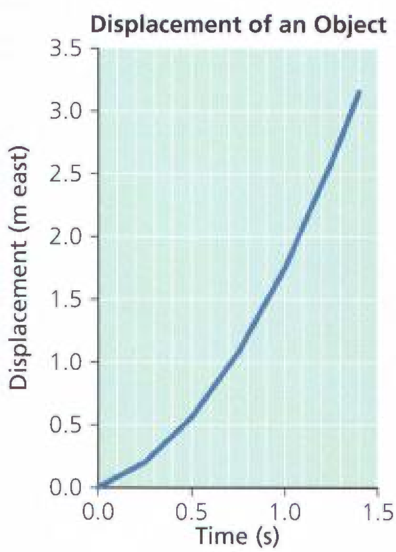


Figure 1 Displacement–time graph

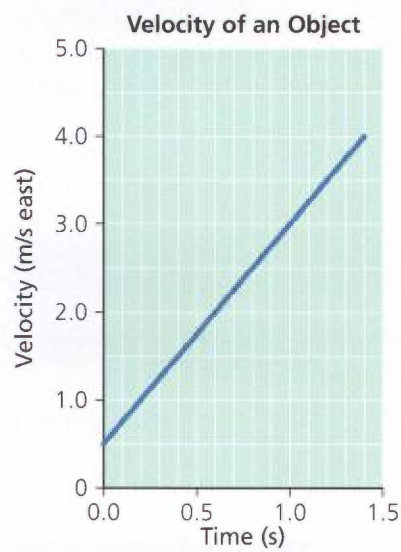


Figure 2 Velocity–time graph

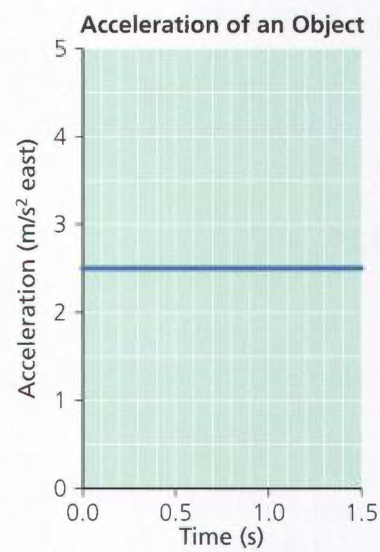


Figure 3 Acceleration–time graph

13B Investigation

Analysis of the Motion of an Object

To perform this investigation, turn to page 394.

In this investigation, you will examine and analyze the motion of an object.

You can see that the slope of the displacement–time graph (Figure 1) is constantly changing, which indicates that the velocity is changing. In addition, the slope is constantly increasing, which indicates that the velocity is increasing. This is shown in the velocity–time graph (Figure 2).

You can also see that the slope of the velocity–time graph is constant. Since the slope of the velocity–time graph is equal to the acceleration, this means that the object has a constant acceleration. The constant acceleration is shown in the acceleration–time graph (Figure 3). 13B *Investigation*

Using Graphs to Analyze Motion

Some problems involve different types of motion for an object. For example, some of the motion could be accelerated and some could be at a constant speed. Sample Problem 1 illustrates how to use graphs and algebra to solve these types of questions.

Some problems involve the motion of two objects. Sample Problem 2 illustrates how to use graphs to analyze the motion of more than one object.

SAMPLE PROBLEM 1

Determine Total Displacement

Figure 4 shows the velocity of a cyclist. At the end of 15 s, how far had the cyclist travelled?

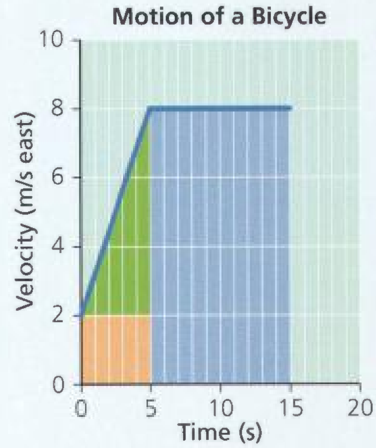


Figure 4 Velocity–time graph

Solution

The displacement is equal to the total area under the line. The cyclist accelerates during the first 5 s. Since the cyclist started with an initial velocity of 2 m/s east, the area is a rectangle and a triangle.

For the orange rectangle:

area = lw = (2 m/s)(5 s) = 10 m [E]

For the green triangle:

$$\text{area} = \frac{1}{2}hb = \frac{(6\ \text{m/s})(5\ \text{s})}{2} = 15\ \text{m [E]}$$

The displacement while accelerating is 25 m [E].

The cyclist travelled at a constant velocity for the last 10 s. The area is a rectangle.

For the blue rectangle:

area = lw = (8 m/s)(10 s) = 80 m [E]

The total displacement travelled was 25 m [E] + 80 m [E] = 105 m [E].

Practice

Figure 5 shows the motion for 30 s of a person riding a motorcycle. Determine the distance travelled by the person during the time shown.

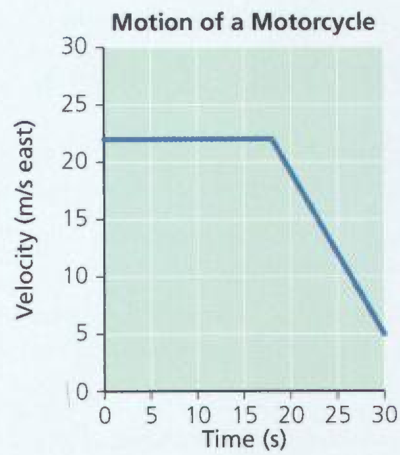


Figure 5 Velocity–time graph

SAMPLE PROBLEM 2

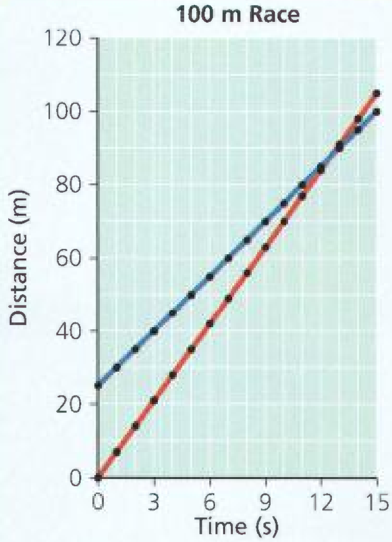


Figure 6 Distance–time graph

Determine Motion

Brenda can run at 5 m/s and Hillary can run at 7 m/s. Hillary gives Brenda a 25 m head start in a 100 m running race. Figure 6 shows a distance–time graph for the race. Hillary's distance is shown in red and Brenda's distance is shown in blue. Who wins the race? How many metres separate the two runners at the end of the race?

Solution

We can see on the graph that Brenda was given a 25 m head start because her original distance is 25 m. We can also see from the graph that Hillary wins the race. Hillary wins the race by about 4 m.

Practice

Paul skates at a velocity of 12 m/s [E]. His friend Ben skates at a velocity of 10 m/s [E]. They are racing together in a 400 m race. Paul gives Ben a 5 s head start. Draw a graph for their motion. Who wins the race? Explain your answer. How many metres separate the two skaters at the end of the race?

When objects are in motion, they often do not have either constant velocity or acceleration. For example, a falling object is accelerated downward by the force of gravity. However, there are upward forces acting on the object that reduce the acceleration. In fact, a falling object may reach a point where the upward forces equal the downward forces. At this point, the object no longer accelerates and is travelling at a constant velocity known as **terminal velocity**.

TRY THIS: Terminal Velocity

Skills Focus: analyzing

In this activity, you will observe a falling object reach terminal velocity and analyze its motion.

Materials: table tennis ball (or balloon), sonar ranger, tickertape, or video camera to record position and time of the object

1. Drop a table tennis ball from a height of about 2 m and record its displacement using a sonar ranger (or other apparatus) by following instructions given by your teacher. Copy Table 1 and record your data for the table tennis ball. Produce a displacement–time graph.

Table 1

Time (s)	Displacement (cm down)

A. Based on the displacement–time graph for your data, describe how the velocity and acceleration of the baseball and table tennis ball changed as they fell.

B. Use the distance–time graph for your data to determine the terminal velocity of the baseball and the table tennis ball.

C. Sketch a velocity–time graph and an acceleration–time graph for the table tennis ball.

D. How do the terminal velocities of the two objects compare? What do you think might cause them to be different?

E. What are the factors that you think affect the terminal velocity of an object?

13.4 CHECK YOUR Understanding

1. (a) How can you determine that a falling object has reached terminal velocity from a velocity–time graph of its motion?
   (b) Explain how you would determine the distance the object travelled. How does your answer differ from your answer to (a)?

2. Table 2 shows the velocity of an object at different times.

Table 2 Motion of an Object

Time (s)	Velocity (cm/s east)
0	0
5	7.8
15	24.3
20	31.8
35	57.3

   (a) Draw a velocity–time graph for the data.
   (b) What is the velocity of the object at 20 s and at 30 s?
   (c) What was the average acceleration of the object?
   (d) What was the displacement of the object at 35 s?

3. A car accelerates at a constant rate and then travels at a constant speed. Draw a sketch of the distance–time graph for the motion of the car. Directly below the sketch, draw a sketch of the velocity–time graph for the motion of the car.

4. Jasmine rode a horse down a path headed north. She started from rest and then accelerated at 0.5 m/s^2 for 12 s and then travelled at a constant speed for 28 s.
   (a) What was her velocity after 12 s?
   (b) Draw a velocity–time graph for her motion.
   (c) What was Jasmine's displacement after 10 s?
   (d) How far did Jasmine travel during her 40 s ride?

5. Figure 7 shows the graph of the velocity of an object as a function of time.

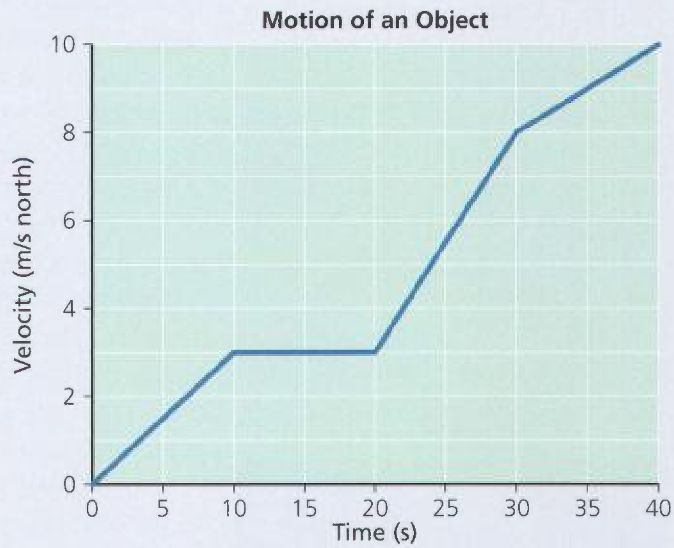


Figure 7

   (a) During what time was the acceleration the greatest?
   (b) What was the average acceleration of the object during the 40 s?
   (c) How far did the object travel during the first 10 s?
   (d) How far did the object travel during the first 20 s?
   (e) What was the displacement of the object at 40 s?

6. Bryce can ride his bicycle at an average speed of 18 m/s, and Ally rides with an average speed of 23 m/s. Ally gives Bryce a 200 m head start in a 1 km (1000 m) race. Use a distance–time graph to solve the following questions:
   (a) Who wins the race? Explain your answer.
   (b) How many metres separate the two runners at the end of the race?

Science **WORKS**

FREE FALLING

Do heavier objects fall faster than lighter objects? Hundreds of years ago, people believed that the heavier the object, the faster the object fell.

You drop a hammer and a feather off a building (Figure 1). Which one lands first: the hammer or the feather? Up until the late 1500s, people believed that heavier objects fell more quickly than lighter ones. Then, around 1590, Galileo Galilei proved that, if we ignore the effect of air resistance, the acceleration of falling objects is constant.

During a hailstorm, Galileo noticed that both large and small hailstones hit the ground at the same time. According to legend, Galileo dropped two cannonballs of different masses from the Tower of Pisa and found that the cannonballs hit the ground at the same time. While the story is easy to imagine and easy to remember, there is some debate about whether Galileo did such an experiment. The story first emerged in a biography of Galileo written by his secretary, Vincenzo Viviani. The story of Galileo dropping objects off the Tower proved so compelling that nearly every subsequent biographer mentioned it.

Figure 1 Which lands first: the hammer or the feather?

In fact, Galileo proved that the acceleration of falling objects was constant in an experiment in which he measured the acceleration of metal balls rolling down a ramp. Galileo found that the acceleration was constant for a constant slope of the ramp. In other words, the acceleration did not depend on the mass of the balls.

Thanks to Galileo, we know that all objects experience the same acceleration when we ignore the effect of air resistance. When the only force is gravity, the acceleration is the same value for all objects regardless of their mass. On Earth, this acceleration value is on average 9.8 m/s^2 down and the value is referred to as the acceleration of gravity. An object that experiences no air resistance when falling is in a state of free fall.

A skydiver experiences free fall immediately upon jumping out of the airplane (Figure 2). While falling, the skydiver's velocity increases. The increase in velocity is accompanied by an increase in air resistance. When the air resistance reaches the magnitude of the force of gravity, the balance of forces means that the skydiver no longer accelerates and has reached terminal velocity. When the skydiver opens the parachute, the amount of air resistance increases so that it is greater than the force of gravity. This means that there is a net force upward, which causes the skydiver's velocity to decrease. As the velocity decreases, the air resistance decreases until the skydiver again reaches a much smaller terminal velocity.

So, which lands first: the hammer or the feather? Of course, disregarding air resistance, they virtually land at the same time. But what would happen if you dropped a hammer and a feather on the surface of the Moon?

Figure 2 These skydivers have adjusted their downward motion so that they can share the thrill of free fall together.

13A **Investigation**

Analysis of an Object Moving at Constant Acceleration

The motion of an object that is accelerated by a constant force also has a constant acceleration. The force of gravity near Earth's surface is constant. The force of gravity will accelerate a cart going down a ramp. Unless there are other forces, such as friction, acting on the cart, the acceleration will be constant.

Question

What does the velocity–time graph of an object with constant acceleration look like and how can the acceleration of the object be determined?

Materials

- recording timer
- tickertape
- ramp
- cart

Procedure

1. Set up the ramp and recording timer as shown in Figure 1. Attach enough tape to the cart to reach the bottom of the ramp and thread the tape through the timer.

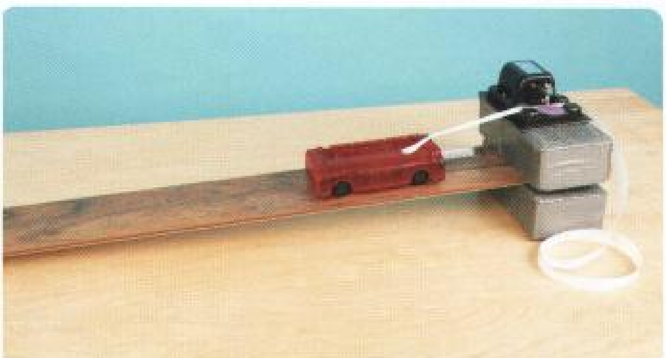


Figure 1

2. Turn on the timer and let the cart go.
3. Draw a line through the first clear dot from the start of the cart's motion. Using a convenient time interval (for example, 0.1 s), draw a line through successive dots for that time interval.

INQUIRY SKILLS

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

4. Copy Table 1 into your notebook.

Table 1

Time (s)	Displacement (cm/s down)	Velocity (cm/s down)
0		

5. Measure the displacement of the cart during each time interval. In the example here, that is the distance of six dots. Record the displacement on your data table.
6. Calculate the average velocity during the time interval and record the value in your data table.
7. Make a velocity–time graph for your data.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Is your line of best fit a straight line? What does this indicate?

(b) Determine the slope of the line.

(c) What was the acceleration of the cart?

(d) How is constant acceleration shown on a velocity–time graph?

Evaluation

(e) If your line of best fit was not perfectly straight, explain the curve.

(f) Does your experiment support your answer for Analysis question (d)?

Synthesis

(g) If the ramp were made steeper and the experiment repeated, how would that affect your answers to the Analysis questions?

13B Investigation

Analysis of the Motion of an Object

The motion of an object can be simple or very complex. The object can accelerate to change its velocity. The acceleration can be positive, negative, or zero. There can be periods when the object is at rest. There are different methods of observing, recording, and describing this motion.

In this Investigation, you will choose an object to observe in motion. You will also determine the types of motion that you will investigate, as well as the method and equipment that you will use to determine the motion. For example, if you choose to watch another student walking, running, and at rest, you could determine the positions of the student using a Global Positioning System (GPS) device (Figure 1). A GPS device makes it possible for anyone to use small and relatively inexpensive receivers to display his or her precise location, speed, or distance from anywhere on Earth.

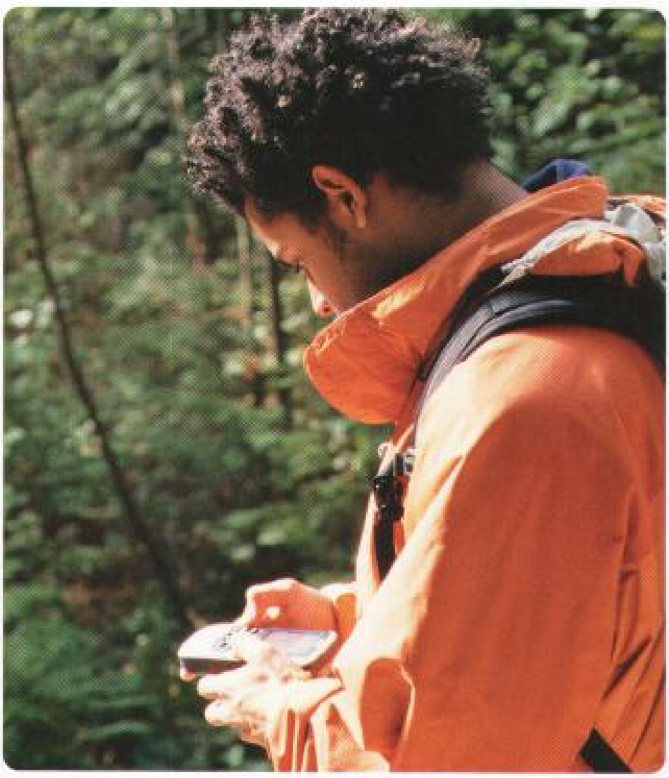


Figure 1 A GPS Device

INQUIRY SKILLS

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

Question

Ask a question that your investigation will answer.

Experimental Design

Design an experiment in which you are able to observe and measure an object's motion. Your teacher must approve your experimental design before you begin.

Materials

Identify the materials and equipment that you will need. You may want to use a GPS device, or a stopwatch, or a stroboscope and camera. Check with your teacher to make sure that the equipment that you would like to use is available.

Procedure

1. In a group, decide on the motion that you will observe.
2. Discuss with your group how you will measure the motion. Write out the numbered steps that you will follow to measure the motion. Your teacher must approve these steps before you continue.
3. Create a table in which to record the object's position. Your table could be similar to Table 1.

Table 1

Time (s)	Displacement (cm/s down)	Velocity (cm/s down)
0		

4. Once your procedure has been approved, conduct your investigation. Record your observations, measurements, and calculations.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Create a displacement–time and a velocity–time graph from the data that you collected.

(b) Determine the acceleration of the object for each time interval. Draw an acceleration–time graph.

(c) Using the acceleration–time graph, find one area where the acceleration is nearly constant. What is the acceleration and what is the mid-point of this time interval?

(d) On the velocity–time graph, determine the slope of the line at mid-interval time. How does the slope of the line compare with the acceleration from the acceleration–time graph?

(e) Using the velocity–time graph, find one area where the velocity is nearly constant. What is the velocity and what is the middle time for this area?

(f) On the displacement–time graph, determine the slope of the line at mid-interval time. How does the slope of the line compare with the velocity from the velocity–time graph?

(g) Use the velocity–time graph to determine the displacement of the object. Use your data table to determine the displacement. How do the two values compare?

(h) Write a statement, based on your evidence, that answers the question posed at the beginning of the investigation.

Evaluation

(i) Did your choice of experimental design or materials affect the outcome of your experiment in an unexpected manner? If so, describe what the effects were.

(j) If you were to repeat this experiment, what could you do to improve the procedure?

Synthesis

(k) What other questions arise from your investigation? How might you go about finding an answer to them?

(l) Could you apply what you learned in this experiment to other situations outside the science program? If so, describe an application.

CHAPTER 13

Review

Acceleration

Key Ideas

Acceleration is the rate of change of velocity.

- Acceleration is a vector quantity.
- Acceleration can be positive, negative, or zero.
- Acceleration can be calculated by using the equation

$$\vec{a}_{av} = \frac{\Delta \vec{v}}{\Delta t}$$

Falling objects are accelerated by the force of gravity.

- Since the force of gravity is constant, the acceleration due to gravity is also constant.
- As an object thrown into the air rises, its velocity decreases until it stops. As it falls, the magnitude of its velocity increases but in the opposite (negative) direction.
- The velocity of a falling object can be calculated using the equation

$$\vec{v}_f = \vec{v}_i + \vec{a}_{av}\Delta t$$

- The acceleration of gravity near Earth's surface is about 9.8 m/s² down.

Vocabulary

acceleration, p. 373

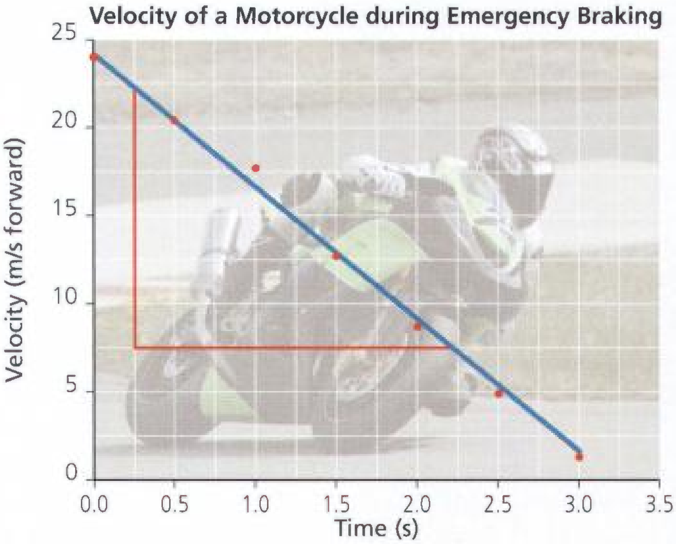
negative acceleration, p. 376

instantaneous acceleration, p. 383

terminal velocity, p. 390

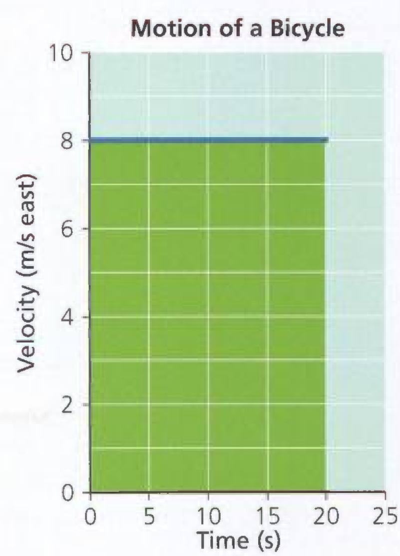
Velocity–time graphs can be used to determine information about an object's motion.

- An object with constant acceleration has a velocity–time graph that is a straight line.
- The slope of a velocity–time graph is acceleration.
- When acceleration is not constant, the instantaneous acceleration is the slope of the tangent to the line of a velocity–time graph.
- The displacement of an object is equal to the area under the line of a velocity–time graph.
- A negative slope on a velocity–time graph indicates negative acceleration.



An object in uniform motion has no acceleration.

- Since acceleration is a vector, uniform motion means that both the magnitude of the acceleration and the direction of the acceleration must be constant.
- An object travelling in a circle with a constant speed is not experiencing uniform motion (sometimes this is called uniform circular motion) because the direction is constantly changing.



Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

K **1.** A coin is tossed at the start of a football game. As the coin rises, the acceleration of gravity is -9.8 m/s^2. What is the acceleration of gravity when the coin is at its highest point (stops) and as it falls?

	Highest point	Falling down
A.	0	-9.8 m/s^2
B.	0	$+9.8$ m/s^2
C.	-9.8 m/s^2	-9.8 m/s^2
D.	$+9.8$ m/s^2	$+9.8$ m/s^2

2. Mary accelerates her car from 80 km/h [E] (22 m/s) to 100 km/h [E] (28 m/s) in 5.0 s. Calculate the average acceleration of the car.

K **3.** The velocity–time graph of a student moving down the school hallway is a horizontal line. Which of the following statements is true?
A. The student is not accelerating.
B. The displacement of the student is not changing.
C. The student has a positive constant acceleration.
D. The displacement of the student is increasing at a constant rate.

4. Table 1 gives the velocity of an object as a function of time.

Table 1 Velocity of an Object

Velocity (m/s)	13	15	18	24	25	22	20	19
Time (s)	0	2	4	6	8	10	12	14

(a) Draw a velocity–time graph for the data.
(b) Determine the average acceleration during the first 6 s.
(c) Determine the average acceleration for the entire time shown.
(d) Determine the instantaneous acceleration at 10 s.

5. Figure 1 shows the velocity of a ball thrown with an initial velocity of 19.6 m/s up and then falling back to the thrower. The acceleration of gravity is 9.8 m/s^2 down.

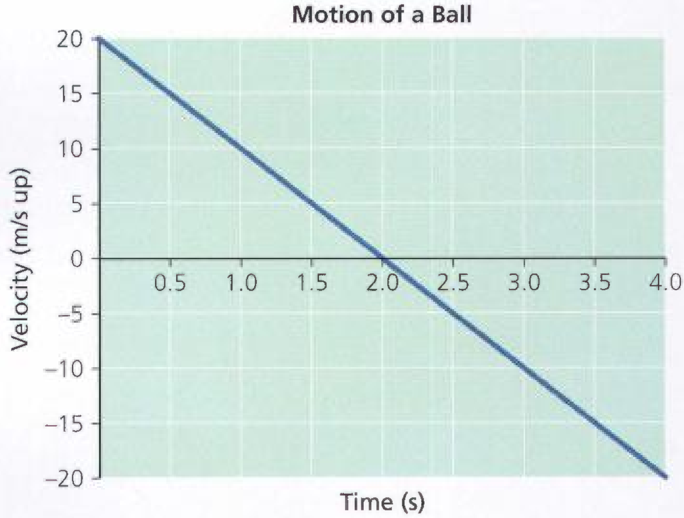


Figure 1

(a) Use the graph to determine the velocity of the ball at 1 s, 2 s, and 3 s.
(b) Show that the equation for determining final velocity can also be used to determine the velocity of the ball at 1 s, 2 s, and 3 s.
(c) When is the ball at its highest point? What is the acceleration of the ball at this point?
(d) Did air resistance affect the acceleration of the ball according to the graph? Explain.

Use What You've Learned

U **6.** A salmon swimming at a velocity of 0.43 m/s [W] sees a lure and speeds up to 2.25 m/s with five sweeps of its tail in 0.68 s. What was the average acceleration of the salmon?
A. 0.6 m/s^2 [W]
B. 2.7 m/s^2 [W]
C. 3.3 m/s^2 [W]
D. 3.9 m/s^2 [W]

U **7.** A ball is thrown upward from the top of a tall building at an initial vertical speed of +14.0 m/s. The acceleration of gravity on the ball is 9.8 m/s^2 down. What is the velocity of the ball 2.50 s later?

A. 10.5 m/s up
B. 10.5 m/s down
C. 38.5 m/s up
D. 38.5 m/s down

U **8.** A cyclist began coasting his bicycle up a hill at an initial velocity of 7.5 m/s. If the negative acceleration was 4.2 m/s^2, how many seconds did the bicycle coast before its velocity was reduced to 2.5 m/s?

A. 0.56
B. 1.2
C. 1.8
D. 2.4

U **9.** Which of the following is true when an object is accelerating?

A. The object's speed is constant.
B. The object's speed must be changing.
C. The object's velocity must be constant.
D. The object's velocity must be changing.

10. A car accelerated from rest and then travelled at a constant velocity for a while before slowing down and parking. Draw a sketch of the velocity–time graph for the motion of the car. Below this graph, draw a displacement–time graph using the same time scale.

11. What is the difference between average velocity and instantaneous velocity?

12. If you were given a velocity–time graph for the motion of an object, what are three facts that you could determine from the graph?

Think Critically

13. What factors affect terminal velocity? Describe how you would design an experiment to investigate how one of the factors affects terminal velocity.

HMP **14.** Figure 2 shows the velocity of a sponge ball after it is thrown upward with a speed of 3.8 m/s and caught when it came down.

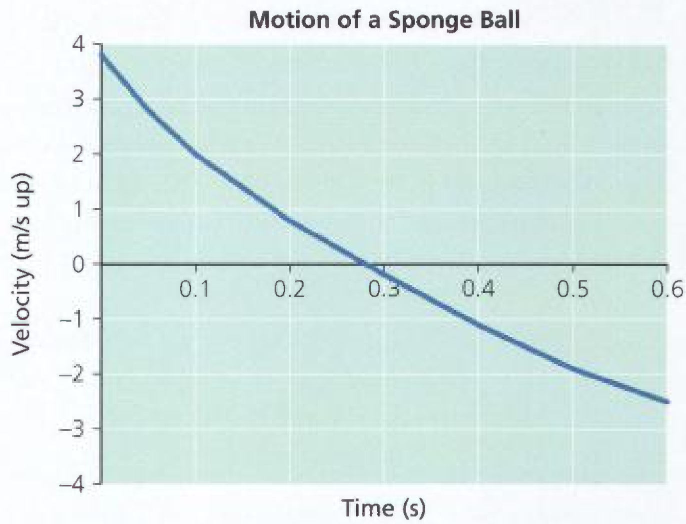


Figure 2

(a) Is the acceleration of the sponge ball constant? Why or why not?
(b) What is the acceleration of the ball at 0.3 s?
(c) When was the magnitude of the acceleration the greatest?
(d) When was the ball at its highest point? How do you know?

15. Choose one track event from the Summer Olympics, and research the winning times for the past 60 years. Draw a graph of the winning times by year. What do you think the winning time will be in the next Olympics? In 60 years?

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Reflect on Your Learning

16. How has what you have learned about acceleration affected how you think about motion?

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UNIT D

Review

Motion

Unit Summary

In this unit, you studied the motion of objects. You learned how the location of an object changes with time. The changes can be measured by velocity (or speed) and acceleration. This unit made a distinction between scalar and vector quantities, and showed how these two concepts affect mathematical results. The motion of an object can be described by data tables, algebra, or by graphs.

Complete a fishbone organizer in your notebook. Check the chapter reviews and vocabulary lists for the unit to ensure that you included the important ideas about each major concept.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. How long does it take for a whale travelling at 15 m/s to travel 100 m?
2. A driver sees a small child dart out from between two parked cars. How far in metres will the car, travelling at 60 km/h, travel in the 0.8 s that it takes the driver to react?
3. A horse ran 600 m in a time of 33 s.
   (a) What was the average speed of the horse?
   (b) Did you make any assumptions about the horse's motion? If so, what were they?
4. A car had a negative acceleration of 5.6 m/s^2 for 2.5 s. If the initial velocity of the car was 28 m/s [E] (let east be positive), what was the car's final velocity?
5. A roller coaster rider travelling at 8 m/s down accelerated at 17 m/s^2 for 1.4 s. (The downward acceleration of the roller coaster is positive.) What was the final velocity of the rider?
6. A hockey puck was sliding at 24 m/s [S] on the rink. It was accelerated at 34 m/s^2 [N] by a hockey stick for 0.19 s. What was the resulting velocity of the puck?

Use What You've Learned

Use Figure 1 to answer questions 7 and 8.

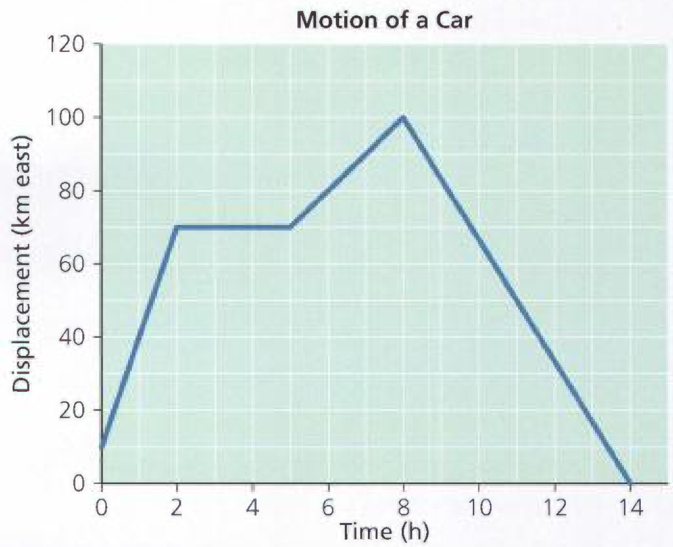

Figure 1

U 7. What was the car's average velocity between 0 and 14 h?
   A. 0.71 km/h [E]
   B. 13.6 km/h [E]
   C. 14.2 km/h [E]
   D. 18.9 km/h [E]

U 8. What was the total distance travelled by the car?
   A. 235 km
   B. 625 km
   C. 700 km
   D. 836 km

U 9. A car starting from rest reaches a velocity of 25 m/s [E] in 12 s. What is the acceleration of the car?

A. 2.1 m/s^2 [E]
B. 6.0 m/s^2 [E]
C. 10.4 m/s^2 [E]
D. 12.5 m/s^2 [E]

U 10. A ball is thrown upward at an initial velocity of +14 m/s. What is the ball's velocity 1.2 s later, if the acceleration is −9.8 m/s^2?

A. −2.2 m/s
B. +2.2 m/s
C. −26 m/s
D. +26 m/s

11. Figure 2 shows a velocity–time graph.

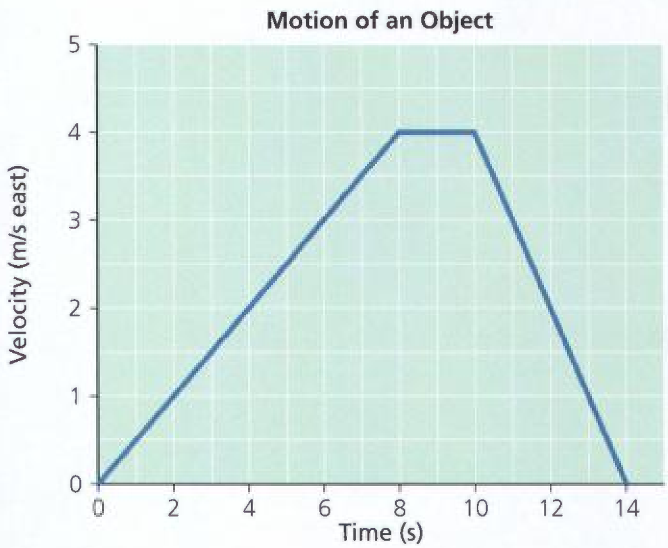

Figure 2

(a) What is the object's velocity at 6 s and 10 s?
(b) What distance did the object travel?
(c) What is the object's average velocity?
(d) What is the object's acceleration at 5 s, 9 s, and 12 s?

Think Critically

Use Figure 3 to answer questions 12 and 13.

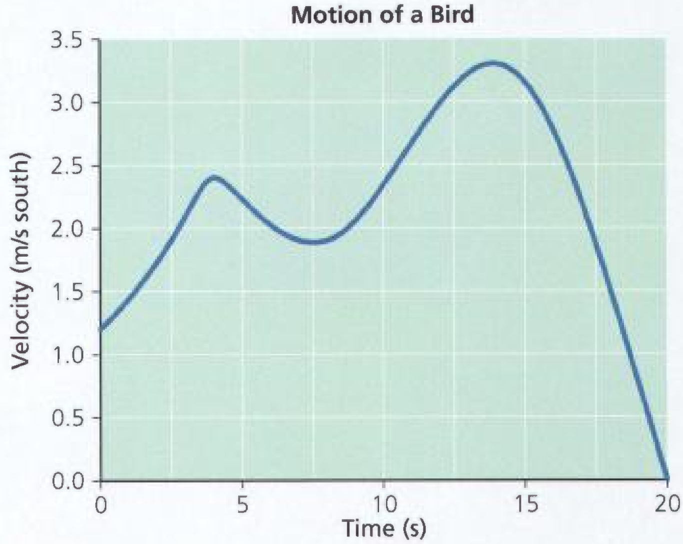

Figure 3

HMP 12. What was the instantaneous acceleration of the bird in flight at 10 s?

A. 0.23 m/s^2 [S]
B. 2.3 m/s^2 [S]
C. 2.8 m/s^2 [S]
D. 4.3 m/s^2 [S]

HMP 13. During which time interval did the bird fly the furthest?

A. 0 s to 5 s
B. 5 s to 10 s
C. 10 s to 15 s
D. 15 s to 20 s

Reflect on Your Learning

14. Describe two ways that your study of motion in this unit has changed the way that you appreciate the movement of objects.

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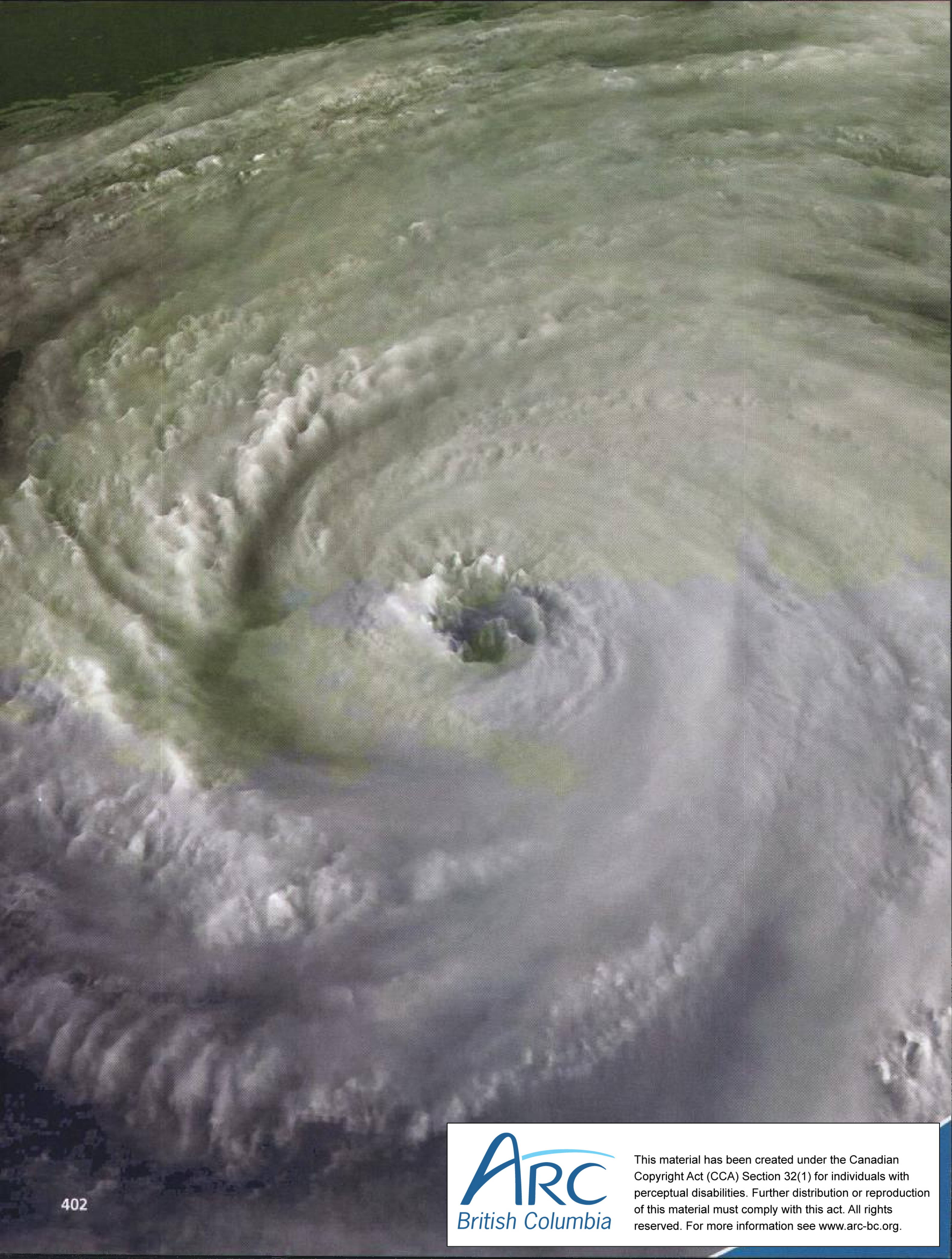


UNIT E

ENERGY TRANSFER IN NATURAL SYSTEMS

Unit Preview

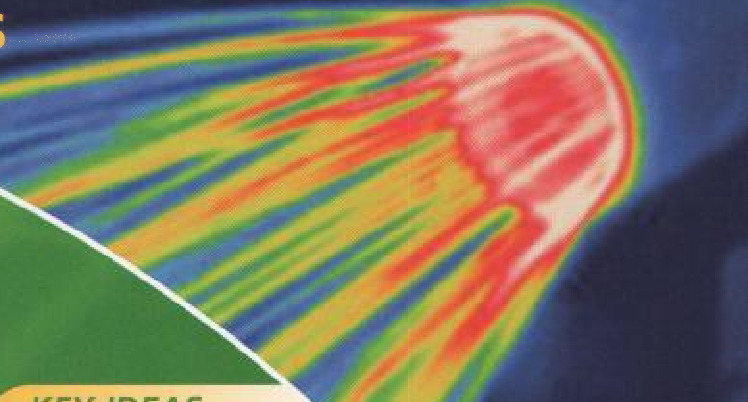
The weather is one of the most talked-about subjects. What causes weather patterns? What makes it hot in the summer and cold in the winter? What causes wind? Why do most Canadian weather systems move west to east?

Hurricane Katrina looks beautiful in the satellite image on these pages, but it was one of the greatest natural disasters in U.S. history. What produces such powerful storms? Strong evidence suggests that human activities are significantly changing global weather patterns. How serious are these trends, and what can be done about them?

In this unit, you will study the driving force behind weather: heat. You will investigate the ways in which this energy moves through natural systems and learn about climate change; maybe the most critical issue facing civilization today.

CHAPTER 14

Heat and Thermal Energy Sources



Chapter Preview

Everyone understands "hot" and "cold." We care about daytime air temperatures, as well as our own body temperature. What is temperature? How can we "heat something up"? Heat and temperature influence many aspects of our daily lives.

On a cold winter day, we may put on extra clothing before venturing out of doors for some snowboarding or ice-skating on a frozen lake. On a hot summer day, we dress lightly and can feel our skin warmed by the sun as we lie on a beach after a good swim.

In our kitchens, we use refrigerators and freezers to keep our food cool, while we use stoves and microwaves to heat our food up.

In this chapter, you will learn the difference between heat and temperature, how thermal energy influences the properties and characteristics of substances, and the natural sources and processes of thermal energy transfer.

KEY IDEAS

- **Thermal energy influences temperature, density, pressure, and a substance's physical state.**
- **Thermal energy can be transferred by conduction, convection, and radiation.**
- **Most of the thermal energy at Earth's surface comes from the Sun.**
- **Earth's interior has large quantities of thermal energy.**

TRY THIS: *Freezing Is Hot Stuff!*

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

In this activity, you will observe the relationship between heat and change of state.

Materials: reusable sodium acetate heat pack, hot plate, 250 mL beaker, thermometer, tongs

1. The reusable heat packs contain sodium acetate, a salt compound. Describe the contents of the heat pack, noting its state and temperature.
2. Read the instructions on the heat pack, then activate it.
3. Observe and record any changes to the properties of the heat pack.
4. Place the pack in a beaker of 90 °C water for 10 min. Observe and record any changes in the sodium acetate.
5. With tongs, carefully remove the heat pack from the hot water bath. Allow it to cool before putting your equipment away.

A. What change in state caused the sodium acetate to heat its surroundings?

B. What change in state occurred when the sodium acetate gained thermal energy from the hot-water bath?

C. When a heat pack is activated, where does the heat come from?

D. Does liquid water absorb or release thermal energy when it freezes?

14.1 Temperature and Thermal Energy

Seven record-high temperatures were set across British Columbia on July 11, 2007. The hottest location was Lillooet, where the temperature reached 39.9 °C. It is not surprising that the high temperatures made headline news across Canada; many people check the forecast before they start their day.

Temperature influences our daily activities (Figure 1). Low winter temperatures can result in snowfalls and skiing opportunities, and high summer temperatures can promote crop growth or cause drought.

LEARNING TIP
Stop and think. When you come across words in bold print, think about each term and ask yourself, "Is this term familiar? Where have I seen it before?"

Figure 1 Temperature influences day-to-day lives in fun and serious ways.

Temperature and the Kinetic Molecular Theory

What *is* temperature? Scientists describe the motion of atoms and molecules using the **kinetic molecular theory**, which states that

- All matter is made up of particles that are in constant motion.
- The more energy the particles have, the faster they move.

Kinetic energy is the energy that a substance has due to its motion. The **temperature** of a substance is an indicator of the average kinetic energy of that substance. Generally, faster-moving particles will have more kinetic energy than slower-moving particles. You already know that particles in a gas are moving faster than particles in a solid. As a solid substance increases in temperature, its particles bump into each other at greater and greater speeds. As a result, the particles spread out slightly. Note in Figure 2 (on the next page) that the individual particles do not change in size; they simply spread out and occupy more space.

To learn more about the kinetic molecular theory, view the animation at
www.science.nelson.com

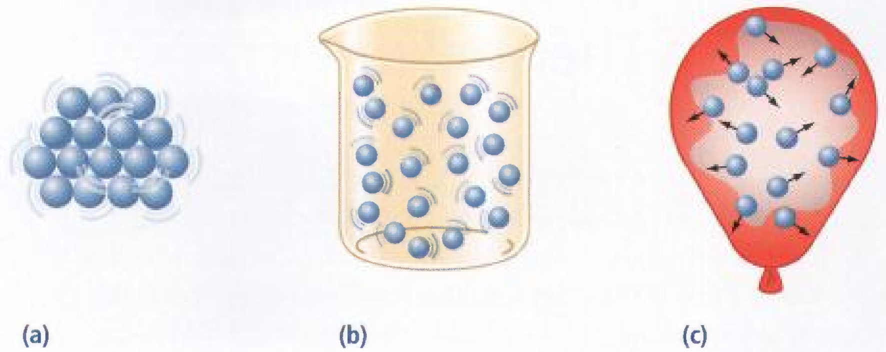


Figure 2 (a) Particles in solids are very close together and can only move back and forth within a very limited range. (b) Particles in liquids are very close together but are able to move and slide past one another. (c) The relatively large spaces between gas particles allow them to move freely past each other.

A gas may have less kinetic energy than a solid, however. For example, oxygen exists as a gas well below −100 °C, while iron and carbon can exist as solids well above 1200 °C. We know that gases at −40 °C have much less kinetic energy than the atoms in the solids at 1500 °C. In fact, the gas molecules are moving much slower than the atoms in the hot solids.

Particle mass also affects kinetic energy. More massive particles will have more kinetic energy than smaller particles moving at the same speed. A very fast-moving small particle, however, can have more kinetic energy than a slower-moving, more massive particle.

Units for Measuring Temperature

In our day-to-day lives, we describe temperature in terms of degrees Celsius. This scale is based on the state of water, starting with its freezing point (0 °C), and divided into 100 equal units to reach water's boiling point (100 °C).

A temperature of 0 °C does not mean that the kinetic energy of the particles is zero. A temperature of 20 °C simply means that the average kinetic energy of the molecules is 20 units greater than the average kinetic energy of water molecules at the freezing point.

In order to talk about kinetic energy, scientists use the Kelvin (K) scale, which is based on the motion of particles. At 0 K, all particles in matter are at a complete stop, and the substance has no kinetic energy. This temperature is called "absolute zero" and is equivalent to −273.15 °C (Table 1).

Table 1 Comparing Temperature Units

Temperature in Celsius (°C)	Temperature in Kelvin (K)	Reference
−273.15	0	absolute zero, no particle motion
0	273.15	freezing point of water
20	293.15	room temperature
100	373.15	boiling point of water

Did You KNOW?

Lowest Temperature Achieved

In 2003, scientists at the Massachusetts Institute of Technology cooled a sodium gas to the lowest temperature ever recorded: half a billionth of a degree above absolute zero.

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LEARNING TIP

Check your understanding. Explain to a partner what the two different 0 values (0 °C and 0 K) represent.

Temperature and Volume

How does increased particle speed change the characteristics of the substance? What observable changes occur when a substance is heated?

TRY THIS: Thermal Expansion of Liquids

Skills Focus: observing, conducting, analyzing, synthesizing

In this activity, you will observe how an increase in temperature changes the volume of two liquids.

Materials: 2 large test tubes, coloured water, coloured alcohol, 2 one-holed rubber stoppers with 15 cm glass tubing, beaker, hot water, safety goggles

Exercise caution when using hot water as it can cause burns. Always wear safety goggles when dealing with hot liquids.

1. Put on your safety goggles.
2. Fill one test tube with coloured water, and the other with coloured alcohol.
3. Insert a stopper into the mouth of each test tube. Adjust the stopper so that the coloured liquid is forced halfway up the tubing (Figure 3). Mark the levels.
4. Place the test tubes into the beaker and carefully add hot water (70 °C to 80 °C) around them.
5. Observe the liquid level in the glass tubes for several minutes and record your observations.

A. What happened to the liquid levels as the test tubes were heated? What does this tell you about the volume of each?

B. According to the kinetic molecular theory, what happened to the molecules in the test tubes?

C. How does your set-up resemble a thermometer?

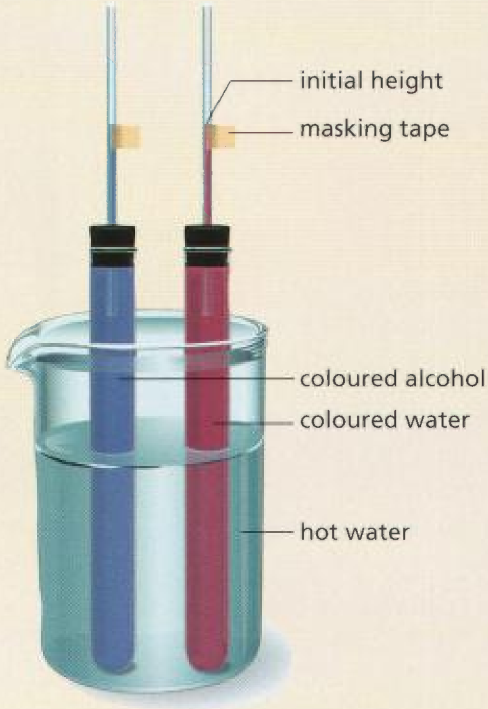


Figure 3

Consider the air in a balloon. As the sunlight warms the balloon in Figure 4, the balloon expands. The air particles are moving faster because of the added thermal energy, and push out on the sides of the balloon. If you put this balloon in the fridge, it would shrink as the temperature dropped.

In almost all cases, an object at a high temperature has a greater volume than the same object at a lower temperature. Since the mass of the object is the same, but the volume increases, the density (mass per unit volume) of the object has decreased. An important exception to this occurs in the formation of ice. Liquid water actually expands as it cools from 4 °C until it forms solid ice. The result is that solid ice is less dense than liquid water, so it floats.

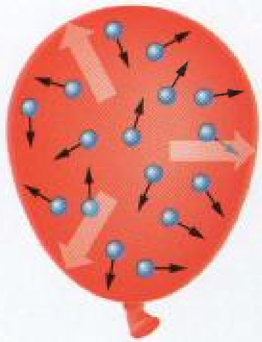


Figure 4 Moving gas particles push on the walls of their container. As they warm up and move faster, the particles spread out, inflating this balloon.

It is critical that engineers and designers take this property of thermal expansion into consideration when designing large structures (Figure 5). For example, the materials in a bridge expand on hot summer days and contract on cold winter days. This would cause buckling and cracking if expansion joints were not part of the structure. On hot days, the gap in these teeth will close as the bridge materials expand.

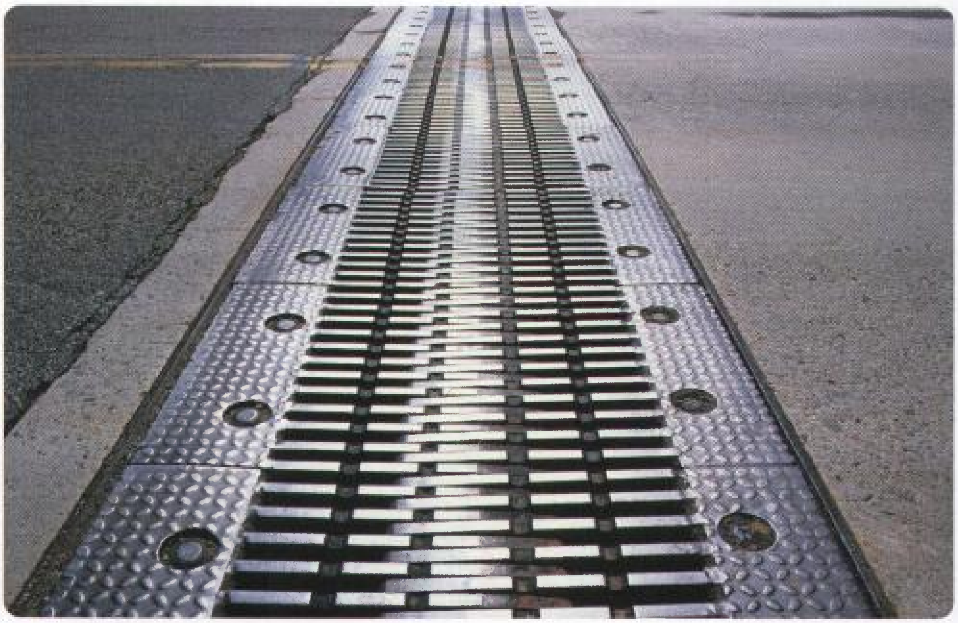


Figure 5 Special expansion joints in this bridge accommodate thermal expansion and contraction when temperatures change, preventing buckling and cracking.

Did You KNOW?

Scuba is a High-Pressure Sport

Scuba tanks hold large quantities of air by compressing the gas. In a typical scuba tank, 2400 L of air is compressed into a 12 L tank, providing 1 hour of breathing time.

In both liquids and solids, forces of attraction hold particles close together. In gases, these forces have been completely overcome and the particles are much farther apart and moving independently of each other. Any quantity of gas is able to spread out and fill any size of container. For this reason, the container in which the gas is held influences the volume of a quantity of gas.

The gas particles are continuously bumping into the sides of the container, creating pressure. Both the number of particles and the kinetic energy of the particles influence this pressure.

In rigid containers such as propane tanks and glass pop bottles, the strength of the walls of the container can prevent gas from expanding. In containers with stretchy walls, the gas will expand until the inward force of the stretched walls of the container and the outside air pressure match the pressure the gas particles are exerting.

The relationship between temperature and the size of a container works both ways. If a container is compressed, the particles inside collide more frequently because there is less space for them to move around. Increased collisions means an increase in temperature. That's why when you pump up a bicycle tire, the pump gets hot.

Temperature and Thermal Energy

Temperature and thermal energy are not the same thing. Temperature is an indicator of the average kinetic energy of the particles in a substance. But substances also have potential energy stored within them. Unlike the kinetic energy of motion, potential energy also depends on the relative positions of particles and the forces of attraction within and between particles (Figure 6).

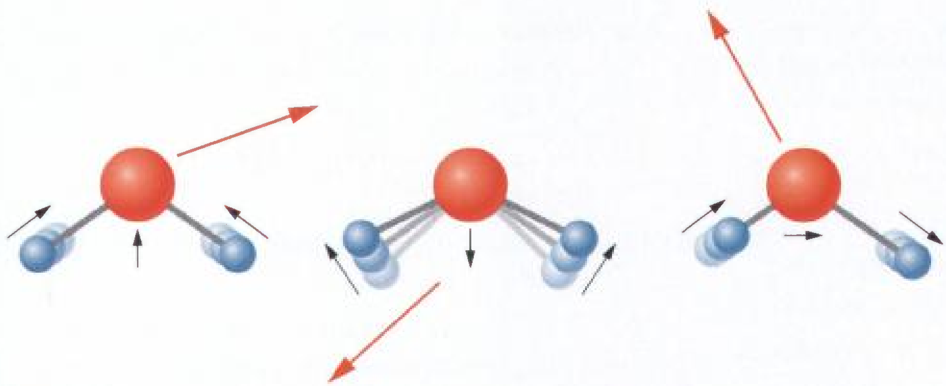


Figure 6 The motions and forces of attraction between atoms within molecules result in both kinetic and potential energy.

Think of an archer who draws the string of a bow. The archer stores potential energy in the bow. When the archer releases the string, the potential energy becomes kinetic energy (motion) and is transferred to the arrow. While a bow's potential energy is related to the motion of its string, the potential energy of a substance is related to the motion of its particles. Both kinetic and potential energy result from the motions and forces of attraction that exist between and within particles.

The forces between particles also affect the total energy. Consider a soccer ball kicked high into the air. It gains potential energy, acting against the force of gravity. As its height increases, some of the soccer ball's kinetic energy is converted into potential energy. Similarly, when particles are vibrating at high speed, they may be able to "pull apart" from each other, acting against the force of attraction. When they do so, they gain potential energy. This is particularly significant during a change of state, when thermal energy is added. The particles gain potential energy, acting against the force of attraction between them. Like the gravitational attraction that will pull the soccer ball back to Earth, the force of attraction among particles can pull the particles back together.

The number of particles also affects the total energy within a substance. We can say that a cup of boiling water and a pot of boiling water have the same temperature (i.e., 100 °C) because their particles are moving at the same average speed. Their total thermal energy, however, is quite different because the **thermal energy** of a substance refers to the total kinetic energy and the potential energy of *all* particles in a substance. The pot of water contains more thermal energy because it contains more particles.

thermal energy = (kinetic energy + potential energy) × number of particles

LEARNING TIP

Check your understanding. Summarize in your own words the difference between temperature and thermal energy.

To view an animation of thermal energy, go to **www.science.nelson.com**

14.1 CHECK YOUR Understanding

1. Using the kinetic molecular theory, explain what happens to the particles being warmed in the following situations:
   (a) hotdogs cook over a campfire
   (b) metal pots warm on a stove but do not melt
   (c) the volume of a liquid increases as it warms
2. Which contains the most thermal energy?
   A. a litre of melting ice
   B. a litre of oxygen gas at 0 °C
   C. a litre of room-temperature water
   D. a litre of oxygen gas at room temperature
3. What happens to the density of a substance as its temperature increases?
   A. Density increases.
   B. Density decreases.
   C. Density doesn't change.
   D. Density fluctuates up and down.
4. How do thermometers measure temperature?
   A. Thermometers are able to directly measure and display the speed of particles.
   B. Thermometers are able to directly measure and display the kinetic energy of particles.
   C. As the thermometer liquid is warmed, the particles speed up and spread out, moving up the tube.
   D. As the thermometer liquid is cooled, the particles speed up and spread out, moving up the tube.
5. Is it possible for the particles in a solid to be moving faster than the particles in a gas? Explain.
6. Compare 0 °C and 0 K. What do the two different 0 values represent?
7. Why is it necessary to put expansion joints in bridges? What would happen to a bridge in winter and summer without expansion joints?
8. Some people run hot water over the lid of a jar to help loosen it. Describe how this helps.
9. Solids and liquids have fixed volumes, and gases expand to fill their containers. Explain this using the kinetic molecular theory.
10. Without adding any gas to a balloon, suggest two ways to increase the pressure inside the balloon.
11. How is "thermal energy" different from "temperature"?
12. It is unsafe to dispose of aerosol cans in a fire. Explain why they could explode.
13. At 20 °C, water is a liquid and carbon dioxide is a gas. Compare the kinetic energies of these particles.
14. Which contains more thermal energy: a cup of hot coffee or an iceberg (Figure 7)? Explain.

Figure 7

15. Safety associations recommend checking your car's tire pressure regularly. Why might this be particularly important in the spring and fall?

14.2 Heat

We routinely refer to changes in a substance's thermal energy. We "heat up" leftovers in the microwave. We say the weather is getting warmer, or we put on a sweater because we feel chilly. Each case relates to an observation about heat. What is heat?

In science, **heat** is defined as the transfer of thermal energy from one object to another because of differences in their temperature (Figure 1). (It only moves from warmer objects to cooler objects.) In applying this definition, scientists explain that heat is not something that an object possesses; objects possess thermal energy. The term "heat" is only used to refer to thermal energy *transfer*.

LEARNING TIP
Important words are in bold print. These are terms that you should learn and use when you answer questions. The terms are defined in the Glossary at the back of your book.

Figure 1 Heat occurs because of differences in temperature. Can you describe the thermal energy transfer in these photos?

In this way, heating something up means that we are adding thermal energy. Cooling something down means that we are removing thermal energy. Many household appliances such as toasters, clothes dryers, air conditioners, and freezers are used specifically to transfer thermal energy from one substance to another.

Heat also happens by natural processes. Everyone is familiar with the warming effects of sunlight and the loss of thermal energy on cold winter days. Accidentally touching the top of a hot stove or deliberately jumping into a cold lake provides compelling evidence that heat flow can be rapid. Whether in nature or in an appliance, thermal energy can be transferred by conduction, radiation, and convection.

Conduction

Conduction is the transfer of thermal energy by direct particle-to-particle contact. When high-energy particles in an object strike lower-energy particles, energy is transferred from the high-energy particle to the lower-energy particle. The faster particles slow down, losing some of their thermal energy, while the slower particles speed up, gaining thermal energy (Figure 2). If the objects remain in contact, this energy transfer will continue until the energy content of the two objects is balanced.

Figure 2 Particles in the solid spoon begin moving faster when they are struck by very fast-moving soup particles, heating up the spoon.

Did You KNOW?

Collision Course

Collisions between particles are *very* frequent. Even in gases that are more than 99.99 % empty space, a typical particle is involved in more than 3 billion collisions per second.

By definition, conduction can only occur when particles are in contact with each other. Recall that both solids and liquids have particles that are closely packed together. In contrast, gas particles are separated by large spaces and are not in direct contact with each other. Gas particles experience far fewer collisions with other gas particles in comparison with particles in solids or liquids. For this reason, the ability of gases to conduct heat is much lower than that of solids or liquids.

Not all substances conduct heat equally well. In general, metals are very good conductors of heat, and non-metals such as glass, wood, and plastics, are poor conductors of heat. The fact that metals are excellent conductors of heat makes them ideal for pots and pans. They do a good job of transferring thermal energy from a hot element to your food. Conversely, plastic pot handles and wooden spoons are used because they are poor conductors and reduce the risk of burns.

TRY THIS: Conduction

Skills Focus: planning, conducting, observing, analyzing

A tile floor feels much colder to your bare feet than a thick carpet does. Does this mean that the tile has a lower temperature than the carpet, or is something else influencing your senses?

Materials: a variety of different surfaces, all at room temperature (e.g., large metal or glass surfaces, wood, fabric, and cushions)

1. Place your hand directly on a variety of different surfaces in your classroom or at home. Objects that are in direct sunlight or are positioned near thermal energy sources should not be included. Note: Any object that has been stationary for an extended period of time will reach the same temperature as its surroundings.
2. Create a data table in which to record whether each surface feels cool or warm.

A. Which surfaces felt cooler?

B. Which surfaces felt warmest?

C. Which surfaces do you think were the best conductors of thermal energy? Which were the worst?

D. Metals are excellent conductors of heat and usually feel cooler than other materials. How does their ability to conduct heat influence this observation?

Radiation

On a bright, sunny day, your body gets warm in the sunshine. Electromagnetic waves from the Sun transfer thermal energy to the surface of your skin in a process called radiation.

Radiation is the only mechanism by which thermal energy can be transferred in the absence of matter, such as through empty space. Radiant energy from the Sun is the primary source of heat on Earth, making radiation an extremely important form of thermal energy transfer.

Although the Sun is our largest and most important source of radiant energy, all particles that have kinetic energy emit some radiant energy. As discussed in Unit C, radiant energy occurs in the form of electromagnetic (EM) waves and includes radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays (Figure 3). These different forms of EM radiation all share similar characteristics and can be distinguished by the wavelength of the waves that are emitted.

Figure 3 Thermograms are images captured using specialized cameras that are able to detect infrared radiation.

Although most objects are not hot enough to emit higher-energy wavelengths, they may be able to absorb them. When radiation strikes an object, some or all of the radiation can be absorbed, reflected, or transmitted in any combination. Energy that is transmitted (passes through the object) or reflected (bounces off) does not change the object's energy. Only absorbed radiation affects the energy of an object. Absorbed radiation is almost always converted to thermal energy, causing the object to increase in temperature. An object's ability to absorb energy can vary, depending on its characteristics, such as colour and state. In general, light-coloured objects are poor absorbers and emitters of radiant energy, and darker-coloured objects are good absorbers and emitters of radiant energy. 14A *Investigation*

14A *Investigation*

Compare the Effect of Radiation on Soil versus Water

To perform this investigation, turn to page 423.

In this investigation, you will explore the effect radiation has on soil and water.

Convection

Unlike solids, particles in liquids and gases can move from place to place. This enables thermal energy transfer by the actual movement of particles as they "flow" from one location to another. **Convection** is the transfer of thermal energy through the movement of particles in fluids. Convection does not normally occur in a solid.

As thermal energy radiates from the baseboard heater in Figure 4, the nearby air warms and expands. This less dense air "floats" up through the surrounding cooler (denser) air, which sinks to the floor.

Hot air now at the ceiling begins to cool, and the cooler air warms as it reaches the baseboard heater. This continuous process creates a cycle until all the air is the same temperature.

In large fluid bodies such as the atmosphere or oceans, convection can move very large quantities of thermal energy. As you will learn in Chapter 15, convection plays a dominant role in distributing thermal energy throughout Earth's atmosphere and oceans.

Did You KNOW?

The Top of the Lake is Warmer

Ever notice that the water in the lake gets colder as you dive down? Convection does not occur when a liquid is heated uniformly from above. The warmed surface water expands, becoming less dense, so it stays "floating" above the cooler water below.

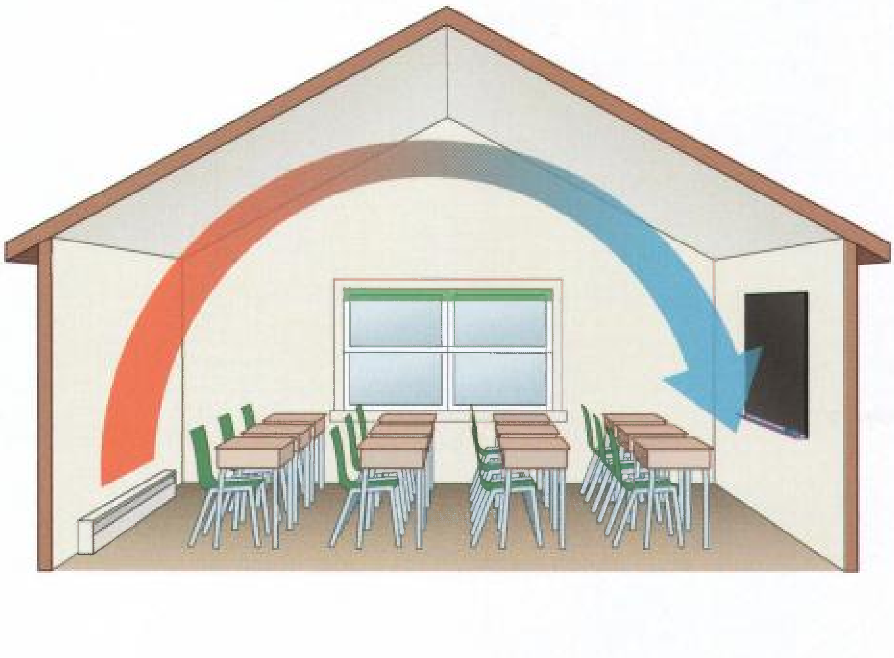


Figure 4 The air in your classroom is a fluid, so convection will distribute thermal energy from a heater throughout the room.

Conserving Heat

In our daily lives, we use heat to keep our homes warm and cook our food. Thermal energy is costly to produce: for living organisms the cost is food; in our homes, the cost is electrical energy or chemical fuels such as natural gas. Preventing the unnecessary loss of this valuable heat can reduce these costs. In our homes and industries, many different materials can be used to reduce thermal energy transfer. Materials that have a restricted or limited ability to transfer thermal energy are called **insulators**. Common examples are polystyrene foam insulation, fibreglass batting, and the thin gas-filled spaces between windowpanes (Figure 5). 14B *Investigation*

14B *Investigation*

Heat Mechanisms

To perform this investigation, turn to page 424.

In this investigation, you will explore heat mechanisms.

Figure 5 Windows like this one are made to reduce heat loss in three ways. The special glass is a poor transmitter of radiation; the layer of trapped gas between the panes is very thin, reducing convection; and the noble gas used to fill the space is a poor conductor.

Heat Capacity

All matter possesses thermal energy in the form of both kinetic and potential energy. The actual amount of thermal energy that an object can possess is dependent on both its size and its chemical composition.

A bathtub full of hot water contains more thermal energy than a cup of hot water, simply because there is more water in the tub. Did you know that the cup of hot water will cool faster? What about a cup of hot water and a cup of hot cheese, will they cool at the same rate? No, even though there is the same volume of each substance. Different substances warm up and cool down at different rates because of the arrangement of their atoms.

A substance's **specific heat capacity** is a measure of the amount of energy (measured in joules) needed to raise the temperature of 1 kg of the substance by 1 °C. For example, it takes 4186 J to raise the temperature of 1 kg of water by 1 °C. So, the specific heat for water is 4186 J/(kg·°C). It takes much less energy to heat up a kilogram of lead or aluminum by 1 °C (Table 1).

Table 1 Specific Heat Capacities

Substance	Specific heat capacity (J/(kg·°C))
water (pure)	4186
ice (0 °C)	2093
water vapour (100 °C)	2080
sandy clay	1381
dry air (sea level)	1005
aluminum	900
concrete	880
quartz sand	795
lead	128

Did You KNOW?

You Can Use a Piece of Ice to Start a Fire

You can ignite a piece of paper by using a lens to concentrate sunlight onto the paper's surface. Because radiation does not cause heating until it is absorbed, a piece of crystal-clear ice carved and polished in the shape of a lens could do the job.

Latent Heat and Changes of State

On a hot summer day, radiant energy from the Sun causes changes of state. Snow and ice melt, and water evaporates from lakes and soil, as well as leaf and skin surfaces (Figure 6).

When thermal energy is added to melt solid ice, the temperature of the water does not change. The apparently missing thermal energy is used to overcome the forces of attraction holding the particles together. As soon as the state changes, the temperature begins to rise again.

The thermal energy stored in the structure of the substance is referred to as latent (hidden) heat. **Latent heat** is defined as the energy needed to change a substance from one state to another without changing temperature. Latent heat is absorbed during the change of state from a solid to a liquid, or from a liquid to a gas (Figure 7). When the change of state is in the other direction, latent heat is released; liquids emit thermal energy as they solidify, and gases emit thermal energy as they condense.

For many substances, a change of state requires considerable heat (Table 2).

Figure 6 This change of state, from a solid to a liquid, requires thermal energy from the surroundings. The result is melting, which actually has a cooling effect.

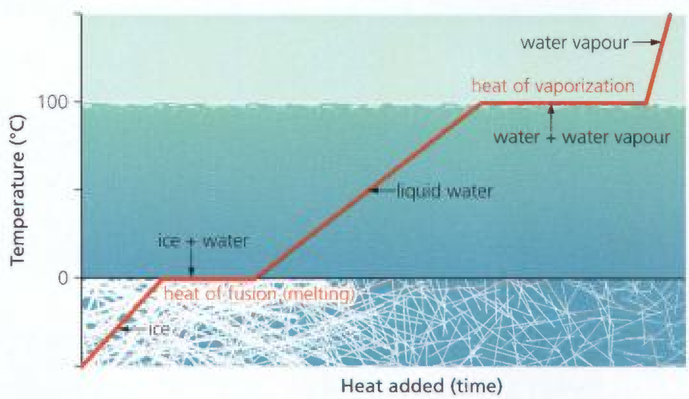


Figure 7 Heating curve of water

Table 2 Comparison of Specific Heat Capacity and Latent Heat

Substance	Specific heat capacity (J/(kg·°C))	Latent heat solid ↔ liquid (J/kg)	Latent heat liquid ↔ gas (J/kg)
water	4186	334 000	2 272 000
ethyl alcohol	2400	104 000	854 000
lead	128	24 500	871 000

Water and Heat

Water has unusual thermal properties:

- It has a high specific heat capacity.
- It requires a lot of thermal energy to change state a (high latent heat value).
- It can be very efficient at transferring thermal energy by convection.

Since 70 % of Earth is covered in water, these characteristics become all the more significant. The hydrosphere plays a very important role in storing and transferring energy around the planet. Expansive water bodies, such as lakes and oceans, absorb or release thermal energy in very large quantities. This has a warming effect in winter, and is responsible for the mild winters of coastal British Columbia.

STUDY TIP

As you read, think about what questions could appear on an upcoming exam. Make notes that will help you answer these questions.

14.2 CHECK YOUR Understanding

1. Using examples, explain the difference between thermal energy and heat.
2. Match each example to a heat mechanism. Terms may be used more than once.

Example	Heat mechanism
(a) Water is heated on a stove. (b) You feel cold near a closed window on a winter day. (c) You feel cool air at your feet when you open the refrigerator. (d) A blacksmith dips red-hot steel into a bucket of water to cool it down.	I. conduction II. convection III. radiation

3. When you reach into a hot oven to remove a pizza, your arm is not burned by the hot air but would be burned if it touched the pan. Explain.
4. A container holds a quantity of liquid nitrogen at a temperature of −200 °C. Explain how each of the following could be used to warm up the nitrogen.
   (a) ice cubes
   (b) hot water bath
   (c) bubbling room air through the liquid
5. If you were standing in a 20 °C room, you could probably stay comfortable indefinitely. However, if you sat in 20 °C water, you would feel much cooler and eventually could suffer a dangerously low body temperature. Explain these observations using your understanding of conduction and insulation.
6. Give two examples of a material used because it is a
   (a) *good* conductor of thermal energy.
   (b) *poor* conductor of thermal energy.
7. What prevents convection from occurring in typical solids?
8. Marcel has a large tropical fish tank with a submersible heater that can be placed anywhere in the tank (Figure 8). Where should he place the heater so the water warms as evenly as possible?

Figure 8

9. Why does convection quickly slow down when boiling water is removed from the stove?
10. Figure 9 is a picture of thermal energy in a toaster. Which colours do you think indicate higher thermal energy content?

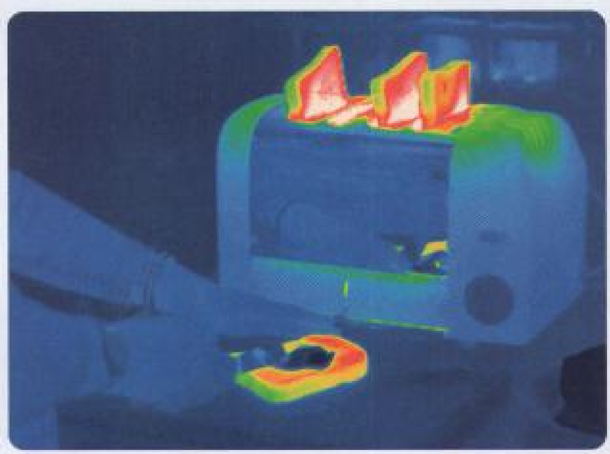


Figure 9

11. Explain how insulation prevents two forms of thermal energy transfer.

14.3 Earth's Heat Sources

Earth's surface receives energy from several sources. Volcanoes, hot springs, and geysers are reminders of the thermal energy trapped within Earth. Warm sunny days and cold nights are reminders of the Sun's contributions.

Before we consider these sources, we need to consider Earth's three distinct surface components: lithosphere, atmosphere, and hydrosphere (Figure 1).

LEARNING TIP
Approach text reading with a critical eye. As you read Section 14.3, ask yourself, "Does this information reinforce, contradict, or add new information to what I already know about Earth's heat sources?"

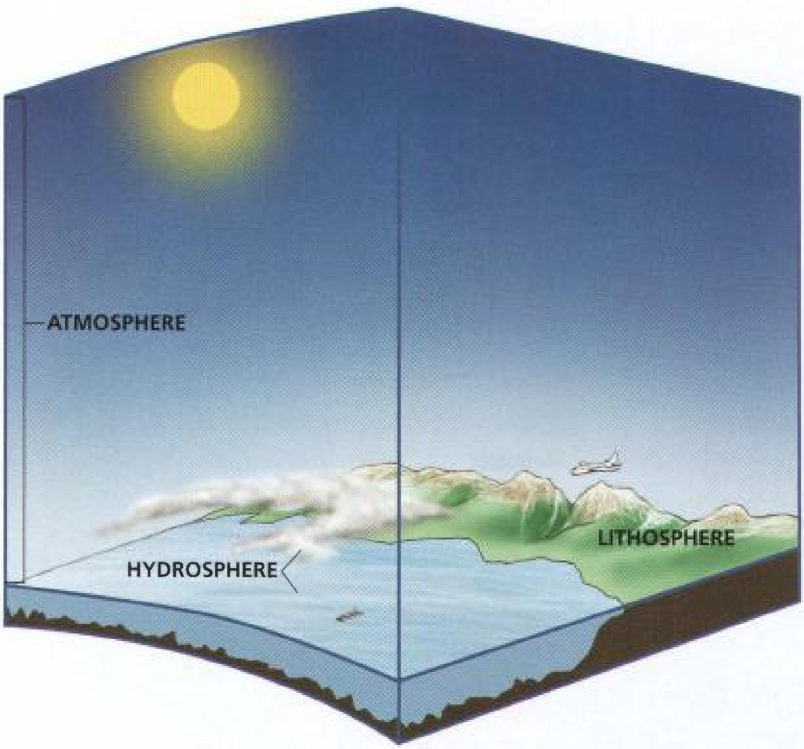


Figure 1 The three main components that surround Earth.

Lithosphere

The **lithosphere** is the solid outer layer of Earth. Its 100 km thickness consists of the inorganic rocks and minerals that make up the ocean floors, mountains and rest of the landscape. You will learn more about the dynamic lithosphere in Unit F.

Atmosphere

The **atmosphere** is the relatively thin envelope of gases (about 500 km thick) that surrounds Earth. It consists of approximately 78 % nitrogen, nearly 21 % oxygen, and about 1 % other gases, such as carbon dioxide and water vapour. The **troposphere** is the lowest layer of the atmosphere, and contains about 80 % of the total mass even though it is only 8 to 15 km thick. Weather occurs in this layer closest to Earth's surface.

Did You KNOW?

Earth's Thin Skin

Relative to the size of Earth, the hydrosphere and atmosphere are extremely thin. Imagine a scale model of Earth 1 m in diameter. The deepest ocean trenches would only be 1 mm in depth, and the highest mountain ranges would be less than 1 mm in height. The entire volume of the oceans would be less than 1.5 L, and the volume of the lower atmosphere would be a little over 6 L. All life exists within these preciously thin layers.

Hydrosphere

The **hydrosphere** includes all of the water in, on, or near Earth's surface: the oceans, rivers, lakes, ice, groundwater, and the moisture in the air. The oceans contain 97 % of Earth's water, with an average depth of nearly 4 km. Of the entire hydrosphere, only 3 % is fresh water; 2 % of this is trapped in glaciers and ice sheets. The remaining 1 % is found in all other forms, including clouds.

Solar Energy

The Sun provides over 90 % of the energy that warms the lithosphere, hydrosphere, and atmosphere. Most visible light from the Sun passes unaffected through Earth's atmosphere; about half is readily absorbed when it strikes Earth's soil, vegetation, and liquid water surfaces (Figure 2).

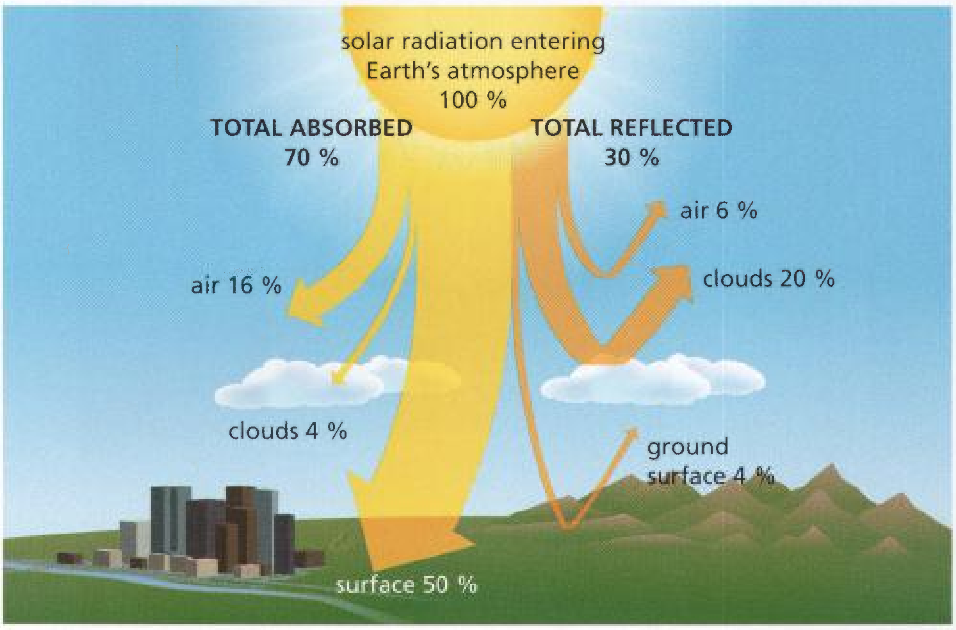


Figure 2 Half the solar energy that reaches Earth is absorbed by the surface. Most of the other half is either absorbed or reflected by the hundreds of kilometres of atmosphere. Eventually, the absorbed energy returns to space as infrared radiation.

- 30 % is reflected back into space by the
  - atmosphere (6 %)
  - clouds (20 %)
  - lithosphere (4 %)
- 70 % is absorbed by the
  - atmosphere and clouds (19 %)
  - lithosphere and hydrosphere (51 %)

This radiant energy is converted to thermal energy, which warms the upper layers of the lithosphere and hydrosphere. Conduction and convection play important roles in transferring this energy across Earth's surface. Gradually, this absorbed thermal energy leaves the surface by conduction, radiation, and convection. The net energy gain is zero. You will learn about this in Chapter 15.

Did You KNOW?

Sun as Earth's Power Plant

Every square metre of Earth's surface receives an average of 342 J of solar energy per second. This is equivalent to the total power produced by the continuous operation of 440 million large power plants. Without a steady supply of solar energy, Earth's surface, with the exception of a few volcanic hot spots, would quickly become a frozen, lifeless solid at temperatures below −200 °C.

The Albedo Effect

The **albedo** of a surface is the degree to which it reflects light. White and shiny objects have a high albedo, and dark and dull surfaces have a low albedo. At any given time, over half of Earth's surface is covered by clouds. Observed from above, these clouds appear bright white because they are highly reflective. Clouds reflect a significant portion of the incoming solar radiation. Other surfaces reflect incoming light to greater or lesser degrees (Table 1).

Table 1 Albedo Ranges for Selected Surfaces

Surface	Albedo
snow	50–90 %
clouds	40–80 %
Earth and atmosphere (average annual)	30 %
sand	20–40 %
grassland	15–25 %
exposed soil	5–30 %
forest	5–15 %
water	5–10 %
black soot	<5 %

The albedo of a surface can have both regional and local influences on energy transfer and temperature. During the winter, snow cover reflects a large fraction of the incoming solar energy. This amplifies the cold conditions in northern latitudes and extends the period of low temperatures. On a local scale, the albedos of large urban centres average less than 10 %. This can result in higher urban temperatures compared to more reflective surrounding areas.

Albedo effects are complex. When global temperatures increase, evaporation and cloud cover can be expected to increase. This increases Earth's overall albedo and blocks some incoming solar radiation. This decreases surface temperatures and lowers evaporation rates. To complicate matters further, clouds are excellent absorbers of the infrared thermal energy radiated from Earth's surface. This counters their cooling effects. Scientists are extremely interested in these significant and contradictory properties of cloud cover.

Internal Sources of Energy

There is an enormous reservoir of thermal energy within Earth itself. Current scientific models of Earth's internal processes and structure suggest that the temperature at the centre of Earth may be as high as 7000 °C. Earthquakes, volcanoes, hot springs, and geysers are frequent reminders of

Did You KNOW?

"Shades" Are an Inuit Invention

The Inuit invented the world's first sunglasses. Their "snow goggles" protect them from the extremely bright light conditions due to a low Sun and snow's high albedo. The goggles below, from the eastern high Arctic, are estimated to be 600 years old and are made from ivory tusks. The narrow slits reduce the eyes' sunlight exposure preventing snow blindness.

STUDY TIP

Here are four things you can do to improve your score on any exam:

1. Examine the entire exam to see how you will be tested and how much there is to do.
2. Spend the most time on the items that count for the most points.
3. Begin by answering the easiest items. Then answer as many of the remaining items as you can.
4. Review your answers before handing in the exam.

this geothermal energy source (Figure 3). Where does this thermal energy come from? And why is Earth's exterior so much cooler?

Figure 3 The natural hot springs in Liard River Hot Springs Provincial Park in Northern B.C. are used as a tourist and recreational attraction.

Heat of Formation

The first and largest source of Earth's internal energy was produced during the formation of the planet. Scientific evidence suggests that Earth formed as a result of the gravitational attraction between large quantities of matter in the early solar system. The extreme energy from these impacts and the gravitational pressure within the young Earth caused its interior to melt, forming a fluid-filled planet. The less dense minerals (mostly oxygen, silicon, and aluminum) "floated" to the surface, while the denser iron, nickel, and heavy metals sank toward Earth's core. Today, energy is still being released by gravitational action within Earth's interior as denser minerals continue to be pulled deeper into the core.

Radioactive Decay

Potassium, uranium, and thorium are thought to be the three main radioactive energy sources within Earth. They release thermal energy as they have continued to break down into other substances over billions of years.

The Cool Surface of Earth

With such a hot core, why is Earth's surface so cool? And why hasn't the interior cooled off? As Earth's early surface radiated thermal energy into space, it cooled and hardened, forming a 50–150 km thick lithosphere. As a solid, thermal energy transfer by both radiation and convection is limited, and the rock composition of the lithosphere makes it a poor conductor. In essence, this thick crust insulates Earth from thermal energy loss, resulting in a planet with an extremely hot interior that is cooling down very slowly.

LEARNING TIP

Evaluate information. After reading Section 14.3, have any of your ideas changed as a result of what you've just read? What questions do you still have?

14.3 CHECK YOUR Understanding

1. Define each term.
   (a) atmosphere
   (b) hydrosphere
   (c) lithosphere
2. Copy and complete Table 2.

Table 2

	Percent of solar radiation absorbed	Percent of solar radiation reflected
clouds		
atmosphere		
lithosphere		
Total		

3. What happens first to all solar radiation absorbed by Earth?
4. How would Earth's surface temperature change if all the solar radiation reached the lithosphere?
5. How has the force of gravity influenced the temperature of Earth's interior?
6. How does radioactive decay provide energy within Earth?
7. Even after billions of years, Earth's centre is extremely hot. Describe the three ways in which the properties of Earth's lithosphere dramatically slow the escape of thermal energy.
8. Most of Earth's landmass is in the northern hemisphere. How might this influence Earth's overall albedo during
   (a) June
   (b) January
9. List three examples of natural activities or events that carry thermal energy from within Earth directly to Earth's surface.
10. How is the energy that reaches Earth's surface returned to space?
    A. radiation
    B. convection
    C. conduction
    D. evaporation
11. Would you expect to find minerals composed of very light elements, such as sodium and lithium, near the surface or deep within Earth's interior? Explain.
12. What three elements are thought to be the main sources of radioactive decay energy within Earth?

I	thorium
II	uranium
III	plutonium
IV	potassium

    A. I, II, and III
    B. I, II, and IV
    C. I, III, and IV
    D. II, III, and IV
13. With all the radioactive decay occurring within Earth, what prevents large quantities of this radiation from reaching Earth's surface?

Awesome
SCIENCE

HOW HUMANS KEEP THEIR COOL

How is the human body able to maintain a safe 37 °C temperature when the air is much warmer?

Our body's core temperature is around 37 °C. A temperature above 39 °C is considered a high-grade fever and warrants medical attention. A temperature above 40 °C is life threatening, and above 41 °C causes brain damage. Keeping your cool is very important!

As well as outside sources, cellular activity within our bodies generates thermal energy. Convection, conduction, and radiation usually help this dissipate. But thermal energy only travels from hotter objects to cooler ones. How do we maintain a safe temperature when the air temperature is above 37 °C? The answer lies in the hidden energy of water that is leaving the body's surface.

Body temperature is monitored and regulated by the nervous system. When the air is warmer than the body, conduction, convection, and radiation no longer provide a cooling effect. Instead, these mechanisms transfer thermal energy from the air to the body. The brain responds by stimulating the body to perspire.

As the perspiration evaporates, it absorbs large quantities of thermal energy from the skin. One gram of perspiration at 37 °C absorbs 2.5×10^6 J of thermal energy as it evaporates: a powerful cooling mechanism.

Figure 1 depicts the energy transfers that occur under different environmental conditions. In both cases, cellular activity within the body produces thermal energy at a rate of 90 W (90 J/s). Therefore, to maintain a constant body temperature, the body must lose 90 W more than it gains.

At 23 °C, thermal energy is lost to the environment through convection, conduction, radiation, and a small amount of perspiration. At 45 °C, thermal energy is actually ***gained*** from the environment through conduction, convection, and radiation. Under these conditions, perspiration becomes ineffective at cooling. Approximately 300 mL of sweat would have to evaporate per hour to maintain a 37 °C body temperature.

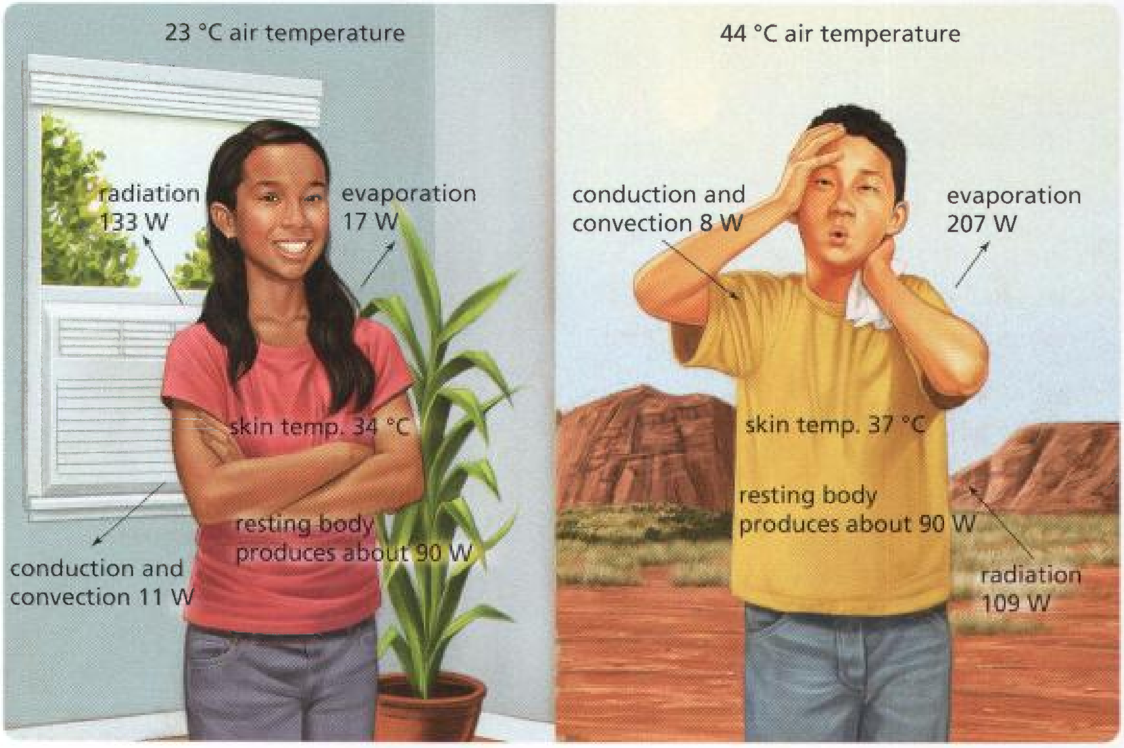


Figure 1 When the skin temperature is greater than the surrounding air temperature, thermal energy is transferred to the air through conduction, convection, and radiation. When the skin temperature is lower than the surrounding air temperature, thermal energy is gained by the body through conduction, convection, and radiation. In this situation, energy loss through evaporation prevents overheating of the body.

14A Investigation

Compare the Effect of Radiation on Soil versus Water

In this investigation, you will compare the effect of radiation on water and land surfaces.

INQUIRY SKILLS

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

Question

How do the colour and physical state of a substance influence its ability to absorb and retain thermal energy?

Prediction

Predict how colour and physical state affect the ability of a substance to absorb and retain thermal energy.

Experimental Design

In this experiment you will model Earth's surface using water and dark-coloured and light-coloured soil placed in trays. You will then monitor their temperatures before, during, and after they are exposed to an energy source.

Materials

- 3 large trays (one with a black bottom)
- water
- light-coloured soil or sand
- dark-coloured soil or sand
- 6 thermometers with bulbs wrapped in small pieces of foil
- 3 heat lamps or strong light sources (150 W bulbs)

Do not let the lights touch the water, as it could cause an electric shock. Do not look directly at the strong light source.

Procedure

1. Fill the dark-bottomed tray with a 4 cm layer of water. Fill the other trays 4 cm deep, each with a different soil.
2. Position two thermometers in each tray: one almost touching the bottom of the tray, and the other just under the surface of the water or soil.
3. Position the light sources 15 cm above each tray.
4. Record the temperatures for each thermometer.
5. Turn on the lamps, and begin recording each temperature every 5 min for 20 min.
6. After 20 min, turn off all the lamps and continue recording the temperatures at 5 min intervals. Stop recording after a total of 40 min.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Plot all three sets of values on the same graph.

(b) Compare the maximum temperature reached by each material. Which was the highest? Why?

(c) Which substance's surface temperature changed the least?

(d) What caused the water's temperature to be more uniform at different depths?

(e) How is it possible for thermal energy to be transferred from the soil surface to the bottom of the tray? How does this differ from the water?

Evaluation

(f) How does using a dark-bottomed tray help model the effects of deeper water?

(g) Did your observations support your prediction? Explain why or why not.

14B Investigation

Heat Mechanisms

In this investigation, you will explore heat mechanisms.

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

Question

What factors influence the transfer of thermal energy by conduction, convection, and radiation?

Experimental Design

In Part A, you will compare the ability of glass and metal to transfer thermal energy by conduction. In Part B, you will investigate convection and observe the formation of a convection current in a fluid. In Part C, you will compare the efficiency of light and dark materials in absorbing radiant thermal energy.

Materials

- safety goggles
- support stand and thermometer clamp
- 15 cm glass rod
- wax candle
- 15 cm metal rod (copper or aluminum)
- large beaker (400 mL or larger)
- ice cold water
- Bunsen burner
- thermometer
- food colouring
- 2 small aluminum pie plates, one spray-painted dull black (on the inside)
- lamp with 60 W incandescent light bulb
- clothespins or clamps
- stopwatch

Keep all flammable objects, including your hair and clothing, away from flames. Always wear safety goggles when dealing with hot liquids. Exercise caution when using hot water and hot wax as they can cause severe burns. Food colouring will stain skin and clothing.

Procedure

Part A: Conduction

1. Using a support stand and thermometer clamp, position a glass rod horizontally about 15 cm above the table. The rod should be clamped close to one end.
2. Using a lit candle, place 4 small drops of wax along the glass rod 2, 4, 6, and 8 cm from the unclamped end.
3. Prepare an identical set-up with a metal rod.
4. Move both rods so that their ends are almost touching.
5. Simultaneously heat the ends of both rods evenly using a candle flame. Begin timing the experiment.
6. Observe the effects of the heating on the solid wax dots, and record the time(s) of any changes.

Part B: Convection

7. Fill a large beaker with ice cold water and let it sit on a support stand undisturbed for 2 min.
8. Place the flame of a Bunsen burner under the outside edge of the beaker. Heat the water with a very hot flame for 15 s. Turn off the heat and wait 30 s.
9. Record the temperature of the water at the surface and near the bottom of the beaker.
10. Repeat Step 7.
11. Hold the food colouring 1 cm above the water and add a single drop to the centre of the beaker. Observe and record the behaviour of the food colouring for 10 s.
12. Repeat Step 8.
13. Resume strong heating of the water at the edge of the beaker, and repeat Step 11.

Part C: Radiation

14. Use the candle to deposit a drop of wax on the outside bottom surface of one shiny and one dull black aluminum pie plate.
15. Using clothespins or clamps, hold both pie plates on either side of a 60 W incandescent bulb, approximately 2 cm from the bulb (Figure 1). The plates should be facing the bulb, with the bottom surfaces on the outside.

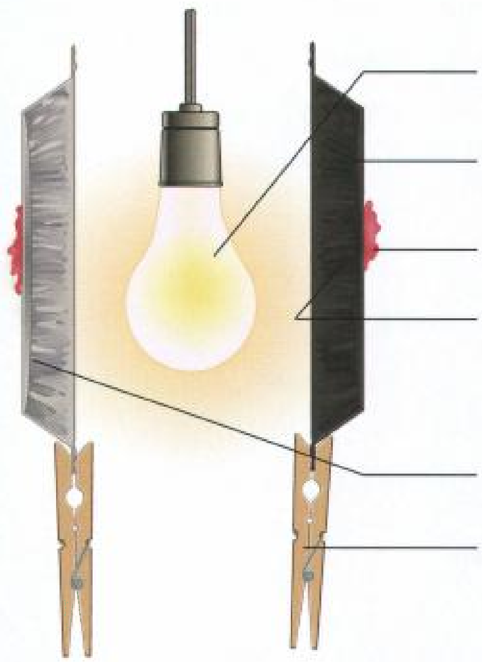


Figure 1

16. Turn on the light, and observe the wax dots for signs of change. Record your observations.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) In Part A, how quickly did the wax dots melt on the metal and glass rods? What can you infer regarding their ability to conduct heat?

(b) Liquid food colouring is slightly denser than water. How might this explain the behaviour of the drop in the beaker of calm water in Part B?

(c) What caused the more complex motion of the food colouring in the heated water?

(d) Why did the wax drops melt at different rates on the pie plates in Part C?

(e) How does a black surface differ from a shiny surface when it is struck by radiation?

(f) How did the thermal energy reach the wax after it hit the surface of the pie plate?

Evaluation

(g) How might the drop of food colouring have behaved if it was added directly over the position of the Bunsen burner?

(h) Painting the second pie plate white, rather than leaving it shiny, would improve this experiment. Explain.

Synthesis

(i) Metals have different abilities to conduct heat. How could this be tested?

(j) If glass is a poor conductor, how is it that windows lose more heat in winter than walls do?

(k) When a dark-coloured solar blanket is placed over a swimming pool, the water surface is heated but no convection takes place. Explain.

(l) Why are the surfaces of solar water heaters coloured black?

(m) Why might you wear light-coloured clothing on hot days and dark-coloured clothing on cold days?

CHAPTER 14

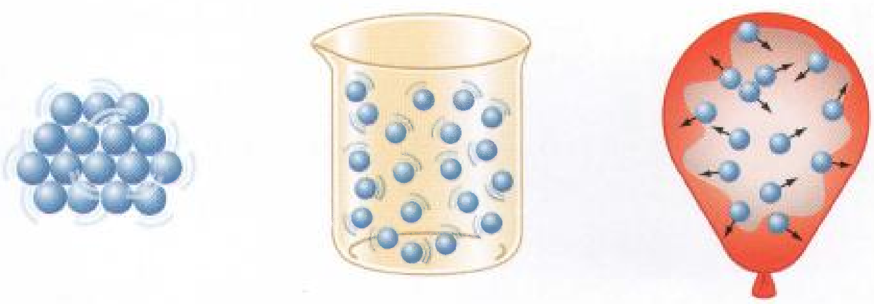
Review

Heat and Thermal Energy Sources

Key Ideas

Thermal energy influences temperature, density, pressure, and a substance's physical state.

- Thermal energy includes both kinetic energy and potential energy from the motion of particles and their relative positions and forces of attraction.
- Temperature is an indicator of the average kinetic energy of particles.
- When the temperature of a substance increases, its particles move faster and spread out. This causes the substance to expand and become less dense.



- Heat is the transfer of thermal energy from one object to another because of differences in their temperature. Heat always moves from warmer to cooler objects.

Thermal energy can be transferred by conduction, convection, and radiation.

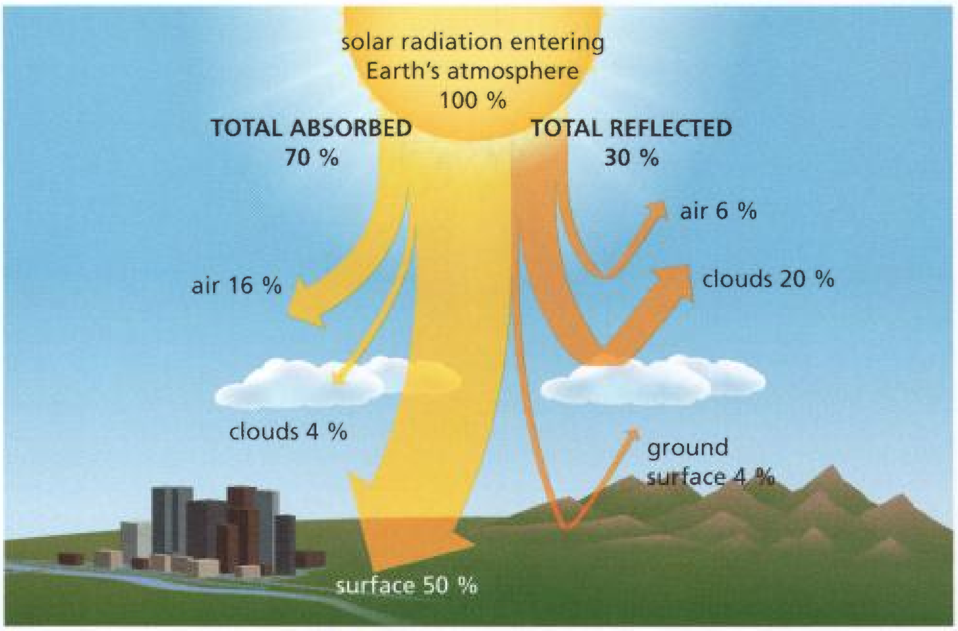
- Conduction is thermal energy transfer through direct contact of particles.
- Convection is a method of thermal energy transfer resulting from the movement of particles in fluids due to density differences.
- Radiation is the process by which thermal energy is transferred via electromagnetic waves, without particles touching.

Vocabulary

kinetic molecular theory, p. 405
kinetic energy, p. 405
temperature, p. 405
thermal energy, p. 409
heat, p. 411
conduction, p. 411
radiation, p. 412
convection, p. 413
insulators, p. 414
specific heat capacity, p. 414
latent heat, p. 415
lithosphere, p. 417
atmosphere, p. 417
troposphere, p. 417
hydrosphere, p. 418
albedo, p. 419

Most of the thermal energy at Earth's surface comes from the Sun.

- Over 90 % of Earth's continuous energy supply comes from the Sun.
- Half of the solar radiation that reaches Earth is absorbed and converted to thermal energy.
- The atmosphere absorbs thermal energy from the Sun as well as from the lithosphere.
- The net energy gain from solar radiation is zero. Over time, most of it is radiated back out into space.



Earth's interior has large quantities of thermal energy.

- Earth's interior is extremely hot as a result of the planet's formation and continuing radioactive decay.
- The Earth's hot core is well insulated because thermal energy cannot easily move through the Earth's lithosphere by conduction, convection, or radiation.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. (a) What happens to the particles in a substance when it is heated?
   (b) How is this related to a substance's temperature?
2. (a) How is the kinetic energy of particles related to the physical state of the substance?
   (b) What general statement can you make about the kinetic energy of particles in solids, liquids, and gases?
3. Why should you expect the air pressure in your tires to increase as you drive the car?
4. Use your understanding of the kinetic molecular theory to explain what is happening in each of the following situations:
   (a) Air pressure in a scuba tank decreases as a diver reaches deeper cold water.
   (b) Substance A is at a higher temperature than substance B, even though the molecules are moving at the same speed.
   (c) When a balloon is filled with hot air, it rises.
   (d) It takes more thermal energy to warm up a swimming pool of water by 1 °C than it does to completely boil away just 1 L of water.
5. Describe the influence of Earth's atmosphere on incoming solar radiation. What portion of radiation is absorbed, transmitted, and/or reflected by the atmosphere?

K 6. Which of the following is a good conductor of heat?
   A. air
   B. argon
   C. metal
   D. plastic

K 7. In which substance would convection occur?
   A. air
   B. wood
   C. metal
   D. a pebble

K 8. Which of the following is the best transmitter of radiant energy?
   A. air
   B. glass
   C. metal
   D. wood

9. Match each term on the left with the correct description on the right.

Term	Description
(a) heat	I. thermal energy transfer that occurs without particles moving
(b) temperature	II. includes both kinetic and potential energy
(c) conduction	III. energy required to increase the temperature of 1 kg of a substance by 1 °C
(d) radiation	IV. transfer of thermal energy
(e) specific heat capacity	V. current within a fluid resulting from differences in density
(f) convection	VI. average kinetic energy of particles within an object
(g) thermal energy	VII. transfer of thermal energy by direct particle-to-particle contact

Use What You've Learned

10. The train tracks in Figure 1 twisted on a very hot July day. Explain why.

Figure 1

11. The blossoms in Figure 2 were intentionally watered during a period of subzero temperatures. What purpose might this serve? Hint: Does liquid water gain or lose thermal energy as it solidifies?

Figure 2

12. (a) The main heating element is on the bottom of the oven. How does this promote even heating?
    (b) Convection ovens use a fan to circulate air within the oven as the food cooks. This greatly reduces cooking time. Why?

13. Fiberglass insulation is fluffy like a cushion, but it loses much of its insulating ability when squished. Explain.

U 14. Picture yourself sitting on hot sand at a sunny beach. By what methods are you gaining or losing thermal energy?

I	conduction between the sand and your body
II	convection as the air moves around you
III	radiation from the sunshine
IV	convection from the sand

A. I and II only
B. I, II, and III only
C. II, III, and IV only
D. I, II, III, and IV

Think Critically

15. Copy Table 1 into your notebook and complete it. Consider examples and applications in industry, around your home, and in recreation.

Table 1

	Example or application	Source of thermal energy	Object receiving thermal energy
Conduction			
Convection			
Radiation			

16. How would your life change if you were unable to heat anything? What would be the most significant changes in your everyday life?

17. Firewalkers are able to walk over burning wooden coals over 500 °C, but are not able to walk through a tray of boiling water at 100 °C. Explain in terms of conductivity.

HMP 18. Which of the following best explains why the temperature changes as you travel down a mine shaft?
A. The temperature decreases beneath the permafrost layer.
B. The temperature increases as you move closer to Earth's hot core.
C. The temperature decreases as you move farther from solar radiation.
D. The temperature increases due to pressure exerted by the surrounding rock.

Reflect On Your Learning

19. Have your investigations of thermal energy, temperature, and heat improved your understanding of how energy is transferred? List three forms of energy transfer you can observe right now.

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

CHAPTER 15

Transfer of Energy on Earth

Chapter Preview

Solar energy reaching Earth's surface is largely responsible for creating and influencing three things necessary for life: warmth, winds, and water movement. Without solar energy, Earth would be a frozen wasteland. No winds would blow and all water would be frozen.

Solar energy is not equally distributed at Earth's surface. Differences in solar energy distribution influence weather patterns, climate, and the changing seasons. Understanding how the Sun's energy influences processes at Earth's surface greatly enhances our understanding of these factors and our ability to predict present and future weather and climatic conditions.

To begin we will want to answer these questions: What causes winds? How do winds help distribute water and thermal energy around Earth?

KEY IDEAS

- Atmospheric pressure results from gravity and the force of the atmosphere pushing down on itself.
- Uneven heating of air produces differences in density and air pressure.
- Wind results when air in high pressure regions moves toward regions with lower air pressure.
- Latitude and landscape influence the absorption of incoming solar radiation.
- Global prevailing wind patterns influence ocean currents and the formation of weather systems.

TRY THIS: Cloud in a Bottle

Skills Focus: observing

In this activity, you will observe how changes in air pressure can influence the interaction of smoke and water vapour.

Materials: 2 L colourless pop bottle, matches, water

1. Pour just enough water into the empty bottle to cover the bottom. Tighten the cap.
2. Shake the bottle for several seconds, then remove the cap.
3. Light a match and let it burn. Blow it out and drop it into the bottle. Tighten the cap again.
4. Increase the pressure inside the bottle by squeezing it as hard as you can without breaking it. After a few seconds, release the pressure. Record any changes you observe inside the bottle.
5. Repeat Step 4 three more times.

A. Explain your observations.

B. What would happen if you did the same experiment without the smoke?

15.1 Atmospheric Pressure and Influences

Solar energy does not reach Earth with the same intensity around the planet, so some areas absorb more thermal energy than others. Since the atmosphere and hydrosphere are fluids, convection helps distribute thermal energy around Earth.

LEARNING TIP

As you read, pause after each word in bold and try to define the meaning in your own words. Reread to check your definition.

Air Pressure and Density

Even though the gas particles that make up the atmosphere are extremely light and fast moving, the force of gravity is strong enough to hold the atmosphere in place. As a consequence of this gravitational force, the weight of the column of air above any point also exerts pressure (Figure 1). This is called the **atmospheric pressure**, or air pressure. Pressure is defined as the force exerted on a given area. The scientific unit for pressure is the pascal (Pa), which is equal to 1 newton per square metre (1 Pa = 1 N/m^2). In Canadian weather forecasts, air pressure is usually reported in **kilopascals** (1 kPa = 1000 Pa).

Did You KNOW?

Scientists use a number of different units to describe air pressure: millimetres of mercury (mm Hg or torr), pounds per square inch (psi), atmospheres (atm), millibars (mbar), and pascals (Pa).

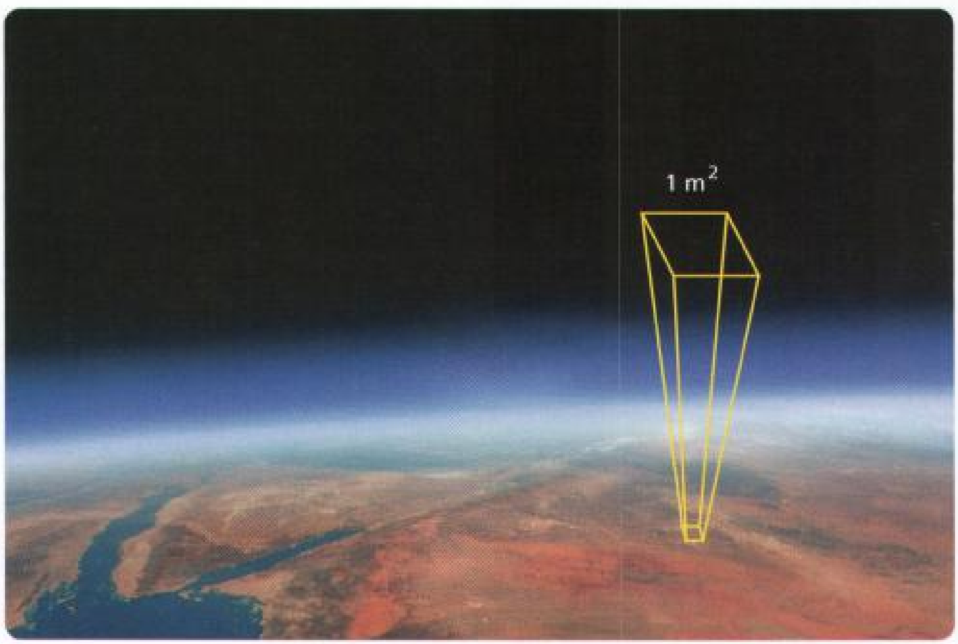


Figure 1 Although low in density, the layer of air surrounding Earth exerts a considerable pressure on the surface below. On average, more than 10 000 kg of air is pushing down on every 1 m^2 of Earth's surface.

As you move up through the atmosphere (in a plane, for example), the air pressure decreases because the air column above you is decreasing. At these high altitudes the air is less compressed and less dense. In contrast, air near Earth's surface is squeezed by the weight of the air above it, making it more compressed and giving it a higher density (Figure 2). For example, at sea level, atmospheric pressure averages 101.3 kPa.

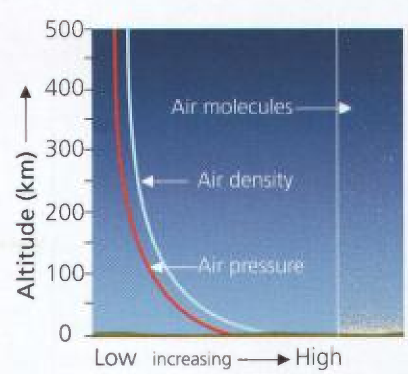


Figure 2 Atmospheric pressure decreases as altitude increases.

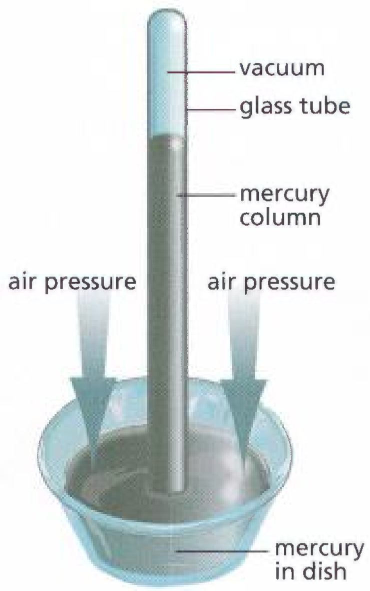


Figure 3 The greater the air pressure pushing down on the mercury in the tray, the higher up the tube the mercury will be raised.

Measuring Air Pressure

In 1643, while trying to create a space devoid of particles, Italian scientist Evangelista Torricelli invented the mercury barometer (Figure 3); an instrument used to measure air pressure. He filled a closed-ended glass tube with mercury, and then inverted it in a tray of mercury. The mercury moved down the tube, leaving an empty space or near vacuum above it. Torricelli knew that the mercury was being held up by the force of air pressure pushing down on the mercury in the tray. He also observed that the level of mercury in the tube changed from day to day. Torricelli realized that this was due to changes in the air pressure.

Today, the most popular instrument for measuring atmospheric pressure is the aneroid barometer. Aneroid means "without liquid." Aneroid barometers use a small, sealed chamber of air. The air expands and contracts, depending on the surrounding air pressure. A small arm attached to the chamber deflects a needle to register these changes.

TRY THIS: *Atmospheric Can Crusher*

Skills Focus: observing, analyzing

In this activity, you will demonstrate the effects of air pressure.

Materials: safety goggles, hot plate, empty pop can, beaker tongs, 400 mL beaker (or large bowl) filled with cold water

Do not touch the hot plate or the hot pop can with your hands. Exercise caution when using boiling water. Always wear safety goggles when dealing with hot liquids.

1. Put on safety goggles.
2. Pour 40 mL of water in an empty pop can, and place it on a hot plate.
3. With the hot plate on high, bring the water to a boil.
4. When the water is boiling rapidly, use beaker tongs to lift the pop can from the hot plate. Quickly and carefully invert the pop can into a beaker of cold water.

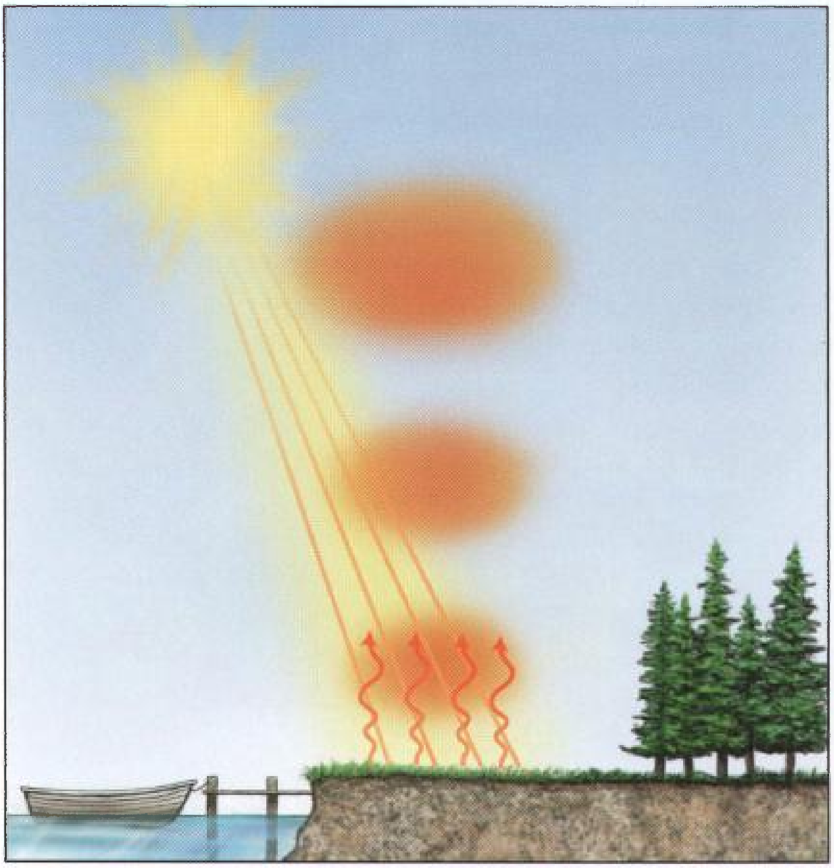
A. Describe what happens to the pop can when it makes contact with the cold water.

B. What happens to the energy of the air molecules inside the can once you remove it from the hot plate? How does contact with the cold water affect their energy?

C. If most of the gas molecules have already escaped from the can once it becomes hot, what prevents the can from being crushed before it is placed in the water?

Thermal Expansion and Air Pressure

Temperature influences air pressure, density, and water content. When gas in the atmosphere is heated, thermal expansion occurs as the molecules speed up and spread out (recall the kinetic molecular theory). This creates an area of low pressure relative to the surroundings. The heated air mass, now less dense than the surrounding air, floats up and is further pushed up by the surrounding denser air (Figure 4).



LEARNING TIP

Stop and think. As you examine Figure 4 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 help me to interpret the diagram?"

Figure 4 As the air near the ground absorbs thermal energy, it expands and becomes less dense. It then floats up through the surrounding cooler, denser air.

Conversely, as air cools, its particles move more slowly and density increases, creating an area of high pressure.

When this process of uneven surface heating occurs on a large scale over an area of many square kilometres, the rising air mass forms an area of lower air pressure at Earth's surface called a **low-pressure cell.** Conversely, if an air mass is or becomes colder than its surroundings, it will decrease in volume and become denser than the surrounding air. The result is a **high-pressure cell,** where denser air sinks and produces a high-pressure region where it hits Earth's surface. Figure 5 shows how low- and high-pressure centres are depicted on maps. Note that lines called **isobars** join locations of equal atmospheric pressure.

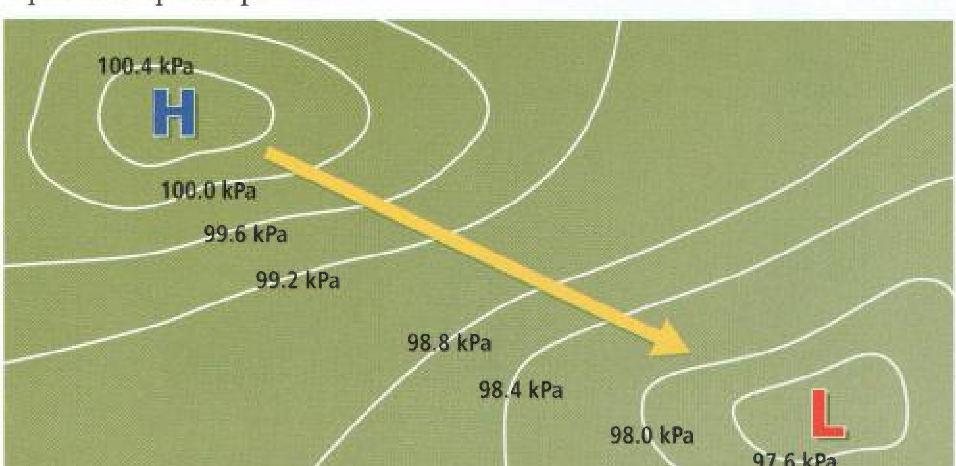


Figure 5 Regions of high and low pressure are designated on weather maps using the symbols H and L. Isobars join locations with the same atmospheric pressure. Note that air always moves from areas of higher pressure toward areas of lower pressure, as indicated by the arrow.

LEARNING TIP
When you are reading bulleted text ask yourself, "How does each point add to what I am learning?" Try to explain the information in your own words.

Uneven surface heating produces

- thermal expansion and areas of low pressure, where air is rising
- thermal contraction and areas of high pressure, where air is sinking
- convection currents, which carry air and thermal energy
- winds as air moves from a region of high pressure to a region of low pressure

Figure 6 As water vapour condenses, minute droplets join together until they are so large we see clouds.

Radiation heats water, making it evaporate from water bodies, soil, and plants. This water vapour mixes with other gases in the warmed atmosphere. Warm air can hold more water vapour than can cold air. As this air rises and cools, the water vapour loses thermal energy and may condense into clouds. Air can rise because of pressure differences, or it can be forced up by changes in the landscape, such as mountains (Figure 6). Clouds are storehouses and transporters of vast amounts of thermal energy (Figure 7).

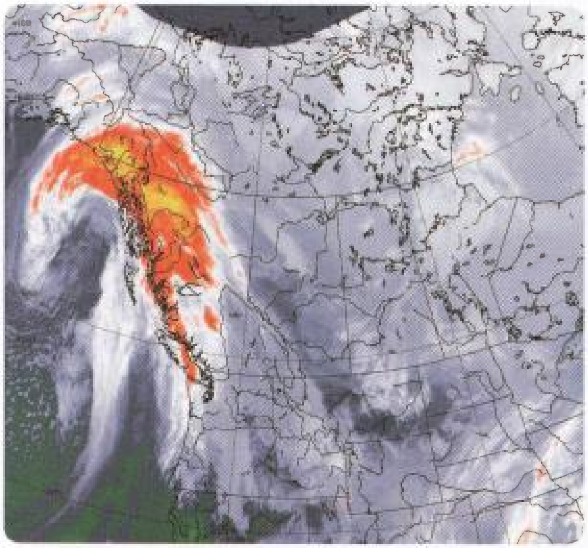


Figure 7 This infrared satellite image indicates areas of thick cloud cover (brightly coloured regions). Here, large quantities of thermal energy are released as water vapour condenses into liquid water droplets and forms rain.

You will see in section 15.2 how these factors influence global wind patterns.

Altitude and Temperature

The troposphere is the lowest portion of the atmosphere, where weather occurs. Throughout the troposphere, it is colder at higher altitudes. Two factors influence this temperature gradient. First, as air rises, it moves away from Earth's surface, a source of radiant energy. Second, rising air masses cool as they expand. The reverse happens with sinking air masses.

An understanding of atmospheric pressure and changes of state allows us to confidently predict the movement of high- and low-pressure systems. For example, in regions of low pressure, air is rising and cooling. If there is adequate moisture in the air, cloud formation is likely, and precipitation may be expected. In regions of high pressure, cold air is falling and warming. Water vapour would be increasing in thermal energy content and therefore not be expected to condense, resulting in clear skies.

15.1 CHECK YOUR Understanding

1. What causes air pressure in the atmosphere?
2. A simple experiment shows that a can of diet pop floats in water while the same brand of pop, only regular, sinks. The regular pop contains a significant amount of dissolved sugar.
   (a) How are these observations related to density?
   (b) Which substance is most dense?
3. How does the slinky toy in Figure 8 model the density/pressure gradient of Earth's atmosphere?

Figure 8

4. How does the thermal expansion of gases produce convection currents and areas of low and high pressure in the atmosphere?
5. (a) Compared to ground-level air, the air surrounding a plane at high altitude provides less air resistance, is very cold, and contains less oxygen per cubic metre. Explain.
   (b) In what way(s) do these properties help flight? What challenges do they present?
6. Which phrase is more accurate: "warm air rises in cold air" or "warm air floats in cold air"? Explain your reasoning.
7. What two factors raise the temperature of a sinking air mass?
8. Why do clouds form in rising air masses?
9. Explain what is happening in Figure 9.

Figure 9

10. Copy Figure 10 into your notebook and label the low- and high-pressure areas. Add an arrow to indicate the general direction of airflow.

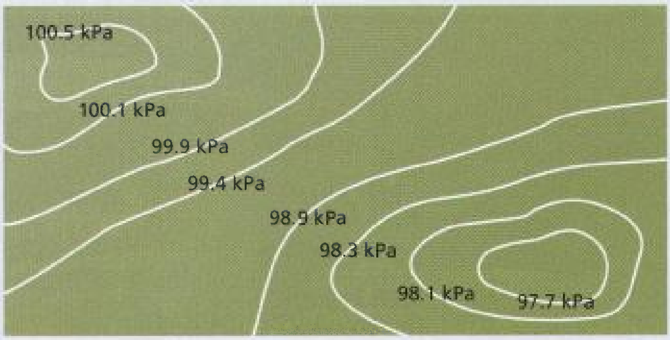


Figure 10

11. Describe the relative air pressure in a warm air mass compared to a cold air mass.
12. High-pressure areas are associated with cooler air masses, and low-pressure areas are associated with warmer air masses. If water vapour condenses and forms clouds when it cools, why do high-pressure systems usually have clear skies, and why do low-pressure systems usually have cloudy skies?

15.2 Energy Distribution

LEARNING TIP

Preview Section 15.2 to set a purpose for your reading. Ask yourself, "What is this section about?" Try to make predictions about the content. Write down your predictions as a reminder as you read.

Canada is a vast country that extends from the midlatitudes to the high Arctic. In southern Canada, temperatures vary dramatically from relatively high temperatures in the summer to freezing temperatures in the winter. In extreme northern Canada, temperatures also vary from season to season, but are consistently much colder. There can be no doubt that temperatures at Earth's surface are neither uniform nor constant. What causes these differences?

Temperature and Latitude

As you have learned, surfaces with higher temperatures radiate more thermal energy than cooler surfaces. Earth's warmest regions lie in tropical latitudes and emit more radiant energy than the cooler polar regions. Figure 1 shows the radiant energy being emitted by Earth in watts per square metre. Heavy cloud cover and convection currents create some irregularities.

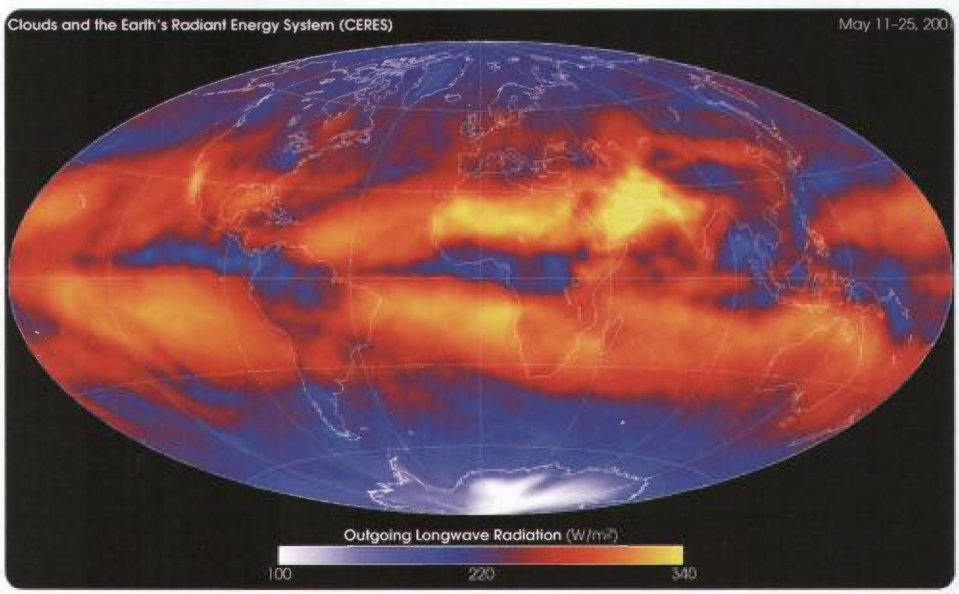


Figure 1 Note the relationship between latitude and the emission of radiant energy.

15A **Investigation**

Comparing Light Intensity

To perform this investigation, turn to page 448.

In this investigation, you will compare the intensity of light striking different surfaces when oriented at different angles to a light source.

Looking at a simple model of Earth and the Sun, it is apparent that, as Earth rotates, any position along the equator is closer to the Sun than any position near the poles. But the difference is only a tiny fraction of the distance to the Sun. This does not account for the temperature differences. What, then, is responsible for the relationship between latitude and temperature? 15A *Investigation*

Think of the radiation from the Sun as a number of equal parallel light rays striking Earth. Each ray delivers the same quantity of energy per second. Light rays that strike Earth near the equator are nearly perpendicular (upright or vertical) to the surface, while those near the poles strike at a very oblique (tilted or slanted) angle, particularly in winter (Figure 2). As you move toward the poles, the same quantity of light is spread out over a larger surface area. The result is less thermal energy transfer per square metre of land and much lower temperatures.

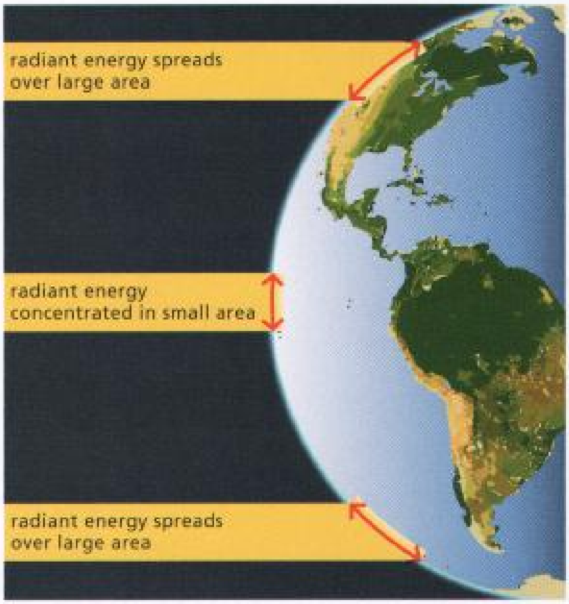


Figure 2 The same beams of radiant energy striking Earth at an oblique angle (at high latitudes) are spread out over a greater area than those striking the surface at a more perpendicular angle (the equator).

Reasons for the Seasons

Earth's axis of rotation is tilted on an angle of 23.5°. As Earth revolves around the Sun, each pole is alternately tilted either away from or toward the Sun throughout the year.

The seasonal temperature differences are due in large part to the angle at which the Sun's rays strike Earth's surface. In the northern winter, when the North Pole is tilted away from the Sun, rays strike northern latitudes at very oblique angles, spreading their energy out over a large area. In the northern summer, with the North Pole tilted toward the Sun, the rays strike northern latitudes more directly and are concentrated over a much smaller surface area. Examine Figure 3, and compare the numbers of rays striking equal land areas in summer and in winter, and in northern versus equatorial latitudes.

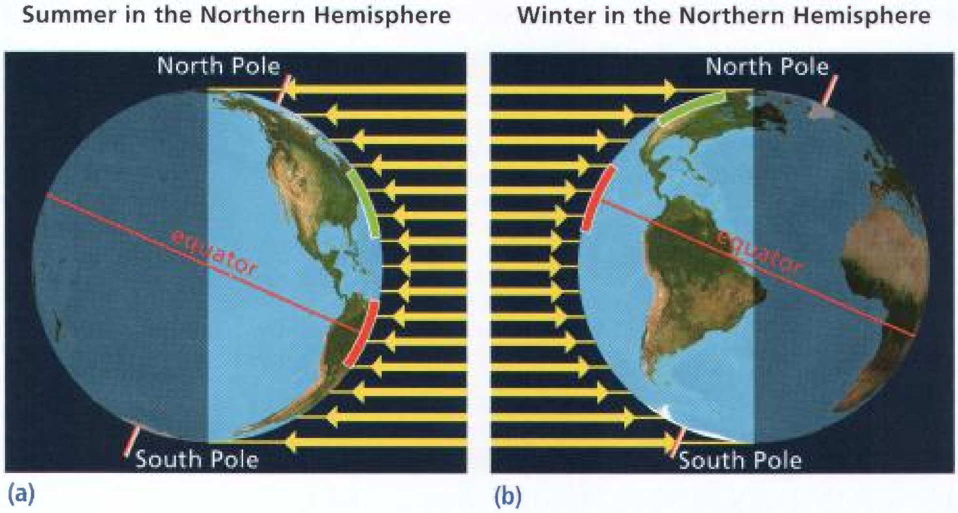


Figure 3 Seasonal differences in the orientation of Earth's tilt influence the angle at which the Sun's rays strike the surface at any given location. During (a) northern summers, more of the Sun's rays strike a given area than they do in (b) the winter.

Land and Sea Breezes

In Chapter 14, you learned that sand and water have very different specific heat capacities. Water warms up much slower and stays warmer longer. This means the air over land and water is influenced by different amounts of thermal energy. You just learned how this creates convection. Let's look at how this creates breezes over water and land.

STUDY TIP

The problem of *when* to study is crucial. A good rule of thumb is that studying should be carried out only when you are rested, alert, and you have planned for it.

Imagine a hot, sunny day. The top surface of the land warms faster than the water's surface. The air above the warmed land receives much more thermal energy than the air over the water. The air over land expands, creating an area of lower pressure. This less dense air rises, as cooler, more dense air from over the water moves in to replace it, creating a **sea breeze** that blows from the sea toward the land (Figure 4a). Sea breezes are usually strongest in the afternoon, after a long day of uneven heating.

Over night, the opposite happens. The thin layer of warmed soil cools much faster than the water. This creates higher pressure air over the land and lower pressure air over the water, which starts to rise. A **land breeze** is created as the more dense air from over the land replaces the less dense air over the water (Figure 4b). Land breezes are generally weaker than sea breezes because the temperature difference between land and water is smaller at night.

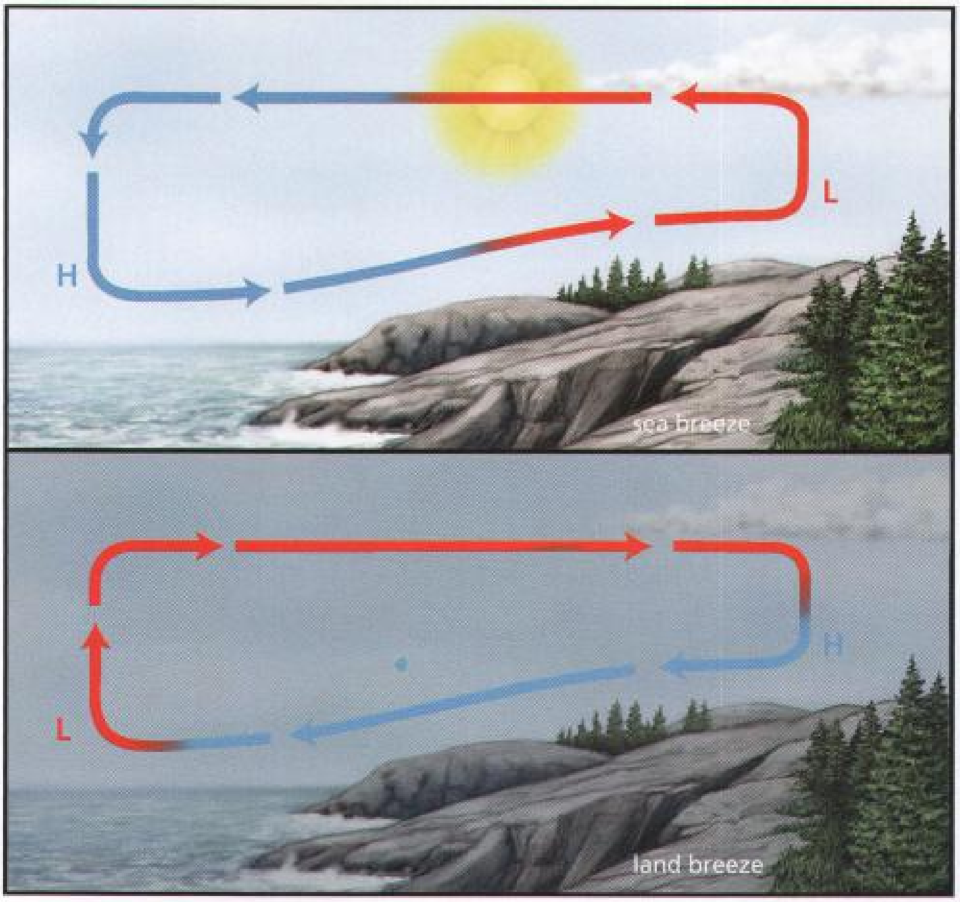


Figure 4 Sea breezes occur when air rushes in from over the water, displacing and lifting the less dense low-pressure air over the hot land. Land breezes occur at night as air cools over land, creating high pressure. The denser air produces a region of high pressure that pushes out over the water.

Figure 5 Funnel clouds and tornadoes form when cold air masses meet very hot, humid air masses.

Tornadoes

A tornado can result when a very hot, humid air mass at the surface is covered by a cooler, dryer air mass above (Figure 5). A **tornado** is a rapidly rotating wind that forms within a thunderstorm. Most tornadoes are 100 to 600 m in diameter, with wind speeds of 125 to 400 km/h. Tornadoes are generally short-lived, lasting only a few minutes but travelling 5 to 8 km. In this brief lifespan, tornadoes release huge amounts of energy.

15.2 CHECK YOUR Understanding

1. Indicate whether each sentence is true or false. If false, rewrite the sentence to make it true.
   (a) Locations near the equator are much closer to the Sun than locations near the poles.
   (b) Our winter is colder in part because the hours of daylight are shorter during the winter months.
   (c) The angle at which the Sun's rays strike Earth has the greatest influence on the temperatures experienced at different latitudes.
2. Copy Figure 6 into your notebook. Add details to show the influence of the Sun's rays on a region in the southern hemisphere during its summer season.

Figure 6

3. Is there any location on Earth that is not influenced by Earth's tilt? Explain.
4. How does Antarctica's location help make it the coldest region on Earth?
5. How might the angle of sunlight striking Earth influence the positioning of solar panels?
6. At higher altitudes, air pressure decreases mainly because
   A. temperature increases.
   B. air particles are closer together.
   C. air particles are moving slower.
   D. there is less air pushing down from above.
7. Draw labelled diagrams to show the formation of land and sea breezes along a coast. Label the time of day during which they occur.
8. Would a sea breeze be more pronounced over a large area of white sand or over a large area of dark soil? Explain your reasoning.
9. Under what weather conditions would a land breeze be strongest?
   A. clear night
   B. extreme cold
   C. bright sunny day
   D. cloudy conditions
10. At night, large bodies of water begin to cool down. Why does the air above them begin to rise?
11. Land breezes are wind that flows from the land toward a large water body because
    A. warm air over the land expands outwards over the water.
    B. water absorbs thermal energy from the air, drawing in air from over the land.
    C. cooler air over the water is rising, pulling in air from over the land to replace it.
    D. cooler dense air over the land pushes under the less dense warm air above the water.
12. A tornado is a rapidly rotating wind that forms
    A. within an intense thunderstorm.
    B. between two storms that collide.
    C. where air is forced to rise over mountain ranges.
    D. as air moves from a region of low pressure to a region of high pressure.
13. During what seasons are the North and South Poles the same distance from the Sun?
    A. spring and fall
    B. fall and winter
    C. winter and spring
    D. summer and winter

15.3 Global Patterns of Wind and Water

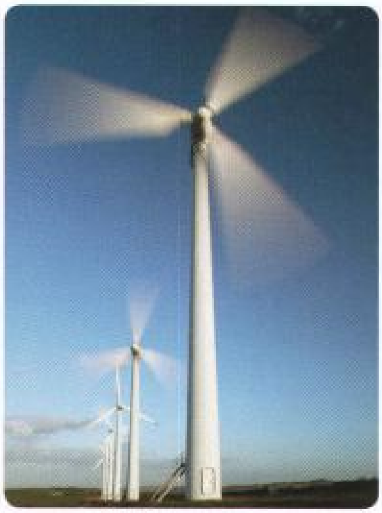


Figure 1 Wind turbines convert the energy from wind into another form of usable energy, usually electricity.

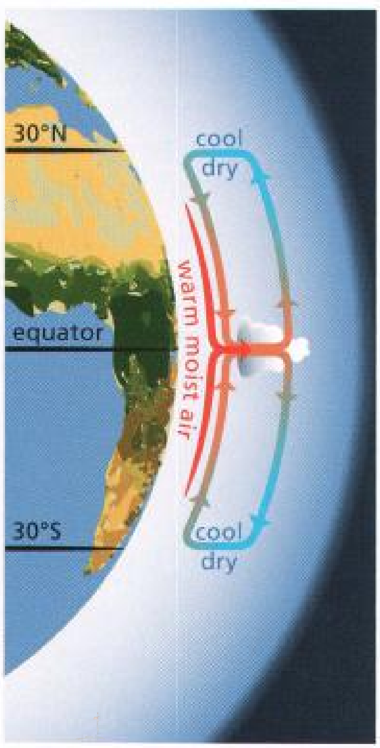


Figure 2 The consistently high temperatures generated at the equator power the Hadley cells. The resulting prevailing winds are both strong and persistent. (Note: the thickness of the atmosphere is greatly exaggerated.)

Wind power is becoming an increasingly popular choice for generating energy (Figure 1). It is economical and has fewer adverse environmental impacts than some other methods. The Canadian government is considering a proposal to build a wind-powered electrical generating facility on the northern end of Vancouver Island. According to the Canadian government, this site has the best wind energy potential in the world. Why is northern Vancouver Island windier than other locations along the coast or inland?

Prevailing Wind Patterns

Prevailing winds move between extensive bands of high and low pressure produced by convection currents. Uneven heating of Earth's surface by the Sun causes two large-scale convection currents, called Hadley cells, to form north and south of the equator (Figure 2). Earth's rotation is not responsible for most air movement or wind. However, Earth's rotation does affect the direction of the **prevailing winds**, winds that blow in a consistent pattern over large portions of the globe (such as easterlies and westerlies). Note that it is the convention to name winds for the general direction from which they originate, not the direction in which they are heading.

The greatest heating of Earth's surface occurs between 30°N and 30°S latitude and is most pronounced at the equator because the Sun's rays are striking the surface nearly perpendicularly. The air circling Earth in this region warms, expands, and becomes less dense, creating a band of lower air pressure at sea level near the equator. This now buoyant, less dense air is lifted by cooler, denser air moving in underneath from both the north and south. This creates a consistent pattern of prevailing winds moving toward the equator. Note that as the air moves toward the equator, it also moves in a westerly direction (Figure 3). This apparent change in wind direction is produced by the Coriolis effect, which we will discuss shortly.

As the air rises, a number of changes take place: the air cools, water vapour condenses, and precipitation results. Near the top of the troposphere, the rising air reaches the temperature of the surrounding air. It stops rising but is pushed aside by the air welling up from directly below. It is forced to move north and south at high altitudes. At these altitudes, the air radiates more thermal energy than it receives, so it continues to cool and condense. By the time these air masses have reached 30°N and 30°S, they have become denser than the air below them, and they begin to sink toward Earth's surface. This creates a band of higher pressure at 30°N and 30°S latitude. As air masses sink, they become warmer and experience little or no cloud formation.

Figure 3 illustrates the average pattern of major convection currents and the prevailing winds that occur from pole to pole.

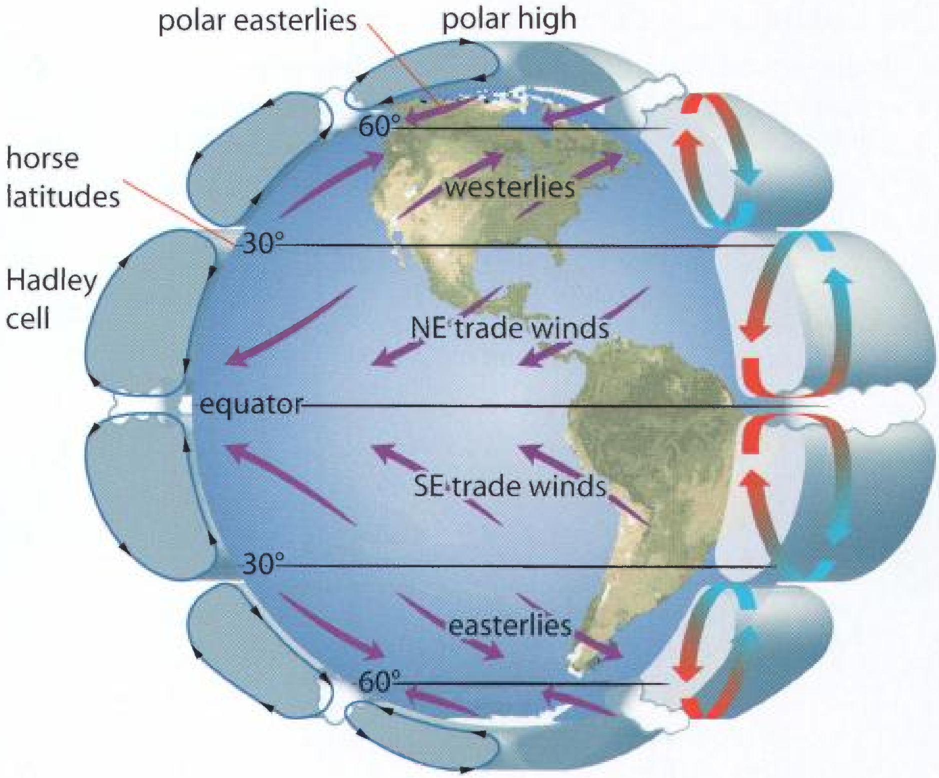


Figure 3 The major patterns of prevailing winds at Earth's surface. Note that these surface winds are produced by corresponding convection cells in the atmosphere.

Prevailing winds are caused by convection currents produced by high- and low-pressure systems. In the northern hemisphere, some of the descending air from the Hadley cells is deflected northward at 30°N, away from the high-pressure area. As the air moves north, it absorbs thermal energy from Earth's surface. At about 60°N, the air meets an air mass approaching from the North Pole. They interact, forcing the warmer air upward. This creates another ring of low pressure circling Earth. The rising air cools and, similar to the convection flow above the equator, reaches the top of the troposphere and spreads north and south.

As the prevailing surface winds move from 30° to 60° latitude, they deflect to the right and become the westerlies.

Above the North Pole, the air is very cold and dense. With almost no source of thermal energy, the air continues to cool and sink, creating a high-pressure area at the pole. The surface air spreads out, moving southward and at the same time curves, or deflects, to the right, creating the polar easterlies. GO

To test your knowledge on global air circulation patterns, go to **www.science.nelson.com**

To learn more about global air circulation, go to **www.science.nelson.com** GO

The Jet Streams

Prevailing wind flows also occur in the upper atmosphere. Although we do not feel these winds directly, they influence weather patterns and airplane routes. Jet streams are narrow bands of high-speed westerly winds that occur near the top of the troposphere (8 to 14 km above Earth's surface) along the boundaries between global air masses (Figure 4). They are 50 to 150 km wide, 2 to 4 km thick, and can be a few thousand kilometres long. Wind speeds in the jet streams can reach 400 km/h, but they are normally between 100 and 200 km/h.

Figure 4 A wavy west-to-east boundary forms where cold polar and warmer midlatitude air masses meet.

The Coriolis Effect

In the discussions above, we noted that some winds change direction as they move north or south. This is due to the **Coriolis effect**, named after the French scientist who discovered it, Gaspard-Gustave Coriolis. This concept explains a moving object's apparent change in horizontal direction due to the rotation of Earth. The hurricane in Figure 5 is rotating in a counterclockwise direction due to the Coriolis effect. This happens because of differences in ground speeds at different points on Earth — a difference in speed we don't feel.

Figure 5 Viewed from above, the winds around this powerful northern latitude hurricane spiral counterclockwise toward the centre of the low.

Did You KNOW?

Flushing an Urban Myth

Bart Simpson once called Australia to ask which way the water turned down the drain there. While the Coriolis effect does influence moving water, you would only notice it in a much larger body. The shape of the sink or even the slightest motion would drastically overpower the Coriolis effect.

In Figure 6, person A at the equator is spinning east with the Earth at 1670 km/h, but feels as if she is standing still. Person B at 60° north of the equator is travelling east with the Earth at 835 km/h, but also feels as if he is standing still. They both throw a ball directly toward each other. While the balls will move northward or southward, they will also *both* be moving east at the same speed as the person who threw them — like throwing a ball from a moving car.

From the perspective of the girl at A1, the ball will travel north as well as travelling east at 1670 km/h, the same speed the girl is travelling east. The path of the ball is shown by the green arrow in Figure 6. Because the circumference of Earth decreases as the ball moves north, and because of the curvature of Earth, the ball moves ahead of girl A. By the time Earth spins to bring the girl to position A2, it will look to her as if the ball followed the yellow arrow. The same is true for the ball thrown by the boy at position B; both balls have curved (been deflected) to the right from the perspective of the person who threw them.

This Coriolis effect alters the movements within the atmosphere and hydrosphere in both the northern and southern hemispheres. In the northern hemisphere, fluids are deflected right of their direction of travel. In the southern hemisphere, they are deflected left of their direction of travel.

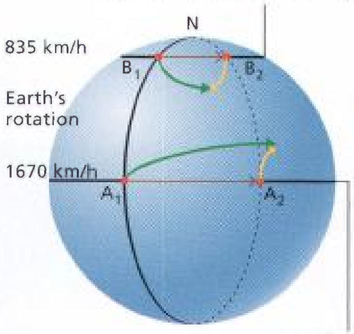


Figure 6 Objects moving straight north or south are deflected to the right in the northern hemisphere, because of the differences in ground speed beneath them.

The Coriolis effect plays a critical role in air circulation around regions of low and high pressure. While studying Figure 7, keep in mind that air moves away from high pressure areas and toward low pressure areas. Compare Figure 7 to Figure 3, on page 441. Notice how the Coriolis effect matches prevailing wind patterns.

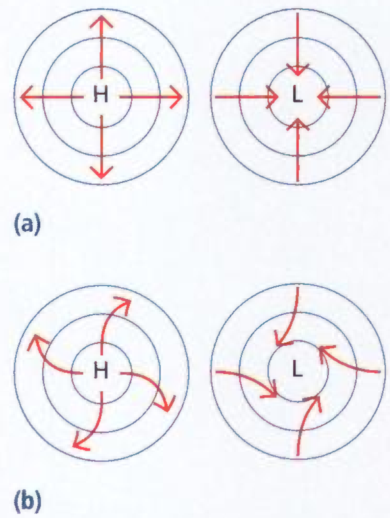


Figure 7 (a) Without the Coriolis effect, air would be expected to move from a high-pressure region directly toward a low-pressure region. (b) The Coriolis effect causes a clockwise rotation around a high and a counterclockwise rotation around a low in the northern hemisphere.

Major Ocean Currents

Similar to the prevailing winds in the atmosphere, oceans exhibit predictable and consistent global currents. However, unlike air masses, which have a very low heat capacity, the ocean has a tremendous ability to store and transport thermal energy. As a result, ocean currents dramatically influence climate patterns around the world. Tropical ocean waters are warmed by the Sun's energy, and then move toward the poles carrying this stored thermal energy. These warm waters increase the temperature of the air above them and have enhanced rates of evaporation. Air blowing over warm ocean waters becomes warm and moist, and can produce mild, wet conditions when it moves over land.

Conversely, cold ocean waters moving toward the equator can reduce air temperatures and evaporation rates. Air passing over these waters may be cool and dry, and yield little or no precipitation if it then moves over land.

Causes of Ocean Currents

Prevailing winds are the major driving forces behind ocean currents. Just like blowing on the surface water in a glass, friction between winds and the ocean surface produces surface flows. Even with relatively small frictional forces, these steady winds, blowing unimpeded across the ocean's surface for thousands of kilometres, produce strong currents.

Ocean current circulation patterns are also influenced by greater heating of water near the equator. This creates convection currents as the warming water expands and becomes less dense. Cooler, denser water from higher latitudes moves in under the warmer water and pushes it up and toward the poles. The strength of these convection currents is limited by the relatively small changes in density produced by heating.

Near the equator, the easterly trade winds produce ocean currents that move from east to west. In the north and south, westerlies drive ocean currents to the east and toward the poles. In addition, moving water experiences the same Coriolis effect as moving air. This further enhances the motions produced by prevailing winds.

For more information on prevailing winds and their effect on ocean currents, go to **www.science.nelson.com**

Since the world's oceans are all connected, water is being circulated around the world. Ocean currents are diverted when they reach a physical obstacle, such as a coastline. When west-flowing equatorial currents strike major landmasses, they are turned north or south. As they get farther from the equator, they come under the influence of the westerlies and are pushed eastward. In the Atlantic Ocean, the Gulf Stream Current moves up the eastern coast of North America, and then across the north Atlantic toward Europe. In the Pacific Ocean, the strong Kuroshio Current flows north and then east, eventually reaching the west coasts of Canada and the United States. Only one ocean current, the Antarctic Circumpolar Current, travels all the way around the world, with no continents in the way (Figure 8).

Water moving from one part of an ocean to another, or from one ocean to another, must return. Currents in the upper layers of the oceans are driven by wind. However, there are also deep ocean currents flowing thousands of metres below the surface. These ocean currents are caused by differences in the water's density due to temperature and salt concentration (salinity).

Salinity at the poles increases because salt is left behind when ice forms. Warmer water then flows in to replace the sinking cold salty water, forming deep currents. Together with surface currents, this global circulation acts as a conveyor belt, carrying thermal energy from the equator to the poles.

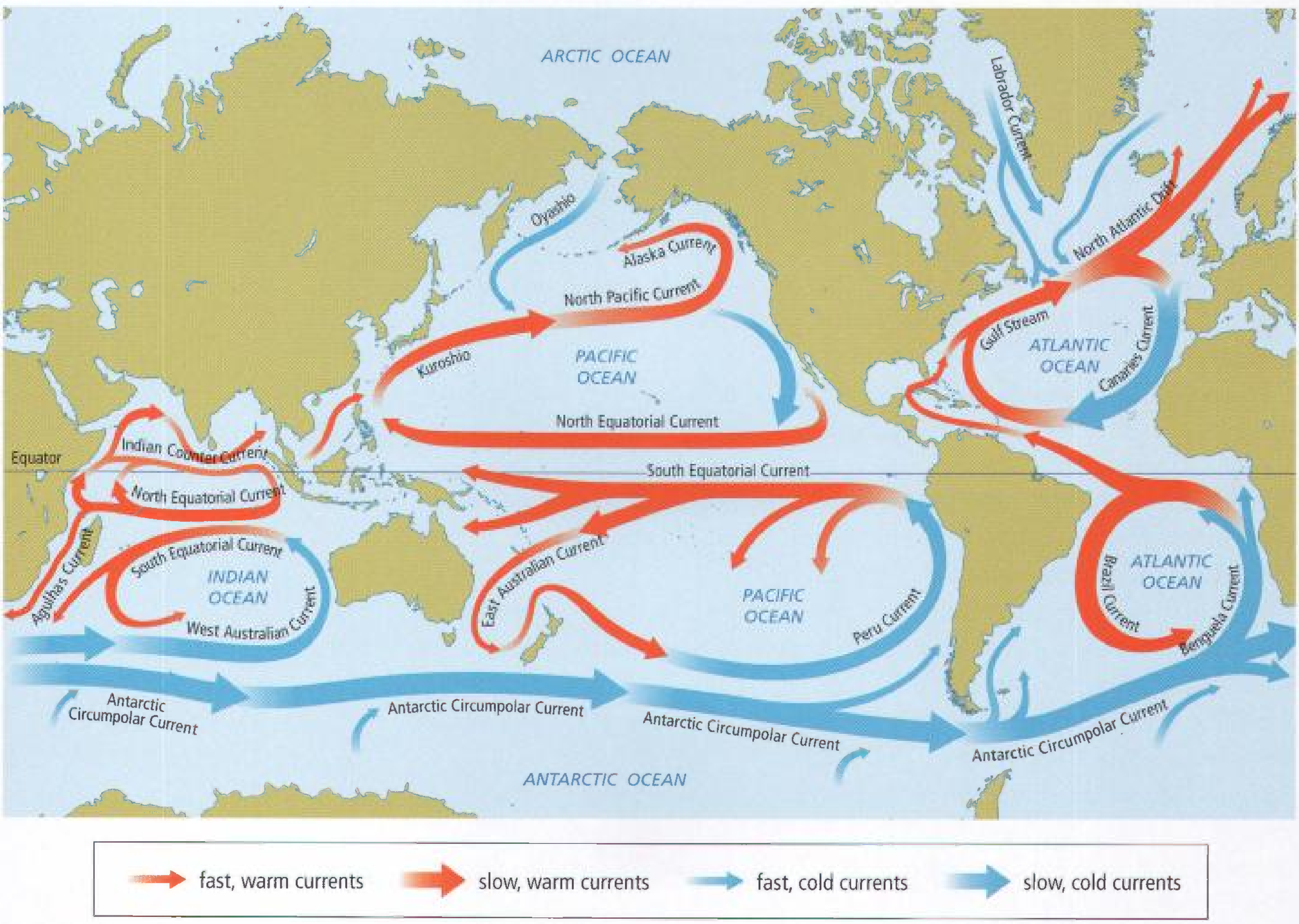


Figure 8 The major warm and cold ocean currents in the world. Compare the directions of the ocean currents with the directions of the major winds in Figure 3, on page 441.

Effects of Ocean Currents

The oceans act as huge thermal energy sinks because water has a high capacity to store thermal energy. As water absorbs solar energy, it takes a long time to warm up. However, once it is warm, the water takes a long time to cool down again. These properties have an important affect on both global climatic patterns and conditions.

In the northern hemisphere, as warm currents move northward, thermal energy transfer occurs with the air. The Gulf Stream, for example, begins in the Gulf of Mexico and follows the east coast of the United States. Water evaporates from the ocean surface, adding both moisture and thermal energy to the air above. This affects both the path and the intensity of tropical storms in the Caribbean (Figure 9).

Did You KNOW?

World's Strongest Currents

The strongest currents in the world are the Nakwakto Rapids, Slingsby Channel, British Columbia, near Queen Charlotte Strait, where the current can flow as fast as 30 km/h.

To learn about the tools scientists use to predict a hurricane's path, watch the video at **www.science.nelson.com**

Figure 9 The path of this hurricane (shown here at three different positions over a period of time) is influenced by both the prevailing winds and the warm Gulf Stream Current below it.

The warm Gulf Stream and Alaska currents illustrate the dramatic effect of ocean currents. Both northern Europe and the western coasts of British Columbia and Alaska experience mild, wet winters. By comparison, Winnipeg, Manitoba, is much farther south than either England or the Haida Gwaii, but has bitterly cold dry winter temperatures.

Because of the moderating effect of the oceans, coastal regions do not experience the extreme temperature variations that are typical of inland climates. On the east coast of Canada, the Grand Banks off Newfoundland and Labrador are influenced by the much colder, southern flowing Labrador Current. The warm, moist air over the Gulf Stream meeting the cold, dry air over the Labrador Current produces some of the foggiest conditions in the world. The Gulf Stream continues across the Atlantic Ocean, and causes the mild, wet winters of western European countries.

Conversely, the ocean current that reaches Peru in western South America is cold, so the air above it is dry. Therefore, the coast of Peru is cool and dry, which helps create the Atacama Desert beside the Pacific Ocean.

In Chapter 16, you will learn about the wide-ranging effects that are experienced when these ocean currents change, such as during an El Niño event.

STUDY TIP

Before you begin to study for an important exam, prioritize! Use the questions found at the end of each chapter in your student book as a way of evaluating what you know and what you need to study. Make up questions from your notes to help you predict what kinds of questions may be on the exam. Draw simple pictures to help you visualize complex processes or relationships.

15.3 CHECK YOUR Understanding

1. What are prevailing winds? In which general direction do prevailing winds flow between latitudes 30°N and 60°N?
2. (a) What is the convention for naming winds?
   (b) In which direction is a northerly wind blowing?
3. Explain the formation and characteristics of the Hadley cells at the equator. Include references to air pressure and prevailing winds.
4. How does the formation of Hadley cells influence the rainfall patterns near the equator and at latitudes 30°N and 30°S?
5. Indicate whether each sentence is true or false. If false, rewrite the sentence to make it true.
   (a) Most winds are caused by Earth's rotation.
   (b) Prevailing winds always move from regions of high pressure to regions of low pressure.
   (c) In the northern hemisphere, prevailing winds tend to twist to the right.
   (d) Ocean currents are not influenced by prevailing winds.
   (e) In the southern hemisphere, the Coriolis effect causes winds to turn counterclockwise around high-pressure systems.
   (f) The Coriolis effect influences winds but has no effect on moving water.
6. Did the hurricane in Figure 10 form in the northern or southern hemisphere? How do you know?

Figure 10

7. Clearly explain how each of the following factors influences the formation and paths of major ocean currents:
   (a) prevailing winds
   (b) convection
   (c) position of the continents
8. If you were flying from Tokyo, Japan, to Vancouver, B.C., what could you do to minimize the time required to make the flight?
9. Carefully examine the pattern of ocean currents in Figure 8 on page 444. List the currents that are travelling in the same direction as the prevailing winds above them.
10. Ocean currents are sometimes described as "conveyor belts" of energy. Explain what this means and why the same phrase is not used to describe winds.
11. Early European explorers had the choice of circumnavigating Earth from east to west or from west to east. Describe how their decision would have been influenced by both the directions and locations of prevailing winds.
12. Victoria, B.C., and Thunder Bay, ON, are located at the same latitude, but the average January and average July temperatures are very different (Table 1). Explain why.

Table 1

Location	January average temperature	July average temperature
Victoria, B.C. (48°N)	3 °C	16 °C
Thunder Bay, ON (48°N)	−14 °C	18 °C

13. Why is the northern tip of Vancouver Island a good site for a wind farm? What makes its location superior to a location at the same latitude on the Atlantic coast of North America?
14. What causes hurricanes in the tropical regions of the Atlantic ocean to move in a westerly direction?

CANADA'S FIRST MISSION TO MARS!

How was the weather?

The Phoenix Mars Lander *was launched on August 4, 2007, and is scheduled to land on Mars on May 25, 2008.* Phoenix *is delivering a high-tech weather station, the first-ever Canadian instruments to land on another planet.*

Phoenix's mission is to gain a better understanding of the present and past roles of water on the surface of Mars. This will help answer the questions of whether life exists or has ever existed on the planet, and how current conditions might influence options for future human exploration of the planet.

There is no liquid water on the Martian surface. However, large quantities of water exist as ice at the poles, and there is some water vapour in the thin atmosphere. Evidence from other missions indicates that liquid water once flowed on the surface. *Phoenix* will land at latitude 68°N, near the northern polar cap, where there are high concentrations of ice just below the surface.

To fully understand the actions of water on Mars, mission scientists require an understanding of the weather conditions on the planet. Canada's multi-instrument meteorological station (MET) will be monitoring both daily weather conditions and seasonal climate changes. An array of sophisticated sensors will monitor temperature, wind speed, atmospheric pressure, and cloud conditions, and send the data back to Earth. Even though the mission is taking place during the Martian spring and summer, the daily highs are only expected to reach about −11 °C, and the nighttime lows are expected to drop into the −100 °C range!

The MET includes a special laser instrument called the "light detection and ranging" tool, or LIDAR, which will monitor ice and dust cloud formation above the planet's surface (Figure 1).

The MET's LIDAR technology is similar to radar, but rather than emitting radio waves, LIDAR produces much shorter wavelengths in the ultraviolet, visible, and near infrared part of the spectrum. This allows LIDAR to detect much smaller particles than radar instruments, enabling LIDAR to reveal very fine dust and cloud particles. This allows scientists to learn how energy flows within the polar atmosphere. The 40 W LIDAR laser beam is capable of reaching 20 km into the Martian atmosphere. By turning LIDAR on for 15 min, four times a day, the team of Canadian scientists hopes to learn what time of day clouds begin to form and at what altitudes. In addition, the MET will enhance scientists' understanding of the planet's atmospheric processes.

It is important to appreciate the significant technological challenges of space exploration. Only five of the previous 15 NASA missions to Mars have been successful. The others have failed due to technical malfunctions, unsuccessful launches or landings, human error, or unknown causes.

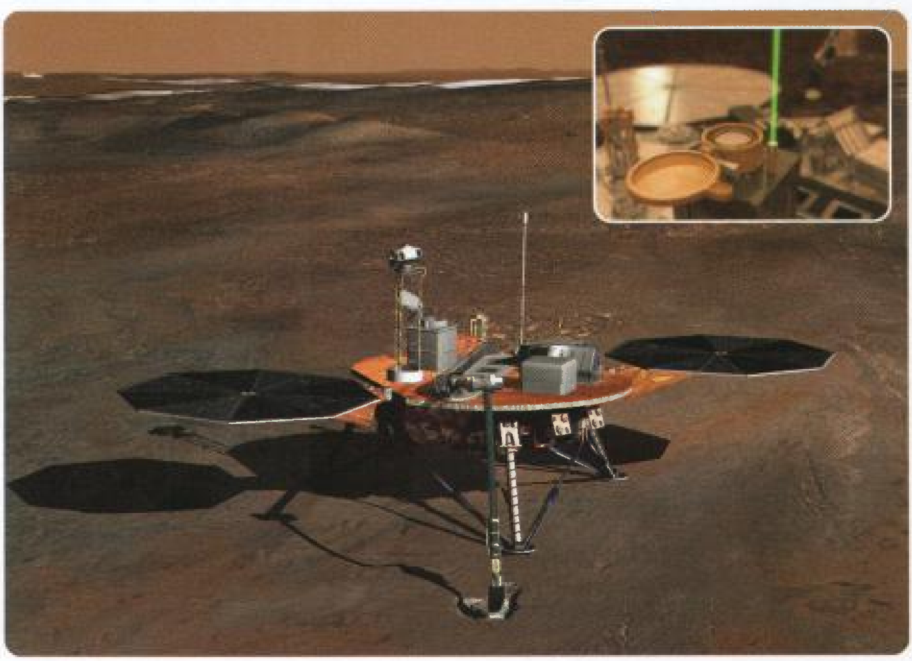


Figure 1 Artist's rendition of the *Phoenix Mars Lander*. Inset: the LIDAR unit is about the size of a shoebox and weighs only 5 kg.

15A Investigation

Comparing Light Intensity

The angle at which the Sun's rays strike the surface is influenced by the curvature of Earth's surface and the tilt of Earth's axis. In general, the rays of the Sun that strike Earth near the equator are closer to being perpendicular to the surface than those striking Earth nearer the poles. In this investigation, you will examine how such different angles influence the amount of light and, therefore, the energy that can be absorbed by the surface.

Figure 1 These solar panels change orientation throughout the day to capture the most sunlight.

Question

How does the angle or orientation of a surface to a light source influence the amount of light that strikes the surface?

Experimental Design

In Part A, you will compare the intensity of light per square centimetre striking an object when oriented at different angles to a light source. In Part B, you will compare the intensity of light striking the surface of a solar panel when oriented at different angles to a light source.

Do not look directly at the bright light source.

INQUIRY SKILLS

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

Materials

- overhead projector or other bright directional light source
- 20 cm × 20 cm piece of stiff paper or cardboard
- metre stick or tape measure
- photovoltaic cell panel
- voltmeter
- protractor

Procedure

Part A

1. Copy Table 1 into your notebook. Use this data table to record your observations during Part A.

Table 1

Angle of panel from vertical	Shadow dimensions	Area
0°		
45°		

2. Shine the projector on the wall at a distance of 3 to 4 m. This is best done in a darkened room.
3. Hold a piece of cardboard 1 m from the wall and at right angles to the light beam (parallel to the wall, or 0° from vertical).
4. While holding the cardboard in position, measure the dimensions of the shadow that it casts on the wall.
5. Calculate the area of the shadow. This area represents the light energy that has been blocked and absorbed (or reflected) by the cardboard. Record this in your data table.

6. Tilt the cardboard so that it is at a 45° angle to the light beam and the wall.
7. Measure the new shadow cast by the cardboard.
8. Calculate the area of the new shadow.

Part B

9. Copy Table 2 into your notebook. Use this data table to record your observations during Part B.

Table 2

Angle of panel from vertical	Voltage reading
0°	
15°	
30°	
45°	
60°	
75°	

10. Connect a photovoltaic cell panel to a voltmeter, and hold the panel in a vertical position.
11. Aim a strong light source at the panel so that the light beam strikes the panel perpendicularly, or 90° from vertical. Adjust the distance to produce a fairly high reading on the voltmeter. Record the distance to the centre of the panel, and the reading on the voltmeter.
12. Tilt the angle of the panel so that it is 15° from the vertical. Ensure that the distance from the centre of the panel to the light source has not changed. Measure and record the new voltage.
13. Repeat Step 12, tilting the panel by 30°, 45°, 60°, and finally 75° from the vertical.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) For Part A, what latitude was modelled by holding the cardboard perpendicular to the light beam? At a 45° angle to the light beam?

(b) What area of light was blocked by the cardboard at 0°? At 45°?

(c) How might the angle of the surface influence its ability to reflect light rays?

(d) For Part B, what latitude was modelled by holding the panel perpendicular to the light beam? What was the voltage reading?

(e) Plot a graph of the voltage output versus the angle of the panel.

(f) What relationship exists between the angle and the output voltage?

(g) What does this relationship suggest about the angle at which a light source strikes a surface and the energy being absorbed?

Evaluation

(h) Compare your results from Parts A and B. Did the results agree with each other?

(i) Which experimental design do you think provided the best or most convincing results? Explain your reasoning.

Synthesis

(j) How might your results be used when considering the installation of rooftop solar panels?

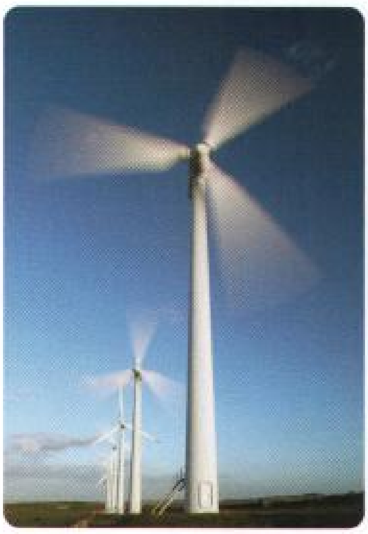
CHAPTER 15 Review

Transfer of Energy on Earth

Key Ideas

Atmospheric pressure results from gravity and the force of the atmosphere pushing down on itself.

- The force of gravity causes the atmosphere to exert significant pressure at Earth's surface.
- The average atmospheric pressure at sea level is 101.3 kPa, which is equivalent to the weight of 10 000 kg of air per square metre.
- Atmospheric pressure decreases the higher up in the atmosphere you go. Because the atmosphere is gaseous, air closest to the surface is the most compressed and is denser than air at higher altitudes.



Uneven heating of air produces differences in density and air pressure.

- Air expands as it is heated, resulting in less dense, warm air with lower atmospheric pressure.
- Warmer, less dense air floats up through surrounding cooler, denser air which flows in underneath the rising air.
- Water vapour condenses to form clouds as air rises and cools.
- As a sinking air mass warms, it can hold more water. Clouds dissipate, producing clear skies and drying winds.
- Low-pressure cells contain warm, rising air with clouds and precipitation.
- High-pressure cells contain cool, falling air with little moisture.

Vocabulary

atmospheric pressure, p. 431
kilopascal, p. 431
low-pressure cell, p. 433
high-pressure cell, p. 433
isobar, p. 433
sea breeze, p. 438
land breeze, p. 438
tornado, p. 438
prevailing winds, p. 440
Coriolis effect, p. 442

Wind results when air in high pressure regions moves toward regions with lower air pressure.

- Land and sea breezes form near large bodies of water due to the differences in heating of the air over water and land.
- The Coriolis effect causes fluids to deflect to the right in the northern hemisphere and left of their path of motion in the southern hemisphere.
- The intense heating of equatorial surface air creates powerful Hadley convection cells.

Latitude and landscape influence the absorption of incoming solar radiation.

- When the northern hemisphere is tilted away from the Sun, locations farther north of the equator receive less radiant energy because of the lower angle at which the Sun's rays strike the surface.
- Different substances (such as soil and water) absorb thermal energy at different rates.
- Water bodies are less reflective than landmasses and absorb the largest fraction of incoming solar radiation.

Global prevailing wind patterns influence ocean currents and the formation of weather systems.

- Additional heating and cooling effects produce convection cells at the poles and midlatitudes. These large-scale convection cells produce the prevailing winds at Earth's surface and the high-altitude jet streams.
- Prevailing winds, landmasses, the Coriolis effect, and changes in water density all influence the direction and pattern of ocean currents.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. Using dots to represent particles of nitrogen, oxygen, and other components of the atmosphere, draw a diagram to show how the spacing between the particles changes as altitude increases.
2. Explain why atmospheric pressure is lower at the top of a mountain than in the valley below.
3. Make a simple labelled drawing to illustrate how a mercury barometer reacts to changes in air pressure.
4. Describe the steps by which uneven surface heating creates differences in air pressure.
5. Copy Table 1 into your notebook, then complete it to compare the characteristics of rising and falling air masses.

Table 1

	Rising air mass	Falling air mass
temperature		
pressure		
movement(s)		

K 6. Why are rising air masses often cloudy, and falling air masses usually clear?
   A. Rising air over water is moist and warming.
   B. Rising air is warmer and can hold more water.
   C. Falling air is warming, so condensation does not occur.
   D. Falling air leaves its water behind in higher, warmer air.

K 7. In which general direction do winds tend to turn in the northern hemisphere?
   A. clockwise
   B. counterclockwise
   C. left of their direction of travel
   D. right of their direction of travel

8. Using a sketch, compare the intensity of light rays from the Sun striking the equator and the Arctic Circle during Canadian winter.
9. Sketch a diagram of Earth to illustrate the patterns of the prevailing winds.
10. Answer the following questions about the atmosphere in the northern hemisphere.
   (a) In which general direction does energy flow?
   (b) In which general direction does warm water flow?

K 11. Which of the following explains why the oceans have a greater influence on north-south energy transfer than the atmosphere does?
   A. There is more water than atmosphere.
   B. Hadley cells keep air contained north to south.
   C. Water has a higher specific heat capacity than air.
   D. Air circulates primarily east-west, not north-south.

12. Are the ocean currents in the southern hemisphere "mirror images" of those in the northern hemisphere? Explain.
13. Describe how convection currents help to maintain the energy balance
   (a) on a global scale in Earth's atmosphere.
   (b) on a global scale in the oceans.
   (c) on a small scale near a lake or seashore.

K 14. A student who lives on the south coast of New Zealand places a message in a bottle, and throws it into the coastal waters. About four years later, another student finds the same bottle floating in the ocean on the coast of Iceland. Use Figure 8 on page 444 to identify which ocean currents would make this possible.
   A. East Australian Current, Peru Current, Gulf Stream, North Atlantic Drift
   B. Antarctic Circumpolar Current, Benguela Current, Gulf Stream, North Atlantic Drift
   C. East Australian Current, Peru Current, South Equatorial Current, North Equatorial Current
   D. Antarctic Circumpolar Current, Peru Current, South Equatorial Current, North Equatorial Current, Kuroshio, Alaska Current

K **15.** Which of the following best describes the air pressure during clear weather with little wind?
- A. low pressure
- B. high pressure
- C. rapidly increasing pressure
- D. rapidly decreasing pressure

Use What You've Learned

U **16.** Why is knowledge of the jet streams important to plane flight?
- A. They create a barrier that planes cannot cross.
- B. They are regions of high turbulence to be avoided.
- C. They create a current that can change flight duration.
- D. They create lanes for air travel, like lanes on the highway.

17. Examine the weather map in Figure 1. Choose any three locations and describe their current weather conditions. Explain your reasoning.

Figure 1

U **18.** On Thursday, you have to decide whether or not to go camping on the weekend. You look at the weather map, and see that there is a high-pressure area west of your destination. What kind of weather do you expect for your trip?
- A. rainy and colder
- B. sunny and colder
- C. rainy and warmer
- D. sunny and warmer

Think Critically

19. The Namib Desert is on the west coast of southern Africa. Explain how this region can be dry, even though it is on the Atlantic Ocean. Consider both the temperature of ocean currents and prevailing wind directions.

20. In British Columbia, Chinook winds are warm and wet and come from the southwest. On the Internet, research the Lil'wat legend of a girl named Chinook-Wind. In your own words, explain the weather pattern illustrated in the legend.

www.science.nelson.com GO

21. Some early balloonists risked their lives to find out more about the atmosphere. Pick two (e.g., James Glaisher and Robert Coxwell from England; Marie Elizabeth Thible and Teisserenc de Bort from France), and research their exploits. Create an illustrated poster about them.

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Reflect On Your Learning

22. The processes that produce weather conditions are complex and challenging to understand and predict. The weather contained in high- and low-pressure air, however is somewhat simpler. Write a paragraph describing how your knowledge of high- and low-pressure air can be used in your day-to-day life.

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

CHAPTER 16

Climate Change

Chapter Preview

Practically every day, we hear media reports about global warming or climate change. They are often difficult to understand, but it is obvious that the news is not good. As often happens in scientific research, we are frequently left with more questions than answers.

What is climate change? Is it the same as global warming? Who is responsible? How quickly is climate change happening? Will everyone on Earth be affected by climate change? Can we stop global warming, and if so, how?

In this chapter, you will explore these and other such issues related to climate change. While you will gain a better understanding of the issues, you may find that there are no clear-cut answers to some of the questions, and your explorations may raise even more questions.

KEY IDEAS

- There is abundant scientific evidence and much agreement in the scientific community that Earth is warming up as a result of global climate change.
- Both natural phenomena and human activities contribute to climate change.
- Climate change affects the environment and has serious long-term implications for organisms, their habitats, and society as a whole.
- There is some disagreement in the scientific community on the extent and the consequences of climate change.
- There is a recognized need for humans to slow down or prevent their negative impact on climate change.

TRY THIS: Seeing the Past in a Tree

Skills Focus: observing, measuring, recording, inferring

If you were to examine a cross-section of a tree, you would see rings. Each ring of wood represents a year of the tree's growth. Scientists analyze tree rings to study present and past climates. By studying very old trees, scientists can determine, for example, the annual rainfall before weather records were kept. In this activity, you will examine a photograph of a cross-section of a tree to see evidence of variation in past climatic conditions.

Materials: photograph of tree cross-section, magnifying glass (optional)

1. Your teacher will provide a photograph of a tree cross-section. Carefully examine the rings, using a magnifying glass if necessary.
2. Estimate the age of the tree. Assuming that the tree was cut down this year, in what year did the tree sprout?

A. Make an inference about the relationship between the width of the rings and the annual amount of rainfall.

B. Assuming the tree was cut down this year, identify five years during which the growing conditions were good and five years during which the growing conditions were poor. Describe any observable climate trends reflected in the tree rings.

C. How might examining tree rings be useful in studying climate change?

16.1 What Is Climate Change?

We hear the terms "climate change" and "global warming" almost daily. These phenomena are closely related, but they are not exactly the same. **Climate change** is a shift in long-term average weather patterns. **Global warming** is an increase in the average temperature of Earth's surface and lower atmosphere. Global warming is one part of climate change, which also includes changes in precipitation and the frequency of extreme weather events such as hurricanes and tornadoes.

LEARNING TIP

Critical readers evaluate information as they read. As you read Chapter 16, stop periodically to ask yourself, "Does what I'm reading change any of my ideas about climate change and global warming?"

The Greenhouse Effect

Greenhouses are great places to grow plants because the glass structure lets thermal energy in, then traps it there. Earth's atmosphere does a similar job, a phenomenon called the **greenhouse effect**. Instead of glass, it is the greenhouse gases (GHGs) in the atmosphere that allow solar radiation to pass through to Earth's surface where it is absorbed (Figure 1). As this thermal energy is radiated back out, those same gases absorb and trap it. Thus, the GHGs act like a thermal blanket, keeping Earth's temperature within an acceptable range. Without the greenhouse effect, Earth would be a very different place. Life as we know it would not exist because the average global temperature would be approximately −18 °C instead of the current 15 °C. The greenhouse effect is, in fact, an essential temperature-regulating system.

Unfortunately, the range of temperatures can change in response to changes in GHG concentrations in the atmosphere (Figure 2). When the concentrations increase above normal levels, more heat is trapped, creating an **enhanced greenhouse effect**. This results in increased average global temperatures.

To view a greenhouse gas animation, go to **www.science.nelson.com**

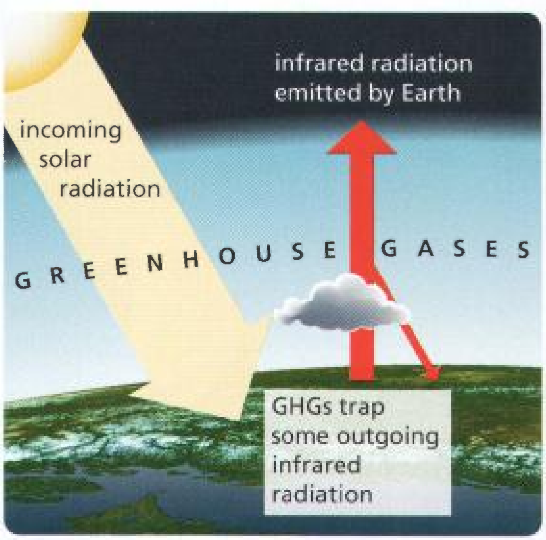


Figure 1 The atmosphere has the same effect as the glass in a greenhouse. It traps the heat radiating from Earth's surface.

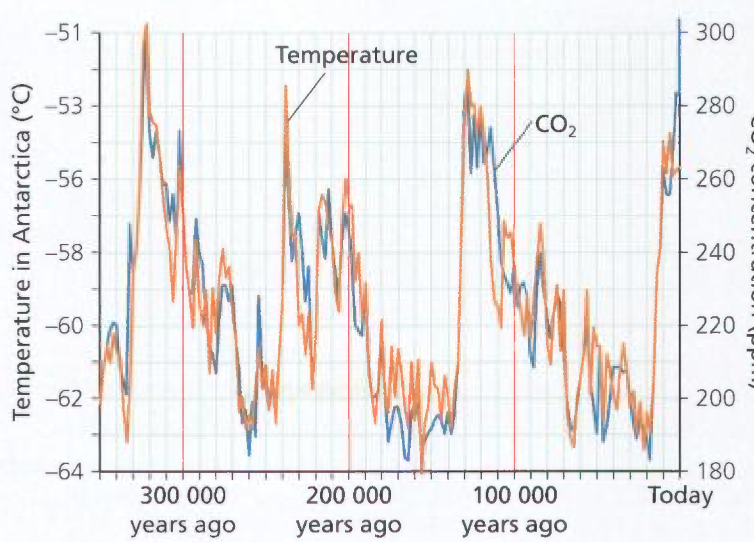


Figure 2 The average annual temperature near the South Pole has varied by more than 13 °C during the past 350 000 years.

Greenhouse Gases

Many natural and synthetic gases contribute to the greenhouse effect (Table 1). These GHGs are all efficient absorbers of heat, but some are better than others. The warming potential of a GHG is standardized against the warming potential of CO_2. For example, the warming potential of methane is equated to an amount of CO_2 that would trap an equivalent amount of heat, and is measured in tonnes (or kilotonnes) of **carbon dioxide equivalent**, or **CO_2 eq**. Methane absorbs 21 times as much heat as carbon dioxide does, so 1 t of methane is equivalent to 21 t of CO_2, or 21 t CO_2 eq.

Table 1 Sources of Major GHGs

GHG	Natural sources	Sources related to human activities
water vapour, $H_2O(g)$	• evaporation and transpiration processes that are part of the water cycle	• combustion of fossil fuels and wood
carbon dioxide, $CO_2(g)$	• plant and animal respiration • decay of organic matter in soil • volcanoes • forest/grass fires • oceans	• combustion of fossil fuels • deforestation • industrial processes, such as cement production and smelting of ores • decay of organic matter in hydro reservoirs
methane, $CH_4(g)$	• decay of organic matter in wetlands • chemical reactions in soil	• cattle farming • rice cultivation • biomass burning • decay of organic matter in landfills and hydro reservoirs • coal mining • combustion of fossil fuels • petroleum refining
nitrous oxide, $N_2O(g)$	• soil and water dentrification under anaerobic conditions	• nitrogen fertilizers
chlorofluorocarbons (CFCs) hydrofluorocarbons (HFCs) perfluorocarbons (PFCs)		• aerosols • refrigeration and air conditioner coolants • solvents (e.g., dry cleaning)

Carbon dioxide is the most significant GHG simply because it is the most abundant in the atmosphere. The main natural sources include the respiration of plants and animals, decomposition of organic matter, volcanoes, forest fires, and the oceans. Methane is the next most important GHG. Methane, once called marsh gas, is produced by bacterial action in the natural decay of organic matter in wetlands, landfills, and hydro reservoirs.

Natural processes remove some GHGs from the atmosphere. For example, water vapour returns to the surface of Earth as precipitation. Vegetation removes carbon dioxide from the atmosphere during photosynthesis. Plants and soil are considered **carbon sinks** because they store carbon for long periods. When natural sources and sinks are in balance, the atmospheric concentration of GHGs is stable.

TRY THIS: *Analyzing Canada's GHGs*

Skills Focus: interpreting data, analyzing, evaluating

The Greenhouse Gas Division of Environment Canada monitors and reports emissions of GHGs from various sources across Canada. In this activity, you will analyze this data.

Materials: handouts of Tables 1 and 2

Table 1: Canada's GHG Emissions by Gas and Sector, 2004

Table 2: Canada's GHG Emission Trends by Sector, 1990–2004

Using Tables 1 and 2

1. Calculate the percentages of each GHG.
2. Calculate the percentage of the total GHG emissions related to the generation of electricity and heat.
3. Identify the source of sulfur hexafluoride emissions.
4. One of the subcategories of agriculture is "enteric fermentation."
   (a) Research this term, and describe this source of GHG.
   (b) What type of GHG is produced in this process?
   (c) What proportion of the total methane emissions comes from this source?
   (d) By what percentage has the emission level of this gas increased since 1990?

A. Which major category of emission sources contributes the most GHGs? What percentage of the total does this represent?

B. Explain the negative values in the Land-Use Change and Forestry category.

C. Identify and describe any significant trends in GHG emissions.

Depletion of the Ozone Layer

One group of synthetic greenhouse gases, the chlorofluorocarbons (CFCs), have another dramatic impact on the atmosphere: they destroy the ozone layer. The **ozone layer** is a layer of ozone (O_3) located about 24 km up in the atmosphere. Even modest thinning of this layer exposes all life on Earth to the Sun's harmful UV radiation.

CFCs are a family of chemical compounds developed in the 1930s as safe, non-toxic, non-flammable substances used in refrigeration, solvents, and spray can propellants. CFCs accumulate in the upper atmosphere, where their chemical breakdown removes ozone from the protective layer. Since CFCs came into use, levels of harmful UV radiation on Earth increased and "holes" developed in the ozone layer over the poles.

LEARNING TIP

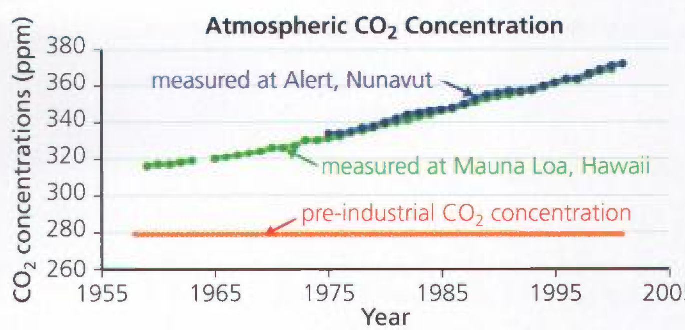
Check your understanding. Explain to a partner the conclusions scientists have reached about CFCs and ozone depletion. In your opinion, what is the main issue or problem?

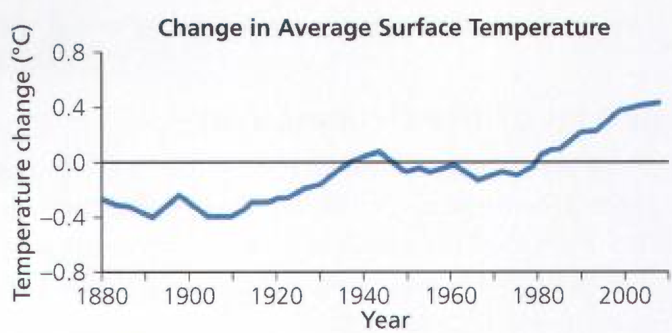
The effect of ozone depletion on climate change is complex. Scientists know that ozone traps heat, so repairing damage to this vital layer may actually enhance global warming. (A tonne of CFC has the same warming effect as 10 000 tonnes of CO_2.) Observations in the late 1900s indicated that the upper atmosphere cooled by 1 to 6 °C. During the same period, the levels of GHGs in the lower atmosphere increased, creating a warming effect. Scientists speculate that the lower atmosphere may be retaining the heat that would normally be warming the upper atmosphere. The processes that destroy ozone speed up at colder temperatures.

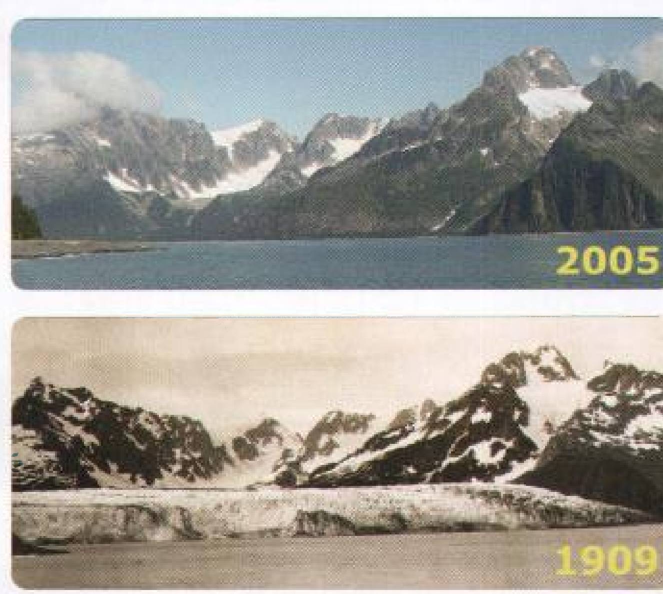
Evidence of Climate Change

Evidence of climate change is found all around the planet. Scientists look for evidence of climate change by analyzing direct evidence (Table 2) and indirect evidence (Table 3) to compare present and past climates.

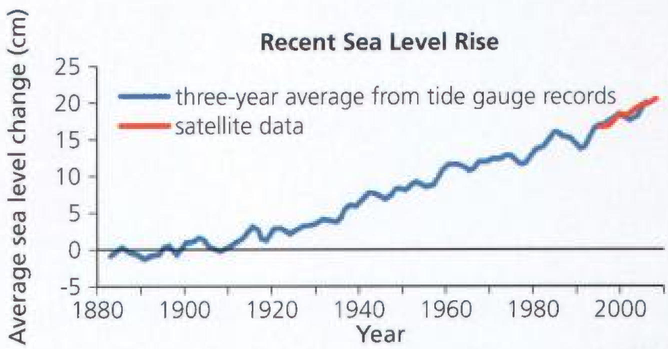
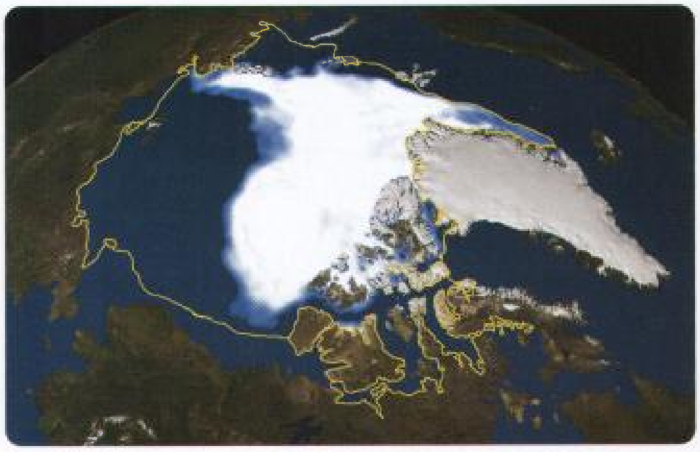
Table 2 Direct Evidence

<table>
<tr><td>Atmospheric CO_2 concentrations
The average levels of atmospheric CO_2 concentrations have been rising steadily since the beginning of the industrial age.</td><td>

Atmospheric CO_2 concentration at Mauna Loa, Hawaii, has been measured since 1958.</td></tr>
<tr><td>Average global temperature
Records since 1880 show that the average global temperature has increased steadily. Knowing that increased levels of the main GHG, CO_2, will enhance the greenhouse effect, we can predict that the average global temperature will continue to rise.</td><td>

Annual variation in global temperature since 1880.</td></tr>
<tr><td>Shrinking glaciers and ice sheets
Direct observations of the end of glaciers and ice sheets allow scientists to determine whether glaciers are growing or receding. Most of the glaciers around the world are receding due mainly to melting during warm summers.</td><td>

These pictures show that this glacier has receded hundreds of metres.</td></tr>
</table>

Permafrost loss The **permafrost** is a permanently frozen subsoil layer up to 1400 m thick beneath almost 25 % of the northern hemisphere. The Arctic permafrost has warmed as much as 3 °C since 1980, and the total permafrost area has decreased by about 7 % since 1900. The southern boundary of the permafrost is expected to recede several hundred kilometres northward by 2100.	 Land collapses when permafrost melts.
Rising sea levels Average sea level has risen over 100 m since the last ice age. Sea level rise results from melting of the ice that covers land and oceans, and also from thermal expansion as the ocean water warms up. Accurate measurements of sea level from satellites have shown that sea level has risen 1 to 3 mm/year since 1990.	 The trend in this graph shows a gradual increase in sea level.
Shrinking Arctic ice Satellite data since 1978 shows that the average sea ice coverage has shrunk 2.7 % per decade. In the summer, it shrinks even faster: 7.4 % per decade. At the current rate, the Arctic Ocean may be ice-free in summer by 2100.	 The yellow line shows there was 20 % more Arctic sea ice in September 1979 when compared to this photo taken in September 2005.

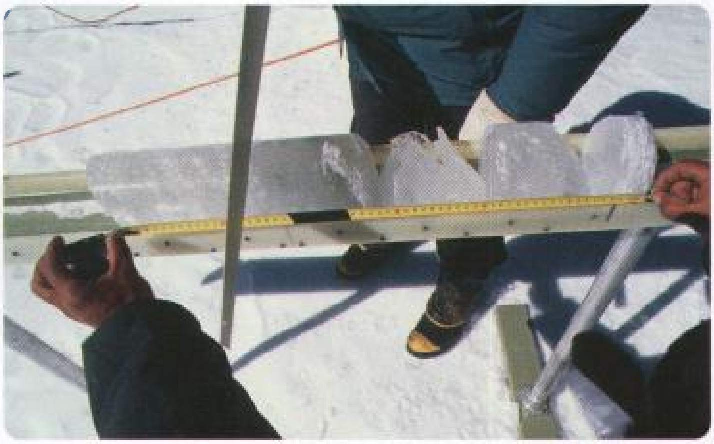
LEARNING TIP

Skim Table 3 to get a general sense of what it shows. Read the text near each image to find an explanation for the information in the figure. Study the images carefully to see if you recognize the details of the image.

Is climate change a natural Earth process? Certainly, but it seems to be happening faster now. Direct observations and measurements of climate are limited to the past 100 years or so. This timeframe is too short to determine whether the current climatic trends are part of a long-term natural variation or a rapid change. To find out, we need to compare the recent climate to the climate thousands of years ago. The study of earlier climates, called paleoclimatology, relies on indirect evidence.

Layers in nature provide a rich record of past climate conditions. The rings of a tree, layers of ice in a glacier, sediments on a lake bottom, a coral's growth rings—all of these reflect the climate conditions at the time they were created. Paleoclimatologists use information from sources such as these as evidence of variations in past climates (Table 3). To access the information trapped in these layers, scientists drill through and remove a cylindrical core sample.

Table 3 Indirect Evidence

Tree rings Analysis of tree growth rings can indicate the temperature and precipitation during the period represented by the rings. The narrow, darker line represents the period of the year when tree growth is slowed or stopped (winter). The lighter coloured, wider ring is wood built up during the growing season.	 Favourable weather results in more growth and, therefore, a thicker ring.
Ice cores Tiny particles of dust, volcanic ash, smoke, or pollen are trapped in snow crystals that fall and accumulate in layers on mountains and polar ice caps over thousands of years. Air bubbles also become trapped as the snow is packed down to become ice. Analysis of these particles provides a picture of the environmental conditions at the time the snow fell. Chemical analysis of trapped air bubbles reveals the levels of CO_2 and other GHGs in the atmosphere at the time.	 The ice in this core was formed during the last ice age, which ended 10 000 years ago.

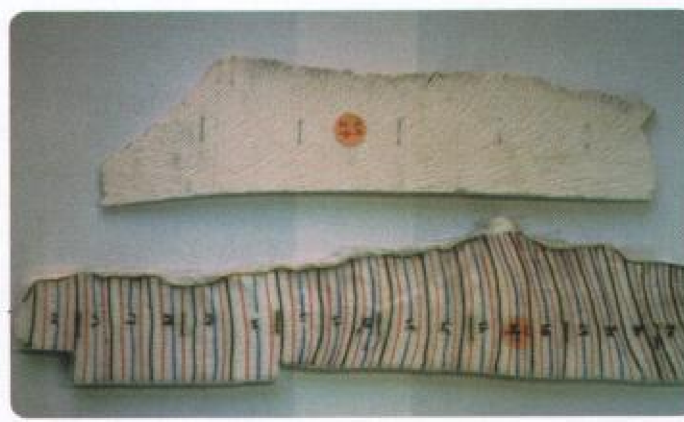
Sediments

Billions of tonnes of sediments accumulate on ocean floors and lake beds each year. As new material settles on top of old material, a vertical timeline is established. Analysis of sediment layers can reveal the rate of sedimentation. A thick layer would indicate a period of heavy sedimentation, caused by erosion during periods of high precipitation and runoff. A thin layer would suggest a period of low precipitation and little erosion.

This vertical sediment core is extruded into slices which correspond to discrete time intervals.

Coral rings

The shells of corals show seasonal bands of growth similar to the growth rings observed in trees. The coral skeleton formed in the summer is thicker and has a higher density than that formed in the winter because of differences in growth rates related to temperature and other growing conditions. Since corals live for very long periods of time (up to a thousand years), their skeletons can be used as a history of ocean temperatures.



In this segment of a coral, the black lines represent years, and the blue and red lines indicate seasons.

Consensus and Disagreement

The Intergovernmental Panel on Climate Change (IPCC) is a network of about 2500 climate scientists from 70 countries. This organization has become the leading authority on global climate change, and its reports represent the consensus of the scientific community. As more research is conducted and more evidence becomes available, there is consensus among the scientific community on a number of points related to climate change, specifically global warming:

1. Earth is 0.6 °C warmer than in 1900, with 0.51 °C of that change happening since the 1980s.
2. Human activities contribute to climate change and global warming.
3. Continued emission of GHGs will likely speed up global warming.
4. Global warming is a problem, and we should do something about it.

While there is consensus, the evidence can be interpreted in different ways. For example, there are virtually no scientists who disagree that the average global temperature has risen by approximately 0.6 °C over the last hundred years. However, skeptical scientists say that the average temperature is deceiving because it does not give a complete picture of what has happened. They indicate that most warming occurs over land, not over water, and that most warming occurs at night.

There is also evidence that greenhouse gases are not the only causes of global warming. Recent NASA research suggests that soot is twice as effective as carbon dioxide in raising global surface air temperatures in the northern hemisphere. Soot is carbon particles produced during combustion of fossil fuels such as diesel fuel and coal, and from burning vegetation. In developed countries, the greatest source of soot is the combustion of diesel fuel and coal. In developing countries, the major source is burning wood, animal dung, or other biofuels. Soot on the surface of snow and ice reduces its ability to reflect light. Clean snow normally reflects about 98 % of the light that falls on it. Soot may reduce the reflection rate to between 80 and 90 % (Figure 3). The increased absorption of radiant energy melts more ice and snow. This effect has usually been attributed only to the enhanced greenhouse effect.

LEARNING TIP

Critical readers ask questions as they read. Ask yourself, "What are the implications for climate change in my community and on the lives of future generations?"

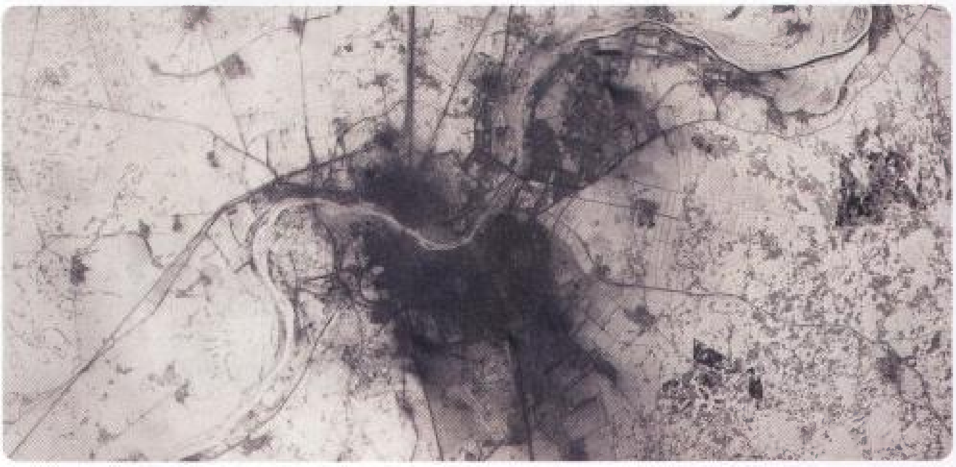


Figure 3 Dark colours absorb more solar energy than light colours. Soot, produced by industries, covers the snow in this satellite picture, and absorbs more of the Sun's energy.

Predicting the Future

The evidence gives us a fairly clear picture of present and past climates. But how do we know what will happen in the future? Scientists have reconstructed past climates using sophisticated computer models. They combine this information with trends in current data to predict what might happen in the future. While there is increasing confidence in these computer models, they cannot predict future climates with 100 % certainty.

In 1990, the computer models projected an increase in the global average temperature of between 0.15 °C and 0.3 °C per decade for 1990 to 2005. The actual increase for that period was about 0.2 °C per decade; within the predictions. This increases confidence that climate models can predict short-term climate changes. Today's computer climate models are much more sophisticated than those of 1990, and are expected to be more accurate.

Uncertainty, discrepancies, and disagreement do not mean that the climate models are not valuable or that we should be unconcerned about the future. It simply points out the need for further scientific study so that the models can be improved and predictions can become more reliable.

Did You KNOW?

Climate Models on Supercomputers

Current models of Earth's climate system require complex calculations involving thousands of variables. These highly detailed models must be run on supercomputers that can perform more than 1×10^{13} operations per second.

16.1

CHECK YOUR Understanding

1. Explain how the terms "climate change" and "global warming" are related.
2. (a) Why is the greenhouse effect essential for Earth?
   (b) How would "enhanced greenhouse effect" be a better term to describe climate change?
3. List the main GHGs. Why are they called GHGs?
4. List and briefly describe the evidence for global climate change.
5. The greenhouse effect describes the process by which
   A. harmful gases contribute to global warming.
   B. greenhouse windows encourage plant growth.
   C. Earth's atmosphere insulates Earth from heat loss.
   D. a layer of atmospheric gases protect Earth from radiation.
6. List and briefly describe some of the evidence used to describe past climates.
7. Closely examine the tree rings in Figure 4. Describe what conclusions can be drawn about the weather when this tree grew.

Figure 4

8. What sources of evidence provide timelines with clues about what happened at different times in Earth's history?
9. Why is the IPCC considered a credible organization that represents a consensus in the scientific community?
10. What are the main points that scientists can agree on regarding climate change?
11. List three sources of evidence of past climates.
12. There may be other factors besides GHGs that contribute to global warming. Identify and describe one such factor.
13. What is the consensus and disagreement over climate change among scientists?
    A. Agree there was change, but not so much.
    B. Agree on the data, but not the interpretation.
    C. Agree on the change, but disagree on the data.
    D. Agree there was change, but not caused by humans.
14. How might depletion of the ozone layer be linked to global warming?
    A. Ozone depletion speeds up at cooler temperatures.
    B. The ozone layer protects us from harmful UV radiation.
    C. CFCs are greenhouse gases that also destroy the ozone layer.
    D. Holes in the ozone layer let more heat into the lower atmosphere.

16.2 Influences on Climate and Climate Change

What causes climate change? In this section, you will learn how natural events and human activities contribute to climate change.

STUDY TIP

You can use a table to help you organize and remember information. Make a two-column table. In the first column, write the headings Natural Influences and Human Influences. As you read the section, record important information under the appropriate heading. To aid in retention, do not confine yourself to words. Use graphics, pictures, and colour to connect ideas. Include the words in bold in your notes.

Natural Influences

The flow of energy around Earth produces both short-term variations and long-term trends in climatic conditions. Some of these energy flows are part of the energy flow system (such as ocean currents). Other phenomena, such as volcanic eruptions, are outside the system but affect it.

El Niño

The natural event with the greatest effect on global climate is El Niño. **El Niño** is a shift in the ocean currents, temperature, and atmospheric conditions in the tropical southern Pacific Ocean.

Most of the time, atmospheric and surface water temperatures appear to cycle from low to normal to high, then back to low again. This causes cycles in ocean currents, surface winds, and atmospheric pressure. El Niño is believed to be caused by changes in the normal patterns of the southeast trade winds. These winds normally move westward, pushing warm surface water to the western Pacific Ocean. This produces more evaporation and more moisture in the atmosphere in Indonesia, the Philippines, and northern Australia, leading to thunderstorms and heavy rainfall. It also raises the sea level on the west side of the Pacific Ocean about 50 cm higher than on the east side. At the same time, the cooler deep water moves eastward and upwells along the coast of South America (Figure 1a).

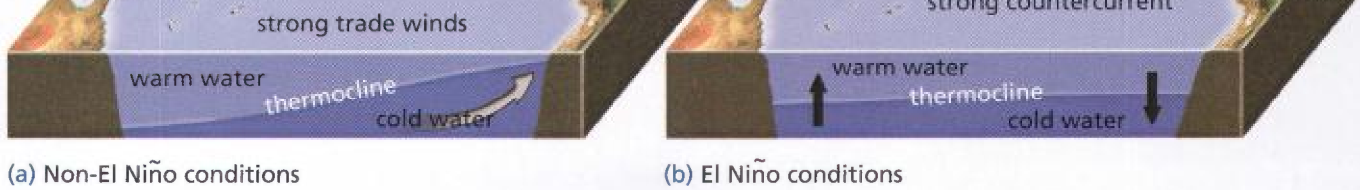


Figure 1 Normally, (a) the west coast of South America experiences colder water temperatures than (b) during an El Niño. El Niño is believed to be caused by changes in the normal patterns of the southeast trade winds.

Note that the thermocline is sloped upward from west to east. The **thermocline** is a region between the warm top and cold deep layers of the ocean. Remember that convection does not occur when water is heated from above, so these layers stay mostly separate. Because the layers don't mix, nutrients are not exchanged between them, resulting in two separate ocean environments.

El Niño effects are observed throughout North and South America, and ocean currents and prevailing winds are affected around the world. During an El Niño, the surface water temperature and the water level in the western Pacific Ocean are much higher than normal. The southeast trade winds are weakened or even reversed. This pushes the warmer surface waters toward the coast of South America and causes greater evaporation from the ocean surface off Ecuador and Peru (Figure 1b). This produces more frequent thunderstorms and heavy rainfalls in areas that are normally dry. Note that the thermocline is now pushed lower near the coast of South America.

In North America, El Niño pushes the polar jet stream farther north, preventing cold Arctic air from reaching parts of eastern Canada and the United States, and causing milder-than-average winters (Figure 2). In summer, this significantly warmer and drier weather increases drought. Even hurricanes are reduced because the reversed trade winds tear apart tropical storms in the Atlantic Ocean before they can turn into hurricanes.

Did You KNOW?

The name El Niño, which means "Little Boy" or "Christ Child" in Spanish, was originally given by the fishermen of Peru to a warm current that appeared off the coast each year around Christmas time. In the 1960s, it was recognized and described as a phenomenon that was not restricted to Peru, but extended over the entire Pacific Ocean and beyond.

LEARNING TIP

Pause to interpret visuals and graphics as you read. Ask yourself, "What additional information can I get on El Niño from reading Figures 1 and 2?"

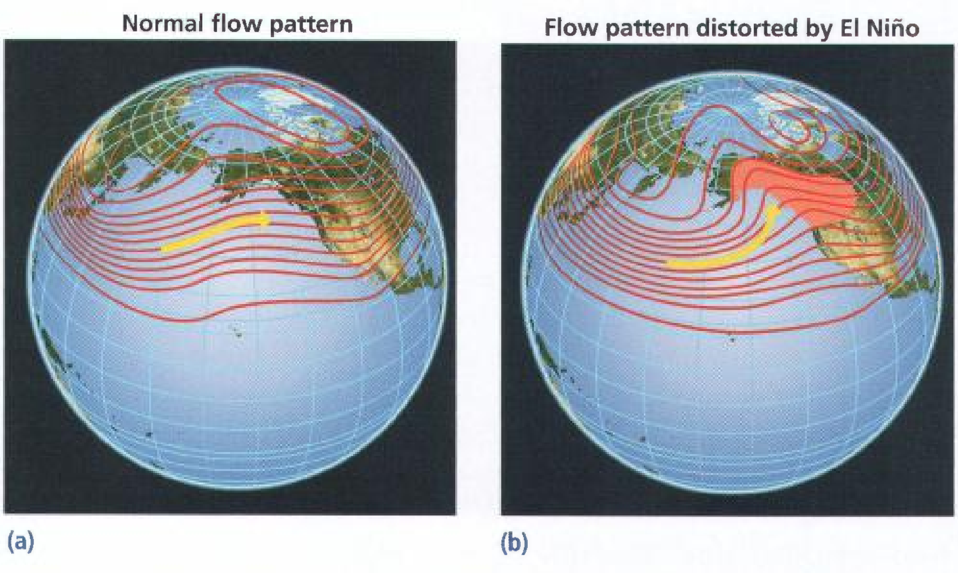


Figure 2 Even though we are far from the equator, (a) normal air flow patterns are distorted during (b) an El Niño event.

In addition to weather changes, El Niño has indirect ecological, social, and economic impacts. For example, the colder, nutrient-rich water that rises along the west coast of South America provides nutrients for some of the largest fish populations in the world. When the warm El Niño waters arrive, this cold water cannot rise, and the food supply disappears. The fishing industry, birds, mammals, and the entire food chain that relies on the fish also suffer. GO

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

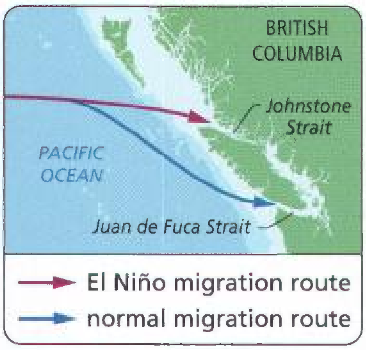


Figure 3 Sockeye salmon change their migration routes during El Niño years.

Did You KNOW?

Fishing El Niño

The diversion of migrating salmon is an advantage for British Columbia fishers. The Johnstone Strait is totally within Canadian waters and can be fished only by Canadians. The Juan de Fuca Strait is shared with the United States. During El Niño years, fewer of the migrating salmon can be caught by Americans.

To learn more about the causes and effects of El Niño and La Niña, visit **www.science.nelson.com**

In British Columbia, El Niño affects the annual migration of fish. During a major El Niño event, the coastal waters off the west coast of North America warm up significantly. This allows new species to migrate to these waters. For example, during previous El Niños, mackerel migrated farther north than usual. Mackerel feed on young salmon, and mackerel caught in Barkley Sound were found to have six to eight young salmon in their stomachs.

The salmon themselves change their migration route when the temperatures shift. During warm water events, a proportion of the Fraser River sockeye salmon stock returns to the river through the Johnstone Strait, rather than through the Juan de Fuca Strait (Figure 3). So the migration of sockeye salmon in British Columbia is determined to some degree by events that take place in the ocean south of the equator. Scientists can now use water temperatures to predict the migration routes of the salmon.

La Niña

The entire El Niño cycle is called the El Niño Southern Oscillation, or ENSO. At the opposite end of the cycle we experience **La Niña**: a shift to colder-than-average ocean temperatures in the eastern Pacific Ocean, as much as 4 °C to 24 °C colder. The effects are opposite to those of El Niño: La Niña usually brings colder, snowier winters to the Canadian West and colder and wetter-than-normal winters from British Columbia to the Great Lakes. In the Atlantic Ocean, hurricanes develop more easily, and there are more frequent extreme weather events.

This El Niño–La Niña cycle is irregular, varying from two to seven years. The abnormal weather may last for only a few months or continue for a year or two. Extreme El Niño events may occur every 20 to 50 years.

Volcanic Eruptions

When a volcano erupts, it throws tonnes of solid and gaseous material into the atmosphere. The volcanic ash suspended in the atmosphere physically blocks sunlight, resulting in cooler temperatures. The sulfur dioxide gas reacts with water vapour in the air to form dense clouds of sulfuric acid. This produces a haze effect, cooling Earth's surface by blocking some of the sunlight and reducing the amount of solar radiation reaching Earth. Scientists now believe that the amount of sulfur dioxide in volcanic emissions is more important than the suspended ash particles in producing the haze effect. Many of the erupted gases are GHGs, which you learned about in the previous section.

On June 15, 1991, Mount Pinatubo erupted in the Philippines, blasting water, gases, and ash particles over 35 km up into the atmosphere (Figure 4). Within a year, wind had distributed the sulfur dioxide over the entire Earth (Figure 5), and the average global air temperature decreased by 0.8 °C. Scientists believe the eruption and temperature change are related.

Figure 4 The last major volcanic eruption that had an impact on global climate occurred in the Philippines, when Mount Pinatubo erupted in 1991.

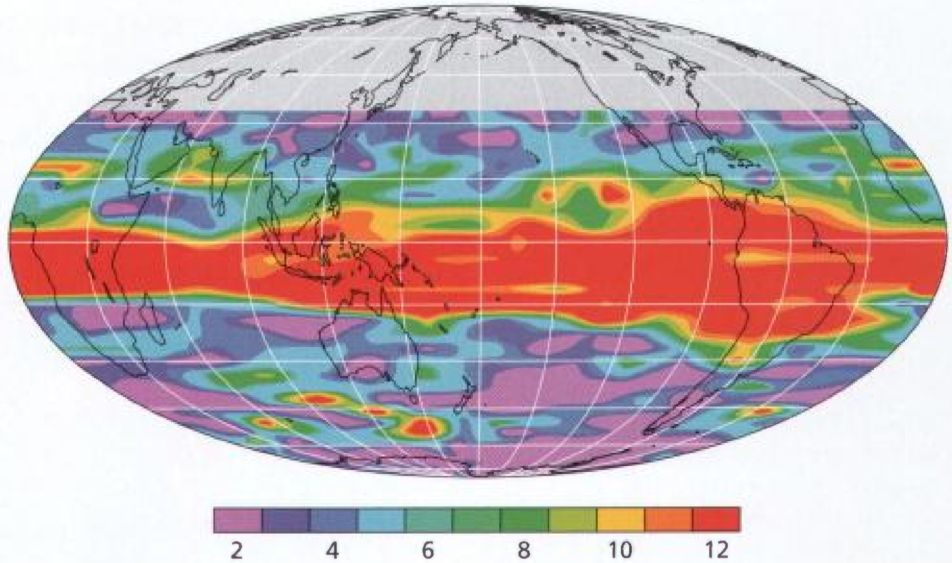


Figure 5 This map, based on satellite images six weeks after the eruption of Mount Pinatubo, shows the distribution around the world of the estimated 17 Mt of SO_2, together with water and ash from the eruption.

Human Influences

The IPCC has concluded that the global climate changes of the past 50 years could not have happened without human input. The greatest impact on global climate is the increase in GHGs, especially carbon dioxide. Many human activities, such as burning fossil fuels for heating or transportation, are obvious sources. However, other human activities also contribute to climate change.

Combustion of Fossil Fuels

The combustion of fossil fuels is the single largest source of GHG emissions. During 2006, Canadians bought and consumed 100 031 900 m^3 (equivalent to 629 400 715 barrels) of refined petroleum products (gasoline, diesel, aviation fuel, and so on). British Columbians bought and consumed 11 420 100 m^3. The largest proportion of these products is gasoline for motor vehicles (Figure 6).

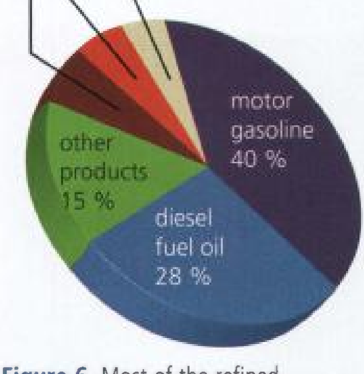


Figure 6 Most of the refined petroleum that is produced is consumed in transportation.

Deforestation and Agriculture

The next biggest contributor of GHGs after fossil fuels is deforestation. Trees remove carbon dioxide from the atmosphere and use it to produce carbon compounds during photosynthesis. These carbon compounds are stored in the biomass, or living matter: leaves, roots, and wood. About 20 % of the mass of a tree is carbon. Forests, then, become huge carbon sinks. Scientists say that the Canadian boreal (northern) forest makes up about one-quarter of the world's forest and plays an important role in balancing the global environment. Forests store an estimated one trillion tonnes (1×10^{12}) of carbon. That is about one and a half times more than is found in the atmosphere.

Humans have been harvesting trees for centuries, but the past few decades have seen a tremendous increase, greatly reducing this natural and enormous carbon sink (Figure 7). The situation is even worse when forests are burned. Burning the trees not only eliminates their capacity to remove carbon from the atmosphere, but the combustion process itself adds even more carbon dioxide and other GHGs to the atmosphere.

Did You KNOW?

Shrinking Sink

The amount of carbon stored in the world's forests decreased by about 1.1 Gt annually for the period 1990 to 2005. Overall, the world's forest ecosystems are estimated to store some 638 Gt of carbon, which is more than the amount of carbon in the entire atmosphere.

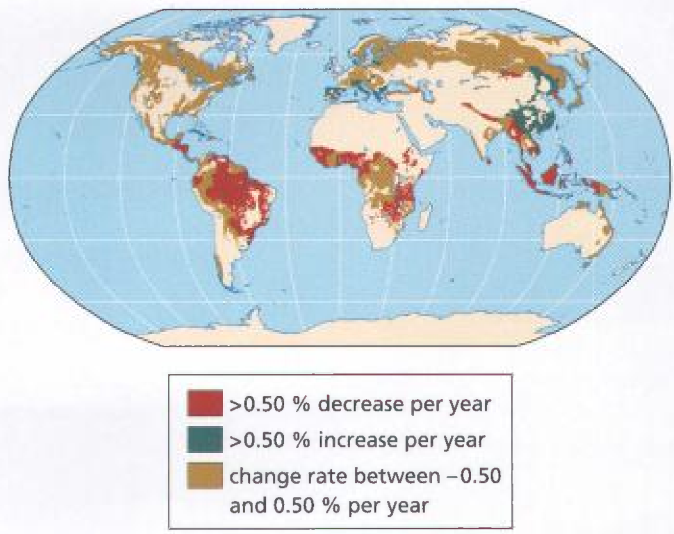


Figure 7 The greatest change in forested area is occurring in the tropical rainforests.

Although agriculture involves growing crops that remove carbon dioxide from the atmosphere, the industry contributes more GHGs to the atmosphere than it removes. It is estimated that primary agriculture—not including transportation or food processing—is responsible for about 10 % of Canada's total GHGs. Most of the total emissions of nitrous oxide (61 %) come from agriculture, as well as 38 % of the methane emissions, and less than 1 % of carbon dioxide emissions.

Industry

Many industrial processes contribute GHGs to the atmosphere (Figure 8). Extraction and refining processes in the oil and gas industries are significant contributors of GHGs. The cement industry is also a heavy user of fossil fuels, both in the operation of cement plants (for example, to power them) and in the chemical processes of cement production. Most industries are trying to reduce their GHGs output through new processes and technology.

Figure 8 Nearly half of Canada's GHG emissions come from large industrial facilities.

Waste Disposal

The decay of organic matter in municipal landfills also produces methane gas. In most cases, this GHG simply escapes into the atmosphere. In some cases, the gas is burned off to prevent accidental fire or explosion. In other cases, the gas is collected for heating or power generation. In recent years, the amount of organic material entering landfills has decreased because of recycling programs. The organic material is diverted from landfills and is composted to produce soil supplements. When organic matter is composted instead, the carbon is stored in the soil.

16.2 CHECK YOUR Understanding

1. (a) Under normal conditions, in what general direction do the Pacific equatorial currents flow?
   (b) Describe what happens to those currents during an El Niño.
   (c) What happens to the Pacific Ocean trade winds during an El Niño?
2. A buoy off the coast of Peru in South America is equipped with sensors to record surface water temperatures. The data for six consecutive months is shown in Table 1.

Table 1

Month	Temp. (°C)
1	28
2	28
3	27
4	26
5	25
6	24

   (a) Describe the probable cause of the temperature decrease.
   (b) What effect will this have on the general winter weather conditions in British Columbia?
   (c) Do you think the fishery will be successful in Peru during the following year? Explain.
3. Describe the energy flows that take place during the El Niño cycle.
4. In what ways could the fishery industry in British Columbia be affected by El Niño?
5. How do volcanic eruptions contribute to climate change?
6. Scientists conclude that the sulfur dioxide in volcanic eruptions is more significant than the volcanic ash in influencing the global climate.
   (a) Why do you think this is so?
   (b) How do you think scientists might have come to that conclusion?
7. Explain this statement: "What the world needs now is more volcanic eruptions."
8. Identify two synthetic GHGs and their sources.
9. Why are forests considered carbon sinks?
   A. Carbon is drained through them.
   B. They store large volumes of carbon.
   C. They create a depression in which carbon gas collects.
   D. Huge amounts of carbon are released when they are burned.
10. Using Figure 9, identify which region(s) of the world had the greatest deforestation from 1990 to 2004, and which region(s) had the least deforestation.

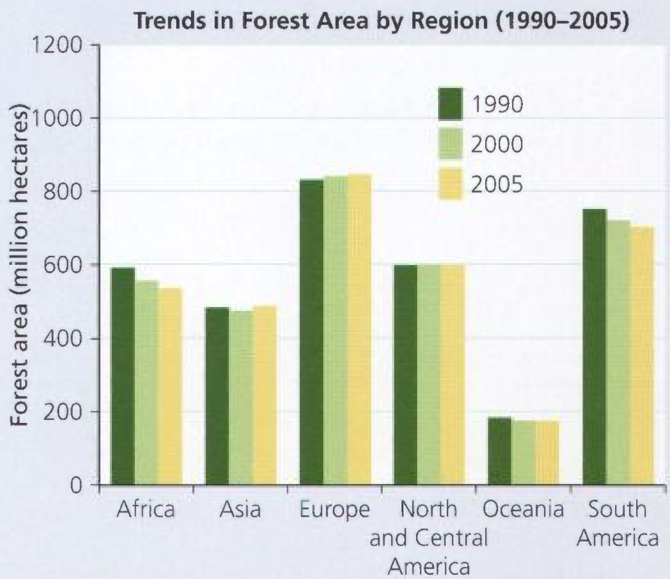


Figure 9

11. Why is deforestation by burning considered a "double hit" for global warming?
12. Explain how cattle farming contributes to climate change.
13. Name five industries that are likely to emit large amounts of GHGs. Explain why.
14. Describe two ways in which the disposal of household garbage contributes to climate change.

16.3 Potential Impact of Climate Change

STUDY TIP

To help you organize the information on the impact of global warming, make a five-column table with the following headings: Forests, Animals, Canada's Northern Regions, Human Health and Safety, and Sea Level. As you read pages 470 to 476, record important information in point-form notes under the appropriate heading.

What impact will climate change have on Earth and its inhabitants? How do we know what will happen in the future? The best scientific models available today predict that global warming will continue for decades even if GHG emissions decrease. These models also predict that global warming will be most significant in more northern regions, and over land rather than over oceans.

Impact of Global Warming

The direct impact of global warming will be on the physical environment, with serious consequences for living organisms, including humans. Table 1 summarizes the possible effects of global warming. Even if the impact is only half as bad as predicted, the consequences remain very serious.

Table 1 Possible Effects of Global Warming

Areas affected	Examples of possible effects	Areas affected	Examples of possible effects
weather extremes	• prolonged heat waves and droughts • increased flooding • more intense hurricanes, typhoons, tornadoes, and violent storms	sea level and coastal areas	• melting of polar ice caps and rising sea levels • flooding of low-lying islands and coastal cities • flooding of coastal estuaries, wetlands, and coral reefs • beach erosion • disruption of coastal fisheries • contamination of coastal aquifers
water resources	• change in water supply • decreased water quality • increased drought or flooding	agriculture	• shifts in food-growing areas • changes in crop yields • increased irrigation demands • increased pests, crop diseases, and weeds in warmer areas
biodiversity	• extinction of some plant and animal species • northward migration of species • loss of habitat • disruption of aquatic life	human populations	• increased deaths • more environmental refugees, increased migration
forests	• change in forest composition and locations • disappearance of some forests • increased fires from drying • loss of wildlife habitat and species • increased pest infestations	human health	• deaths from heat and disease • disruption of food and water supplies • spread of tropical diseases to temperate areas • increased incidence of respiratory disease • increased water pollution from coastal floods

Weather Changes

Associated with the long-term change in climate are changes in weather. Depending on the location, weather patterns will change. Some of these changes may be perceived as positive. For example, Canadians who experience a long, cold winter may consider the effects of global warming as beneficial, with lower heating costs and safer travel. However, many of the consequences will be negative. In most locations in Canada, we will see generally hotter, drier summers and milder winters. Depending on the location, there may be increased precipitation leading to flooding and the problems associated with it.

Over the past century, the average temperature in coastal British Columbia has increased about 0.6 °C. However, the average temperature of the interior of British Columbia has increased by over 1 °C, double the global average. The warming trend for the northern region is nearly three times the global average (Figure 1).

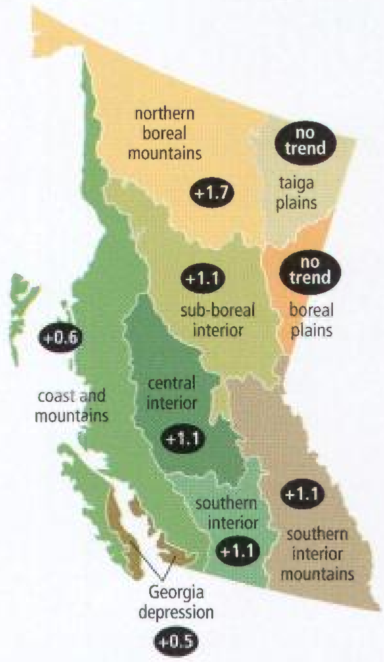


Figure 1 The interior of British Columbia has experienced and will continue to experience greater temperature increases than coastal regions.

Impact on Forests

Photosynthesis is one of the few processes that may benefit from increased CO_2 in the atmosphere. Plant growth could increase; however, the warmer, drier climate may not provide enough water and nutrients to support this enhanced growth. The warmer, drier forest is also much more susceptible to damage by insects and fire. Also, the more frequent and intense storms cause extensive wind damage, especially in coastal regions (Figure 2).

The forests of British Columbia are currently experiencing a serious infestation of the mountain pine beetle, a pest that was previously present but under control. The mountain pine beetle is a small insect that spends its larval stage burrowing underneath the bark of pine trees, cutting off the tree's supply of nutrients and eventually killing the tree (Figure 3).

The insects are normally unable to survive intense cold periods during the winter, keeping the population in check. In recent years, however, warmer winters combined with a higher proportion of mature lodgepole pine trees (the preferred habitat of the beetle) have led to an epidemic, and millions of hectares of commercial forests have been destroyed. This has both positive and negative economic implications for communities and thousands of families who depend on the forestry industry.

Figure 2 The strong windstorms of December 2006 destroyed thousands of trees in Stanley Park, on Vancouver Island, and in other coastal regions of British Columbia.

Figure 3 The trunk of this pine tree is scarred by pine beetle infestation.

Impact on Animals

All species are affected by changes in the abiotic components of the environment. Temperature and precipitation levels, in particular, are very important factors for most species, including salmon. As the oceans warm, migratory species such as salmon may venture farther north, meaning longer return journeys to their spawning grounds. Increased river temperature will also mean that salmon will use more energy swimming up-river. Lower precipitation and earlier runoff result in lower water levels in rivers, making it more difficult for salmon to navigate obstacles. All these stresses will impact reproduction and, therefore, future populations (Figure 4). This will reduce the food supply for species that eat salmon, such as eagles and bears. Similar impacts will be felt by other migratory animals and their prey.

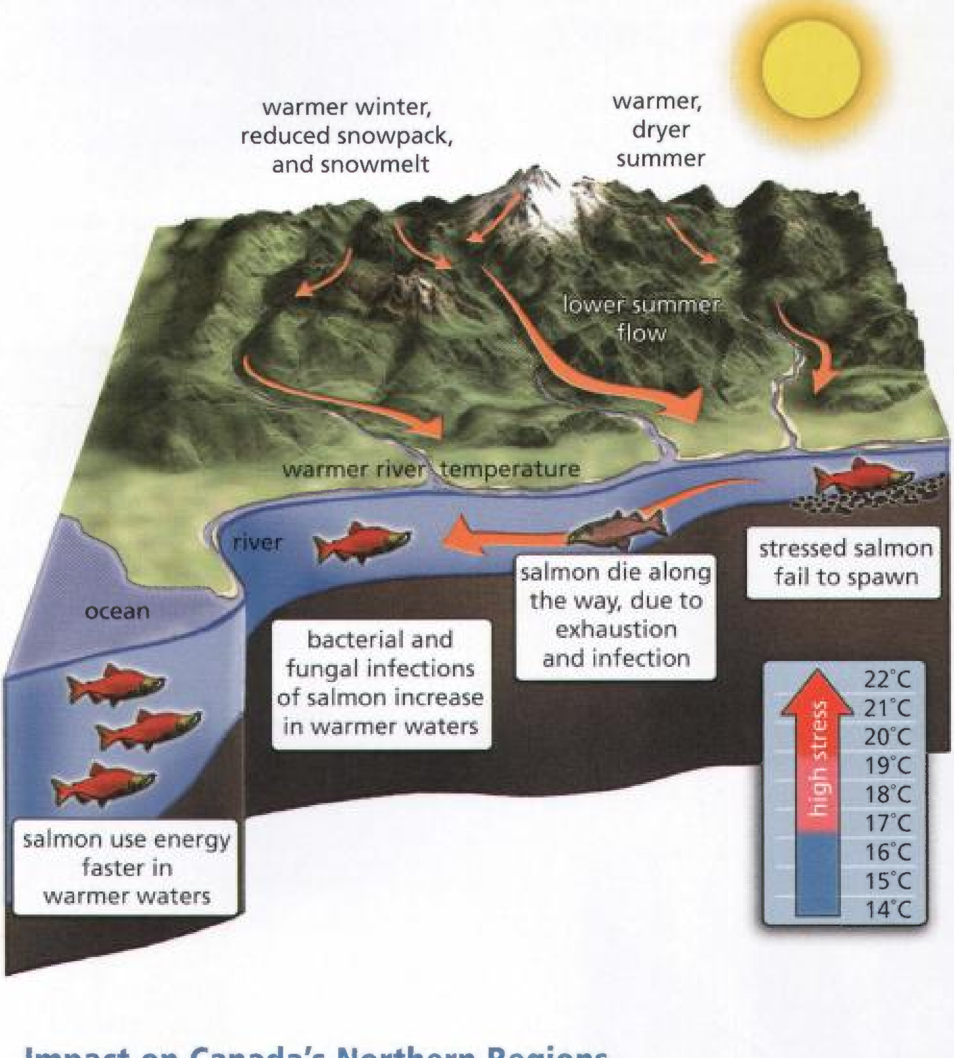


Figure 4 Salmon face increased stresses from environmental changes caused by global warming.

Impact on Canada's Northern Regions

Northern regions will be affected by global warming more than other latitudes. The IPCC concluded in its third report that, "Climate change in the Polar Regions is expected to be among the largest and most rapid of any region on Earth, and will cause major physical, ecological, sociological, and economic impacts, especially in the Arctic."

The permafrost prevents water drainage, so shallow lakes and bogs are plentiful in the summer. These wetlands of the southern Arctic are the major nesting area for a variety of migratory birds, such as ducks and geese. The southern Arctic is also the summer range and calving grounds for Canada's largest caribou herds, and is home to many other animals such as bears, wolves, moose, squirrels, foxes, and lemmings. Disruption of the migration or reproduction of any one of these animals will ripple through the entire Arctic food web.

As temperatures rise, the permafrost melts and the ground cracks and settles. This increases the potential for erosion and threatens the infrastructure and transportation systems: buildings, pipelines, bridges, roads, and waste disposal systems (Figure 5).

Figure 5 This house was damaged as the permafrost below it thawed.

In August 2007, a new record was set for the lowest Arctic sea ice area since satellite observations began in 1979. And it happened a month earlier than the usual summer minimum. At the current rate, the Arctic Ocean may be free of summer ice by 2050 and almost certainly by the end of the century. This may make the Arctic Ocean navigable longer each year, easing transport costs and barriers. However, the polar bear and other animals that depend on cold weather are affected. The northward movement of the ice floe boundary and longer periods without ice cover make it difficult for polar bears to hunt seals, and they resort to scavenging for food in community dumps and landfills. Snow conditions may affect the ability of the polar bears to find suitable snow caves where they can give birth to their young.

The traditional lifestyle of Northern Canada's people is threatened by all these changes. It hurts their hunting practices, the quality of their food supply, their access to clean drinking water, and their ability to travel safely.

To hear an audio clip about the effects of climate change on Canada's northern regions, go to **www.science.nelson.com**

Impact on Human Health and Safety

The impact of global warming on human health and safety is not entirely known. Some of the negative results may include

- northward spread of insects carrying diseases such as West Nile virus, Lyme disease, and malaria
- increased air pollution due to longer periods of hot, stagnant weather (Figure 6)
- increased heat-related illnesses and respiratory health problems such as asthma which, in turn, increase health care costs and reduce productivity
- increased property loss and death due to more frequent and more destructive tropical storms (Figure 7)

Figure 6 Longer and more frequent periods of hot weather will also increase the smog in densely populated areas such as the Lower Fraser Valley.

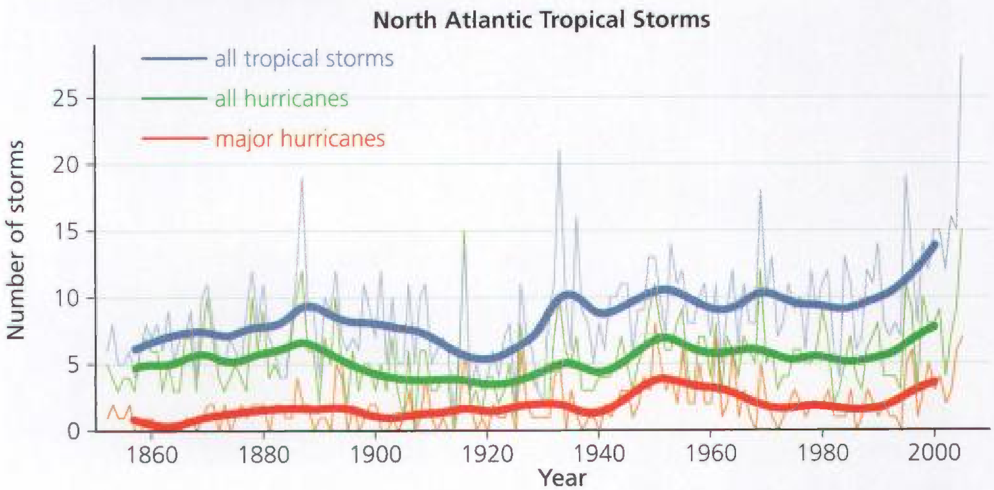


Figure 7 Since records began in 1860, tropical storms in the North Atlantic have become increasingly intense and more frequent.

Impact on Sea Level

The most significant threat from future climate change is sea level rise. Sea level has risen an average of 1.8 mm per year from 1961 to 2003. The rate during the last decade (1993 to 2003) was much higher: 3.1 mm per year. The total volume of the oceans is increasing because of ice melt and expansion due to temperature rise. Using data from the last century as indicators, sea level may rise between half to one metre in the next 100 years, and up to 10 m in the centuries after.

The Pacific coastal zone, where British Columbia and the Pacific Ocean meet, is one of the most diverse and productive environments in Canada. Coastal wetlands are a crucial habitat for a large number of birds and fish (Figure 8). Estuaries are a nursery for many of the fish species we eat. Flooding of estuaries with seawater changes the salinity of the water and the optimal conditions for the development of young organisms. Loss of these areas could have a devastating impact on the populations of many species.

Coastal wetlands evolve as sea level rises. They collect sediment and produce soil on which plants can grow. The flooded land becomes new wetlands. However, this evolution is a slow process, and it appears that the projected rate of sea-level rise is faster than new wetlands can develop.

Figure 8 Coastal wetlands are among the most biologically diverse ecosystems in the world.

If sea level rises by 0.5 m in the next century as is predicted, half the coastal wetlands in North America could be flooded and permanently damaged.

About two-thirds of the world's cities and over five million people live in low-lying areas. In Canada, about 38 % of the population lives within 20 km of an ocean or Great Lake. The potential impact of sea-level rise is nowhere more evident than in the Lower Fraser Valley where 100 km^2 is within 1 m of sea level. Figure 9 shows the extent of flooding of the Fraser River delta if current sea levels were to rise by 6 m.

Flooding will also increase erosion and the loss of wetland — some of the most diverse and productive environments in Canada (Figure 9). Fresh water supplies in the ground and lakes may also be contaminated by seawater moving in.

Did You KNOW?

Ice Volume

The melting of the Greenland Ice Sheet alone is enough to raise sea level 6 m to 7 m.

Figure 9 With a 6 m rise in sea level, most of Richmond would be flooded, along with three-quarters of Delta and a third of New Westminster. Vancouver Airport and the Tsawwassen ferry terminal would also be submerged.

Responding to Climate Change

We have only scratched the surface of the many and wide-ranging impacts of global warming. Similar and worse consequences are experienced around the world. In Canada, we may be able to adapt and adjust to the changing climate. Those living in developing countries will be hardest hit and have fewer resources to devote to change.

You will explore federal government initiatives in section 16.4. However, these are not the only key to success in reducing GHGs. Provinces, municipalities, and companies are all voluntarily implementing strategies that reduce GHG emissions. Over 900 organizations across the country have developed, registered, and implemented voluntary plans to reduce their GHG emissions.

Aboriginal peoples are keen observers of changes to weather patterns and wildlife abundance because their traditional lifestyle is so closely connected to Earth and the climate. The Assembly of First Nations is prepared to support Canada's response to climate change: their Traditional Ecological Knowledge and Wisdom is an important component of climate change research.

LEARNING TIP

Evaluate your learning. What are your opinions about what you have read on the impact of climate change? How does climate change affect your life and your community? Do other students agree with your reactions?

British Columbia's Progress and Plans

Statistics from Environment Canada show that GHG emissions in British Columbia have increased by nearly 30 % since 1990. The production and use of fossil fuels accounts for 83 % of this. Along with other provinces, British Columbia has initiated its own plan to reduce its contribution to global warming (Table 2).

Whether we realize it or not, each of us is responsible for our share of air pollution, GHGs, and climate change. We may not be directly responsible, but when we consume food, produce waste, use manufactured goods, and travel, we are indirectly causing GHGs to be added to the atmosphere, and we are therefore contributing to global warming and climate change. GO

To learn about ways you can reduce your GHG emissions, go to www.science.nelson.com GO

Canada will need innovative technological solutions to slow the trend of climate change and to adapt practices we cannot avoid, such as burning fossil fuels. Equally important is the need to change the attitudes and lifestyles that lead us to squander energy resources.

Table 2 British Columbia's Climate Change Plan

Area	Examples
energy production and use	• generate 50 % of new electricity from cleaner sources such as hydro, landfill gas, and wind • promote development of hydrogen and fuel-cell technology
transportation, buildings, and communities	• develop new building and equipment standards to promote energy efficiency and alternative energy sources
forest and carbon sinks	• practice sustainable forest management • reduce agriculture's GHG emissions by 8 % (by 2008)
government leadership	• develop targets and guidelines for cleaner government buildings and vehicles
water management	• develop forecasting for coastal flooding

TRY THIS: Greenhouse Gas Calculator

Skills Focus: interpreting data, analyzing, evaluating

The Greenhouse Gas Calculator allows you to estimate your personal influence on the climate through GHG emissions.

1. Access the Greenhouse Gas Calculator on the Internet, or obtain the downloaded version from your teacher.
   www.science.nelson.com GO
2. Answer the questionnaire as accurately as possible. You may have to estimate some answers.

A. What are your estimated GHG emissions?

B. How does your GHG contribution compare with the per capita average for your province or territory? How does it compare with the national average per capita emission of GHGs?

C. What is the largest single source of GHGs in your province or territory? What percentage of the total does it represent?

D. What recommendations are made for reducing your GHG emissions?

E. Evaluate the accuracy of the Greenhouse Gas Calculator. Identify potential sources of error that might influence its accuracy. Do you think these sources of error affect its value as a tool to help people understand their personal impact on the climate? Explain.

16.3 CHECK YOUR Understanding

1. Why might some people think global warming is a positive thing?
2. Figure 10 shows the variation in the Fraser River's water temperature. There are approximately the same number of summers when the average water temperature was below 16 °C as when the average temperature was above 16 °C. Why, then, is there a concern that the increasing water temperature will affect salmon populations? Explain the straight line on the graph.

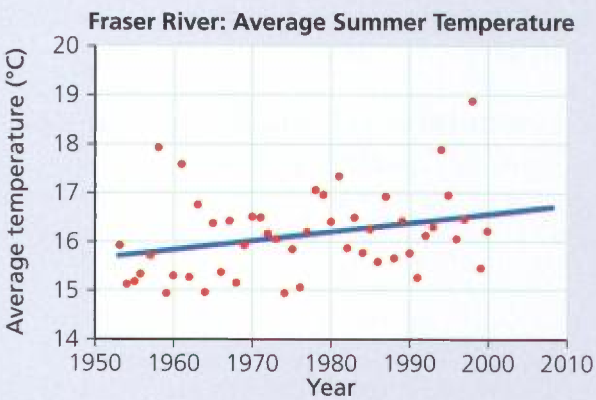


Figure 10

3. How might plants benefit from increased carbon dioxide in the atmosphere?
4. The mountain pine beetle has been in British Columbia since the early 1900s. Why hasn't there been an epidemic infestation before now?
5. In addition to warmer temperatures, what other factor may have contributed to the infestation of the mountain pine beetle in British Columbia forests?
6. During the mountain pine beetle infestation, the lumber industry in British Columbia experienced a boom. Explain this, and predict what is likely to happen in the future.
7. Why is Canada's North more at risk from climate change than the rest of the country?
8. What are the possible implications of melting permafrost? Speculate about possible benefits.
9. Briefly describe three impacts of rising sea levels.
10. Explain why loss of wetlands is such a serious consequence of rising sea levels.
11. Canada's population is 31 million. Approximately how many people live within 20 km of a coastline or a lakeshore?
12. In the natural environment, everything is connected to everything else. Use examples from the climate change issue to explain and illustrate this statement.
13. Nature will take care of itself. When all the trees have died, the mountain pine beetle will also die. New forests will grow to replace the old forests. Is it acceptable to let nature take care of itself? Explain.
14. Getting climate change on the political agenda is a positive thing. Explain why.
15. Provide five examples of how you have personally contributed to atmospheric GHGs today.
16. List steps that you and your family could take to reduce the emission of GHGs. Beside each step, list any extra benefits that might result.
17. "Every minute of every day, everyone is producing GHGs." Write a paragraph explaining this statement.
18. The average Canadian personally produces approximately 5.5 t of GHGs per year. Yet the total per capita emissions of GHGs in Canada is approximately 24 t per year. Explain the discrepancy.

16.4 Explore an Issue

DECISION MAKING SKILLS

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

The Kyoto Protocol

It is widely accepted that human activities have had and continue to have a significant impact on climate change. We also know that the potential consequences of climate change are very serious. So, what can we do about it? What have we done about it so far?

The Kyoto Protocol was an attempt to reach international agreement to reduce GHG emissions. Each country's government was responsible for enacting legislation and implementing programs to reduce GHG emissions that would ensure common targets were met.

The Issue: Canada's Commitment to the Kyoto Protocol

In 2007, the federal government of Canada determined that Canada's GHG emissions target set by the Kyoto Protocol was unachievable. They issued a new plan called *Turning the Corner: the Action Plan to Reduce Greenhouse Gases and Air Pollution.*

Statement

The decision by the Government of Canada to implement an independent plan for GHG reduction (and not the Kyoto Protocol) was the right decision.

Background to the Issue

Canada has one of the highest per capita emissions of GHG in the world, and the total emissions continue to rise due to several factors:

- Canada has the second largest land mass of any country in the world, and its population is distributed over an enormous area, which means that we consume a lot of energy to transport people and goods.
- Canada has a cold climate, which means that we consume a lot of energy for home heating.
- A large part of Canada's economy is based on natural resources, which means a high demand for energy, for example, in smelting ore.
- Canada has a very high standard of living, which means that we produce and buy many goods and can travel to other parts of the world. The production and transportation of goods and travel all consume energy.

In 1997, delegates from 161 nations gathered in Kyoto, Japan, to work out a new treaty aimed at reducing atmospheric GHGs. The Kyoto Protocol commits countries to reducing GHG emissions to 5.2 % below 1990 levels by 2012. In 1990, the total GHG emissions for Canada were equivalent to 599 Mt of CO_2. The Kyoto target for Canada was 6 % below this level. Then Prime Minister Jean Chrétien signed the treaty on December 17, 2002, but the debate over its implementation became and continues to be a controversial political issue. Opposition to the Kyoto Protocol in Canada was primarily economic, arguing that it would be expensive and cost jobs. Supporters claimed that its implementation would create savings and new jobs to offset any job loss. The United States, which is the largest emitter of GHGs, did not sign the agreement.

In 2002, the federal government released its Climate Change Plan for Canada. This plan outlines strategies and initiatives that the government would undertake to meet its GHG reduction targets under the Kyoto Protocol. Even though Canada committed to the 6 % reduction in GHG emissions, our emissions have actually *increased* by about 30 % over the Kyoto target (Figure 1).

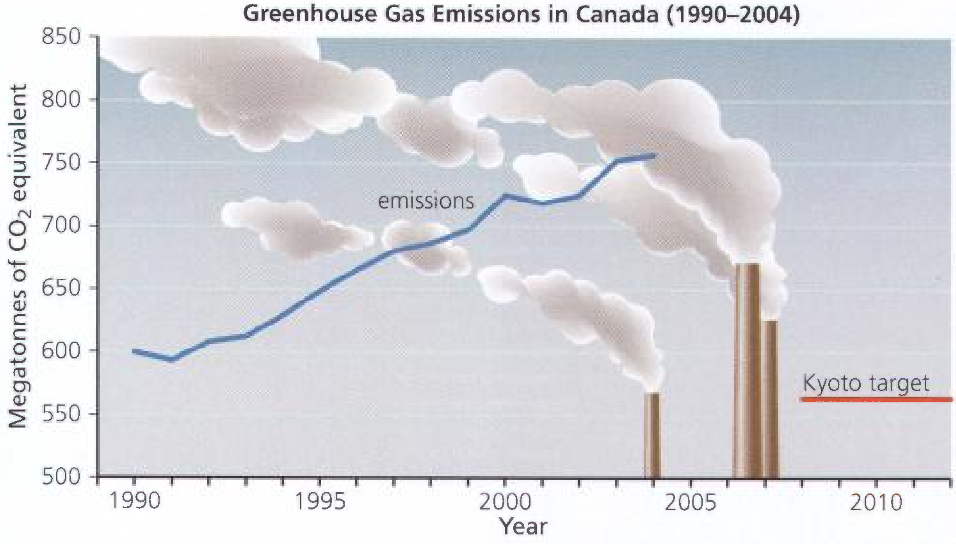


Figure 1 Canada's GHG emissions continued to rise despite the commitment to meet the target set under the Kyoto Protocol.

In 2007, the federal government, led by Prime Minister Stephen Harper, decided that the Kyoto Protocol target was unachievable and opted out of its Kyoto commitment. It then launched its own plan *Turning the Corner: the Action Plan to Reduce Greenhouse Gases and Air Pollution.* Released on April 26, 2007, the plan imposes mandatory targets, requiring industry to reduce GHG emissions by 150 Mt (20 % of 2006 levels) by 2020.

The new plan provides strict regulations and financial incentives for companies to invest in new technologies that will reduce their GHG emissions. But the critics of Canada's new plan point out that the new targets address emission intensity rather than actual emissions. Emission intensity refers to the amount of GHG produced per unit of production. In other words, a company could reduce its GHG emission intensity (emissions per unit of production), but still increase the actual amount of GHGs if its production increased.

Take a Position

LEARNING TIP
When taking a position on an issue, it is helpful to step into the person's shoes, and imagine what it would be like to be him or her.

You are a member of a provincial team who will attend a conference on climate change to gauge the level of support for the federal government's decision to replace the Kyoto Protocol with a new plan.

1. In your group, decide which position you will take, for or against the plan. As a team, prepare to debate. (You may or may not personally agree with the position taken by your group.)
2. Obtain a copy of *Turning the Corner: the Action Plan to Reduce Greenhouse Gases and Air Pollution* and analyze the plan.
3. Research arguments and supporting facts, including
   - activities that contribute to Canada's GHG emissions
   - levels of Canadian GHG emissions since 1990
   - economic forecasts of the costs or benefits of reducing GHG emissions
   - the new GHG reduction plan
   - a climate change action plan proposed by a province, a municipality, or a business

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Communicate Your Position

4. Based on your research for the debate, prepare a persuasive one-page report to convince people to support (or reject) the plan for reducing GHGs.
5. Present and defend your group's position in a classroom debate.
6. Did your research change your opinion on climate change? Why or why not?
7. Based on your research, describe what you consider to be the most appropriate way to reduce GHG emissions. Explain the advantages and disadvantages of your method.

Evaluation

8. After the debate, did you think of anything you could have done or said differently? Explain.
9. How could you have improved your group's performance?

CAN YOU CHANGE A LIGHT BULB?

Major initiatives such as alternate energy sources are not the only way to reduce our impact on climate change. There are many simpler actions, such as changing light bulbs, which can reduce our environmental impact.

Reducing reliance on fossil fuels will cut the biggest source of greenhouse gases. Alternative energy and more efficient technology make this possible.

One of the best known of these technologies is the compact fluorescent light bulb (CFL). CFLs use approximately one-quarter of the energy used by traditional incandescent light bulbs, while producing the same amount of light. For example, a 15 W CFL gives off the same amount of light as a 60 W incandescent bulb (Figure 1).

If every one of Canada's 12 million households replaced a single 60 W incandescent light bulb with a 15 W CFL, our fossil fuel power plants could cut GHG emissions by about 400 000 tonnes annually. This is equivalent to taking over 66 000 cars off the road for a whole year. Because CFLs last up to 10 times longer than a traditional light bulb, we would send less hazardous waste to landfills, too. It could also save Canadians $73 million a year in energy costs (Table 1).

(a) (b) (c)

Figure 1 All of these light bulbs give off equivalent light, but the (a) incandescent bulb uses the most energy and burns out the fastest. The (b) CFL and (c) LED bulbs are far more efficient, and last 9 and 50 times longer, respectively.

Light emitting diodes (LEDs) are emerging as an even better technology. A 9 W LED sheds almost as much light as the 60 W incandescent bulb, and can last 50 times longer. LEDs are already used for traffic signals, seasonal decorations, flashlights, and landscape lighting. In addition to energy efficiency, the advantages of LEDs include long life, low heat, improved visibility, resistance to shock and vibration, low maintenance costs, compact size, and light weight.

The Government of Canada announced, in April 2007, that it would establish efficiency standards for all lighting. Most incandescent light bulbs will be phased out of use by 2012. Light bulbs are a simple and cost-effective way for everyone to reduce their GHG emissions.

Table 1 Sample Comparison of Equivalent Light Bulbs

	60 W incandescent	**15 W CFL**
Expected life (hours)	1000	9000
Initial purchase cost	$ 0.50	$3.99
Cost of replacement bulbs	8 bulbs × $0.50 = $ 4.00	0 bulbs = $0
Electricity cost per year	9 bulbs × 1000 h × 60 W × $0.08/kWh = $43.20	1 bulb × 9000 h × 15 W × $0.08/kWh = $10.80
Total cost of equivalent lighting hours	$47.70	$14.79

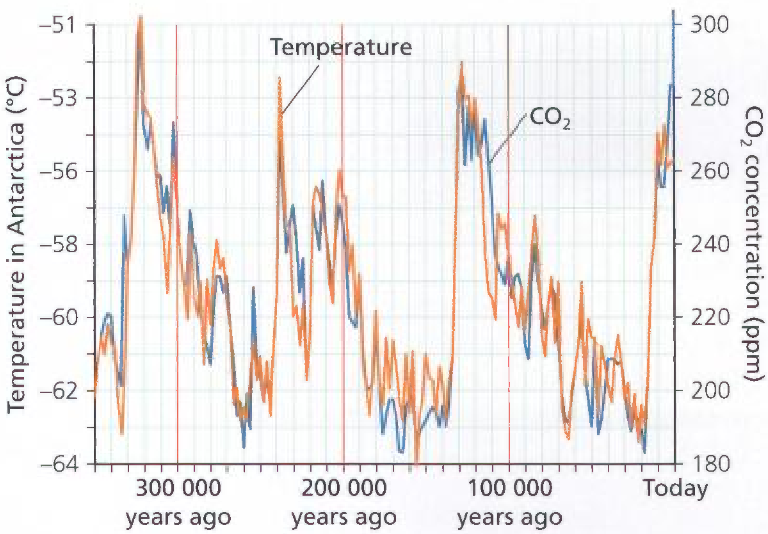
CHAPTER 16 Review

Climate Change

Key Ideas

There is abundant scientific evidence and much agreement in the scientific community that Earth is warming up as a result of global climate change.

- The greenhouse effect keeps Earth's temperature within a range that can support life.
- Increased levels of greenhouse gases from human activities enhance the greenhouse effect, warming Earth.
- Evidence shows that the average temperature on Earth has increased much faster in recent decades than in the preceding centuries.
- Even a temperature rise of as little as 1 °C can have widespread devastating effects.
- Natural processes remove some GHGs from the atmosphere and store them in sinks.



Both natural phenomena and human activities contribute to climate change.

- Plant and animal respiration is the main natural source of carbon dioxide in the atmosphere.
- Combustion of fossil fuels is the main source of GHGs from human activity.
- Digested or decaying organic matter is the main source of methane.
- Volcanic eruptions release ash particles and sulfur dioxide gas that block sunlight and help cool Earth.

Vocabulary

climate change, p. 455
global warming, p. 455
greenhouse effect, p. 455
enhanced greenhouse effect, p. 456
carbon dioxide equivalent (CO_2 eq), p. 456
carbon sink, p. 456
ozone layer, p. 457
permafrost, p. 459
El Niño, p. 464
thermocline, p. 465
La Niña, p. 466

Climate change affects the environment and has serious long-term implications for organisms, their habitats, and society as a whole.

- Weather events and extremes are likely to become more frequent and more intense.
- Warmer temperatures may extend the northern range of disease-carrying insects.
- Rising sea levels will mean a loss of valuable habitat, flooding of communities, and contamination of water supplies.
- Canada's northern regions will be more affected than southern regions.
- The natural environment and human populations will adapt and evolve in response to global climate change.

There is some disagreement in the scientific community on the extent and the consequences of climate change.

- Climate change data can be interpreted in different ways.
- Computer models are valuable tools but they cannot predict future climates with 100 % accuracy.

There is a recognized need for humans to slow down or prevent their negative impact on climate change.

- Many countries are working (together) toward national strategies to reduce GHG emissions.
- Canada's many levels of government have presented plans to reduce GHG emissions.
- Canada's climate change plan calls for a 20 % reduction in 2006 levels of GHGs by 2020.

Many of these questions are in the style of the Science 10 Provincial Exam.
The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. Explain the greenhouse effect.
2. Why is the term "enhanced greenhouse effect" more appropriate for describing the influence of GHGs on the global climate?
3. K Which of the following are greenhouse gases?

I	nitrous oxide
II	methane
III	carbon dioxide
IV	sulfur dioxide

A. II and III only
B. I, II, and III only
C. II, III, and IV only
D. I, II, III, and IV

4. Explain why it is important to reduce the amount of GHG emissions into the atmosphere.
5. K Which of the following would be considered a carbon sink?
A. rocks
B. clouds
C. forests
D. atmosphere
6. How could a series of major volcanic eruptions affect global weather?
7. Name one source for each greenhouse gas: CFCs, methane, and carbon dioxide.
8. K In what way does deforestation contribute to the greenhouse effect?

I	eliminates a carbon sink
II	exposes more land to absorb solar radiation
III	causes soil erosion
IV	processing and transportation release GHGs

A. I and II only
B. I, II, and III only
C. I, II, and IV only
D. I, II, III, and IV

9. What is the thermocline?
10. Explain Canada's target under the 2007 climate change plan. Provide both percentage reductions and the actual reductions in carbon dioxide equivalents.
11. K Which of the following would be considered indirect evidence of global warming?
A. sea level rise
B. ice core samples
C. receding glaciers
D. atmospheric CO_2 concentration

Use What You've Learned

12. Science is promoted as an objective, unbiased way of studying and understanding the world. If this is true, why is there disagreement among scientists about the causes, the extent, and the potential impacts of global warming?
13. Describe the source of evidence for climate change that happened
(a) in the several hundred years before records were taken
(b) hundreds of thousands of years ago
(c) millions of years ago
14. How would the tree rings of a tree in northern British Columbia compare to the rings of a similar type of tree growing in southern California? Explain.
15. State, with a reason, whether the greenhouse effect would occur
(a) on the Moon
(b) in a car with the windows up in the summer
16. Why were GHGs produced by human activities not a problem until about 200 years ago?
17. Explain why learning about El Niño and La Niña would help to improve long-term weather forecasting.
18. U How many tonnes of carbon dioxide will produce the same warming potential as 5 t of methane?
A. 1
B. 21
C. 105
D. 300

Think Critically

19. Table 1 shows energy use and carbon dioxide emissions statistics for 10 countries that lead the world in per capita energy consumption.

Table 1 2004 Energy Use and CO_2 Emissions

Country	Energy consumption per capita (kg of oil equivalent)	CO_2 per capita (tonnes)	Population
Qatar	21 395.8	63.1	841 000
United Arab Emirates	10 538.7	33.6	4 380 000
Iceland	11 718.0	7.6	301 000
Bahrain	10 250.5	31.0	753 000
Luxembourg	9 408.8	22.0	467 000
Netherlands Antilles	9 198.5	22.7	192 000
Kuwait	9 076.0	31.1	2 851 000
Trinidad and Tobago	8 555.1	22.1	1 333 000
Canada	8 300.7	17.9	32 990 000
United States	7 794.8	19.8	301 950 000

(a) Describe factors that contribute to the values in Table 1. (Use a map to locate countries you are unfamiliar with.)

(b) Knowing that "per capita" means per person, calculate the total carbon dioxide emissions from each of the countries. What do these calculations reveal?

(c) Repeat (b) for energy consumption. Rank the countries from highest to lowest total energy consumption.

(d) Predict changes that the data in Table 1 may undergo in the next 50 years. Give possible reasons for your predictions.

20. A large proportion of tree cutting in Canada supports the pulp and paper industry.

(a) Describe how we could change our habits to reduce our need for paper and paper products.

(b) How will these strategies help reduce climate change?

21. Research the current status of the global warming debate. Have the viewpoints converged at all? Describe any new evidence. What new tools are being used to gather evidence?

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22. Describe why warming in northern Canada is, or could be, a problem for

(a) the transportation industry

(b) the mining industry

(c) vegetation

(d) animals

(e) the construction industry

23. People have been cutting down and burning trees for thousands of years. Suggest reasons why these practices are becoming more widespread and more of a problem now than ever before.

24. There are a variety of new technologies designed to reduce the production of greenhouse gases, including more fuel-efficient vehicles, high-efficiency natural gas furnaces, and energy-saving technologies for the home. Select one new technology and research relevant information on it. Identify a target group of people, and prepare an advertisement (poster, video, audio, or Web) designed to promote their use of the technology you have researched.

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Reflect on Your Learning

25. In terms of GHGs, climate change, and global warming, are you concerned for the future? Describe your level of concern. What are you willing to do to positively influence the future climate?

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UNIT E

Review

Energy Transfer in Natural Systems

Unit Summary

In the first two chapters of this unit, you learned about the transfer of energy in natural systems. The transfer of energy from one location to another is the basis for the weather patterns and climatic conditions on Earth. In the last chapter, you used this knowledge to examine some of the evidence of climate change. You also learned about the various natural and human activities that contribute to theses changes, as well as the possible consequences for the environment and all living things.

To summarize your learning in this unit, design a brochure to inform the public of the concerns related to climate change. Your brochure should include a scientific explanation of the changes that have been observed, as well as predictions of future changes. The brochure should also explain how changes in one area affect other regions because of energy transfer systems that cross the globe. Sketch the visuals that will help explain the concepts. Include a panel with actions that individuals can take to lessen their contribution to global climate change.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

1. Match the term on the left with the phrase on the right.

Term	Description
(a) thermal energy	I. average kinetic energy of the particles in a substance
(b) heat	II. energy required to raise 1 g of material by 1 °C
(c) latent heat	III. the pressure exerted by a column of air above any point
(c) temperature	IV. energy associated with changes of state
(d) atmospheric pressure	V. total kinetic and potential energy of all particles in a substance
(e) specific heat capacity	VI. transferred thermal energy

2. Explain how heating causes the volume of an object to increase and its density to decrease.

3. Copy Table 1 into your notebook, then complete it.

Table 1

State	Possible forms of heat transfer	Examples
(a) solid		
(b) liquid		
(c) gas		

K 4. What happens when a container of a liquid is heated from above?
   A. Temperature imbalances create convection currents.
   B. Radiation travels right through the liquid, heating it evenly.
   C. The heated liquid expands, pushing the cooler liquid around.
   D. No convection occurs since the hotter material is already on top.

5. Convert the following temperature units:
   (a) 30 °C to kelvins
   (b) 260 K to degrees Celsius
6. Indicate whether each sentence is true or false. If false, rewrite the sentence to make it true.
   (a) When heated, gas particles expand and take up more space.
   (b) The kinetic energy of a particle depends only on its speed.
   (c) Heat is always transferred from hotter objects to cooler objects.
   (d) Cold objects do not emit radiant energy.
   (e) Water can transmit, reflect, and absorb radiant energy.
   (e) All radiant heat is in the infrared portion of the spectrum.
7. (a) List the sources of thermal energy responsible for the high temperatures within Earth.
   (b) What characteristics of Earth's crust prevent energy within from reaching the surface?
8. What topographic features affect the directions of prevailing winds as well as the directions of major ocean currents?
9. Explain how each of the following influences atmospheric pressure:
   (a) temperature change
   (b) increase in altitude
10. What makes Hadley cells the most powerful convection cells that circle Earth?
11. If you are standing on the shore of a very large lake on a hot, sunny afternoon, from which direction would you expect a breeze to be blowing? Explain your reasoning.

K 12. In a high-pressure air mass in the northern hemisphere, which way is the wind deflected?
   A. clockwise
   B. up and out
   C. in and right
   D. counterclockwise

K 13. Which are the key characteristics of low-pressure air masses?

I	warmer
II	sunnier
III	less dense
IV	higher moisture content

   A. I and III only
   B. I, II, and III only
   C. II, III, and IV only
   D. I, II, III, and IV

K 14. Which of the following is evidence of how climate change affects natural systems?
   A. El Niño
   B. shrinking permafrost
   C. measuring CO_2 levels
   D. narrower temperature extremes

K 15. Conduction is a method of thermal energy transfer that only occurs
   A. in a fluid.
   B. in empty space.
   C. when particles touch.
   D. when a substance is hotter at the bottom.

K 16. Currents caused by uneven heating in a fluid are called
   A. Coriolis effect.
   B. radiation.
   C. conduction.
   D. convection.

K 17. The atmosphere is
   A. a unit for measuring air density.
   B. a layer of gases enveloping Earth.
   C. the lower portion of Earth's external gas layer.
   D. the layer around Earth consisting of all water and gases.

18. You notice that over the last few days of December the air pressure has fallen dramatically. Describe the changes in weather that are most likely to accompany these pressure changes.

19. Describe how Canadian climate is influenced by El Niño and La Niña.

Use What You've Learned

20. Several days after a snowstorm, the roof of one house is completely snow-covered, but another roof has no snow. How is each house's insulation responsible for this difference?

21. Pizzas are often cooked at temperatures in excess of 200 °C. After they have been in the oven for 15 min, everything is very close to this same temperature: the air, the oven racks, and the pizza itself. However, when you reach into an oven to remove the pizza, your skin is not burned by the hot air but it is burned by the metal rack if you accidentally touch it. Explain.

22. In the 1947 Kon-Tiki Expedition, six adventurers sailed a raft across the Pacific Ocean. Which ocean currents and prevailing winds could have helped them?

U 23. Which industry is likely to have the greatest impact on global warming due to atmospheric greenhouse gases?
A. tourism
B. forestry
C. agriculture
D. transportation

U 24. Which statement best expresses why CO_2 is the most important greenhouse gas?
A. CO_2 is the most abundant greenhouse gas.
B. CO_2 is produced during the combustion of fossil fuels.
C. Volcanoes release CO_2 into the atmosphere during an eruption.
D. A molecule of CO_2 can absorb more heat energy than a molecule of any other greenhouse gas.

25. Explain how measuring the surface temperature of the Atlantic Ocean would help you forecast the strength of hurricanes in a particular season.

Read the following passage and answer questions 26 and 27.

> Paleoclimatologists can use fossils of tiny organisms called foraminifera to understand ocean temperatures of the past. These fossils are found deep in the sediments at the bottom of the oceans. One species of foraminifera lives in the cold waters of the Arctic and Antarctic. If the fossils of these cold-water foraminifera are found in the sediments at different locations in the oceans, scientists can infer that cold water must have existed at these locations during that period of Earth's history.

U 26. Which of the following best describes the role of a paleoclimatologist?
A. studies present climates to understand past climates
B. analyzes fossils of foraminifera to study ocean temperatures
C. determines past climates by analyzing fossil and other evidence
D. analyzes fossils to determine if they became extinct because of climate change

U 27. Shells of warm-water foraminifera are found in sediments at the bottom of the cold Arctic Ocean. What were the likely conditions in the Arctic Ocean at the time the sediments were deposited?
A. ice-covered
B. not ice-covered
C. deeper than it is now
D. much warmer than it is now

28. List five human activities you observed this week that had an impact on greenhouse gases.

29. Describe how deforestation may affect the future weather and climate
(a) on a global scale
(b) in the region surrounding the original forests

30. During an El Niño event, the fishing industry in Peru fails, but the fishery off the west coast of Canada reports catching fish that are not normally found there. Explain these changes.

Think Critically

HMP 31. Which of the following statements is supported by the information in Figure 1?

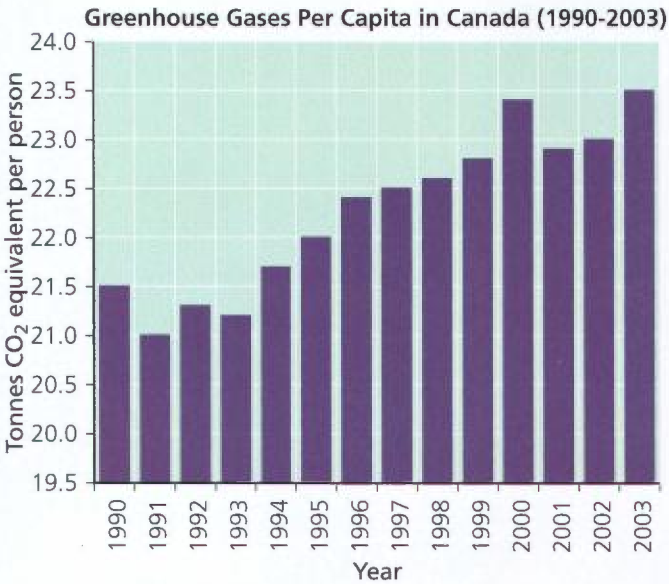

Figure 1

A. The amount of GHG emissions per Canadian citizen is increasing.
B. The amount of GHG emissions per Canadian citizen is decreasing.
C. Canada as a whole is reducing the total amount of GHG emissions.
D. Canada as a whole is increasing the total amount of GHG emissions.

32. In a brainstorming session, list as many careers as possible in which people would benefit by knowing about weather watches, advisories, and warnings. In a column, classify the careers under one of two headings: Nice to know the weather; Must know the weather.

33. Research the jet streams to find out when and how they were discovered. Report to the class briefly on what you learn.

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34. Prepare a concept web to show the social, economic, cultural, political, and environmental issues in the global warming debate. For example, one of the issues could be transportation. Identify key points related to this issue. Prepare a poster, and include quotations or pictures to illustrate the key points.

35. Write a possible scenario for a world in which the average global temperature increases by 3 °C. Discuss three effects this would have on your community and environment.

36. A carbon tax has been suggested as a way to reduce carbon dioxide emissions. Proponents believe that a tax will encourage people to conserve.
   (a) If the various greenhouse gases were taxed at different rates, which gas should be taxed the most? Explain.
   (b) In your opinion, do you think a carbon tax is realistic or practical? Explain.

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Reflect On Your Learning

37. List ten things you can do to prevent climate change. Which are you willing to do? If there are things that you are not willing to do, explain why.

38. The lifestyles in the developing world contribute few greenhouse gases compared to the lifestyles in the developed world. Yet, according to the Kyoto Protocol, some of these countries are expected to reduce their greenhouse gases by the same percentages as developed countries. Do you think this is fair? Explain.

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UNIT

F

PLATE TECTONICS

Unit Preview

Why is Earth so restless? What causes the ground to shake violently, volcanoes to erupt, and mountain ranges to continue to rise? Are the forces acting on Earth today the same as those in the geologic past? To answer these questions, you need to understand the structure of Earth and the geological, glacial, and fossil evidence that helps explain the changing Earth.

In this unit, you will learn how geologic events provide evidence of Earth's composition. You will also learn about the changing nature of our planet's surface and the events and processes that form it.

CHAPTER 17

The Dynamic Earth

Chapter Preview

Geology is the study of Earth and how it changes over time. Geologists study features such as mountains, coastlines, valleys, volcanoes, and earthquakes to understand past changes and predict future ones. Geophysics is the study of the processes that cause geologic change. New technologies such as global positioning systems (GPS) make new and better observations possible so that new theories can be developed.

What makes up Earth? How can we find out? How is this related to mountains, trenches, and other geologic features? Why are the same rock formations and fossils found on distant continents?

KEY IDEAS

- **Earth is composed of layers.**
- **Earth's outer layer has moved.**
- **Plates of the outer layer move continuously.**
- **This movement explains Earth's geologic features and events.**

TRY THIS: *Find the Inner Structure of a Wall*

Skills Focus: analyzing, conducting, communicating, recording

You could demolish a wall to discover its inner structure. But demolition is impractical because it is destructive, and often the structure is too large. How else can you find out about an object's internal structure?

Materials: strong magnet, painter's tape, wood-framed wall with a drywall surface

1. Mark a 1 m × 1 m area of the wall with painter's tape.
2. Tap the wall with your knuckle, moving across the area. Describe the sounds and draw a diagram indicating where the sound is different.
3. Cover the magnet with painter's tape so it does not mark the wall, then run the magnet over the area to locate the drywall screws. On your diagram, indicate the magnetic areas.

A. Did the magnetic and sound patterns on your diagram match?

B. On your diagram, indicate the location of the wall's frame.

C. How can locating screws help determine the internal structure?

17.1 Structure of Earth

Earth is nearly spherical, 12 800 km around at the equator. These facts were known more than 2000 years ago. However, it was only in the last 100 years that some understanding was reached about the internal structure of our planet. Today, we know that Earth is made up of layers (Figure 1).

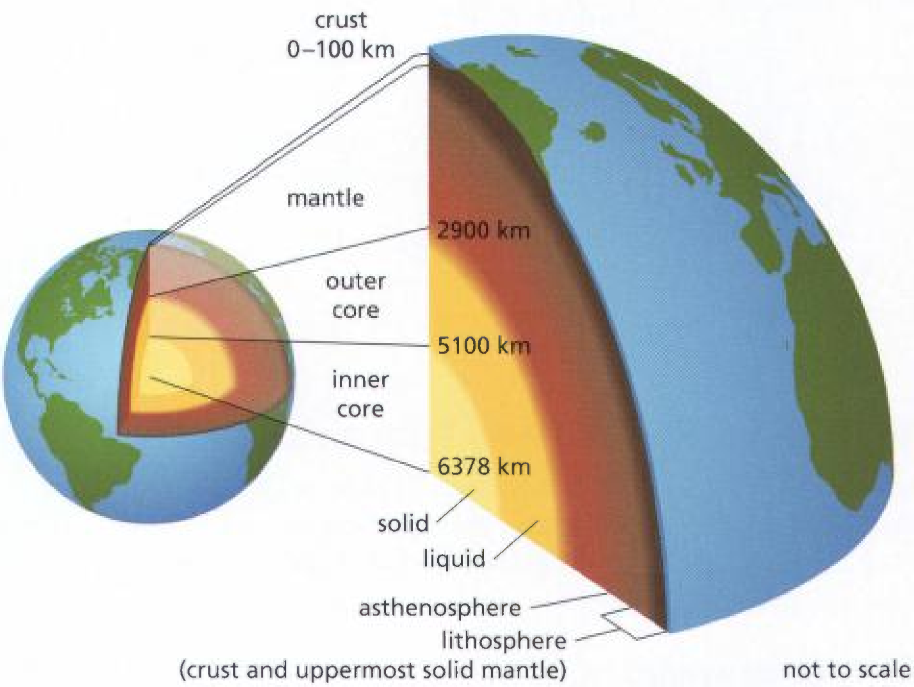

Figure 1 Each layer of Earth contains a different mix of materials and has distinct physical properties.

Earth's outermost layer is the **crust**, the rigid rock of the continents and ocean floors. The ocean floor crust is only 5–7 km thick, but is more dense than the continental sections. It is generally high in magnesium, calcium, and iron, but lower in silicon. The crust in the continents is 30–100 km thick, is less dense than the sea floor crust, and contains more silicon.

Under the crust lies the **mantle**, nearly 3000 km thick. There are three layers within the mantle that we will discuss. First, just beneath the crust is the solid outer mantle. Together with the crust, this layer forms the rigid **lithosphere**. Beneath the lithosphere is the **asthenosphere**. It is so hot and has so much pressure on it from the lithosphere above that it behaves like a viscous fluid, or soft plastic, even though it is solid mantle. Beneath that is a dense inner layer of lower mantle.

The core is the nearly spherical centre of Earth. It has a radius of about 3500 km with two distinct layers. The **outer core** consists of liquid iron and nickel, while the **inner core** is mostly very dense solid iron.

LEARNING TIP

Previewing gives you a quick glimpse into the content of the chapter. Skim Chapter 17 to note the headings, words in bold, and the graphics. What information is new to you? What topics do you need to pay attention to?

Did You KNOW?

Deepest Hole

In 1970, scientists began drilling a research well on Russia's Kola Peninsula, near the Arctic Ocean. Their goal was to sample the rock from as deep within Earth as possible. When they stopped drilling in 1994, the borehole was over 12 km deep. The temperature of the rock at the bottom was more than 180 °C, part of the reason they could not drill deeper. The surprising things they found along the way changed our understanding of Earth's crust.

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TRY THIS: *Can a Solid Act Like a Fluid?*

Skills Focus: analyzing, communicating, creating models, observing

The material in the lower mantle of Earth is a solid, but behaves like a fluid in some ways. This is because of the intense heat and pressure far beneath the surface. In this activity, you will observe a change in a substance's properties when under pressure.

Materials: 250 g creamed honey, wax paper, board, dinner knife

Push gradually, using proper body mechanics.

1. Cool the unopened container of honey to just below room temperature.
2. Remove the honey from the container in one big chunk by running the dinner knife around the edge of the container.
3. Place the honey on a 30 cm^2 sheet of wax paper. Observe the state of the honey and record your observations.
4. Place another sheet of wax paper over the honey and use a board to press down on the honey until it begins to squish.
5. Uncover the honey and record your observations again.
6. Tilt the wax paper under the honey and observe whether the honey will flow.

A. Before pressing, does the honey hold its shape? Does it provide resistance when you press gently on it? Is the honey a solid or a fluid?

B. After pressing, would you describe the honey as a solid or a fluid? Explain.

Finding Out About Earth's Structure

Scientists obtain information about the structure of Earth in a variety of ways. Through direct and indirect observations, geologists build a theory about the structure of Earth. Theories are tested in experiments and updated to include new discoveries.

Direct Observations

Volcanoes provide scientists with one of the best ways to directly observe Earth's interior. Some volcanoes bring molten rock from deep within Earth's mantle. Sampling ancient and fresh lava flows allows scientists to compare the minerals in magma to other minerals in rock at or near the surface (Figure 2a). Rock samples are also collected from holes drilled into Earth for oil exploration or mining (Figure 2b).

(a) (b)

Figure 2 (a) Sampling lava flows and (b) drilling rock samples are types of direct observation. The rock samples show light grey continental rock and grey-black rock of the ocean floor.

Indirect Observations

Scientists use observations made at the surface of Earth to make suggestions about the structures and processes underground. Sometimes measuring one thing can tell you a lot about something else:

- Measuring the magnetic field of layers of ancient lava flows gives a record of the strength and direction of Earth's magnetic field over time. This record can then be compared to measurements across the sea floor to make inferences about the age of sea floor rock.
- Measuring the local strength of gravity gives geologists clues about the density of material below the surface because denser rock increases the local gravity.

The most important tool for investigating the interior of Earth is the study of seismic waves. If you snapped your fingers under water in the sink, you would see waves on the surface. Imagine how those waves would be different in a sink full of honey. When slabs of Earth's crust break, crack, or slip by each other, they create waves through the surrounding rock. These **seismic waves** cause the destruction associated with earthquakes, but they also tell scientists about earthquake dynamics and the structure of Earth. The speed and direction of the waves change as they travel through different types of rock, just like the waves from a finger snap are different as they travel through water or honey. You will learn more about seismic waves in Chapter 18.

Modern Mapping

Mapping techniques allow scientists to plot the locations of geologic formations such as volcanoes, mountain ranges, lava flows, fossil beds, and ancient oceans. New remote sensing technologies make mapping increasingly accurate:

- satellite and aerial photography record vast areas (Figure 3);
- Global Positioning System (GPS) receivers are used to track very small movements (in millimetres per year) of Earth's crust; and
- infrared and radar images are combined to illustrate features not visible from Earth's surface.

Figure 3 The Coast Mountains are too big to see completely from the surface of Earth. Scientists use satellite images like this one to study such large features.

LEARNING TIP

Check your understanding of direct and indirect observation by explaining them to a partner. Try to use examples in your explanation.

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

Did You KNOW?

Seismographs

The same instrument that measures earthquake waves (a seismograph) can be used to monitor nuclear test detonations. It is impossible to test a nuclear device in secret because the explosion creates waves in Earth's crust that are easily detected all over the world. Mineral exploration also uses seismic wave studies, setting off small explosive charges to provide "mini-earthquakes" on demand. The analysis of the resulting waves helps predict where minerals can be found.

17.1

CHECK YOUR Understanding

1. Name the three main layers that make up Earth. List them in order starting at the outside, and describe their relative thickness.
2. Explain Earth's layers by comparing Earth to a familiar object such as an avocado (Figure 4). How are the layers similar? How are they different?

Figure 4

3. The lithosphere is composed of the rigid crust and the uppermost layer of the mantle. How does this top layer of the mantle differ from the underlying asthenosphere? Copy the Venn diagram in Figure 5, then complete it to compare their properties.

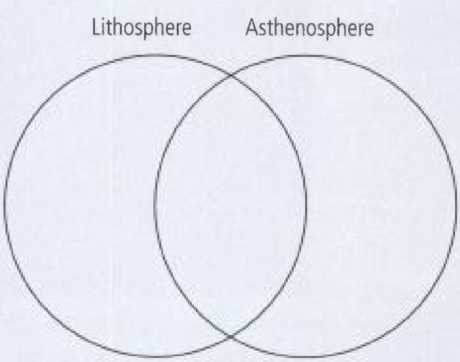


Figure 5

4. What extreme conditions cause the rock of the asthenosphere to act like a fluid?
5. What kinds of direct observation can be made about the structure of Earth?
6. How can measuring one thing provide clues about something else? Give an example.
7. Collecting lava samples is dangerous work; the rock is extremely hot and releases toxic gases. What makes these risks worthwhile?
8. By measuring the local strength of gravity, what can a scientist learn about formations on Earth?
9. Copy Table 1 and list methods scientists use to make observations about the interior of Earth. Explain one.

Table 1

Methods	Type of observation

10. Lava that solidifies on the surface cools quickly and forms small mineral crystals. Magma that solidifies underground cools slowly and forms large mineral crystals. Explain how examining rock core samples could help you infer where the rock formed.
11. No one has been able to collect samples or take direct measurements of each of Earth's layers. Why not?

17.2 Evidence of a Dynamic Earth

Today we know that the surface of Earth moves constantly. New sections of lithosphere are produced and older sections are recycled. The lithosphere is divided up into **tectonic plates**, both large and small pieces that float on the denser asthenosphere. Plate tectonics is the theory that explains this plate movement and its consequences. As the plates move past, over, and under each other, they cause volcanoes, earthquakes, and faults. As the plates spread apart or collide, they form mountains, rift valleys, and a global network of ocean-floor ridges. This theory took a long time to develop and involved many scientists from different fields of study. It also required new technology such as sonar to gather supporting evidence.

Continental Drift

When people began drawing fairly accurate maps of the world, they were intrigued by the apparent fit of the continents. It looked as if they were puzzle pieces that had been pulled apart (Figure 1). In 1912, German meteorologist Alfred Wegener was also intrigued by this. He knew other scientists had gathered evidence of several more geologic peculiarities:

- the puzzle fit of the continents (mainly Africa and South America)
- match of geologic features on distant coastlines (eastern Americas match western Europe and Africa)
- identical ancient fossils on distant coastlines (Africa, South America, Australia)
- the presence of coal deposits in non-tropical areas (Antarctica)
- evidence of glaciers near the equator (Africa)

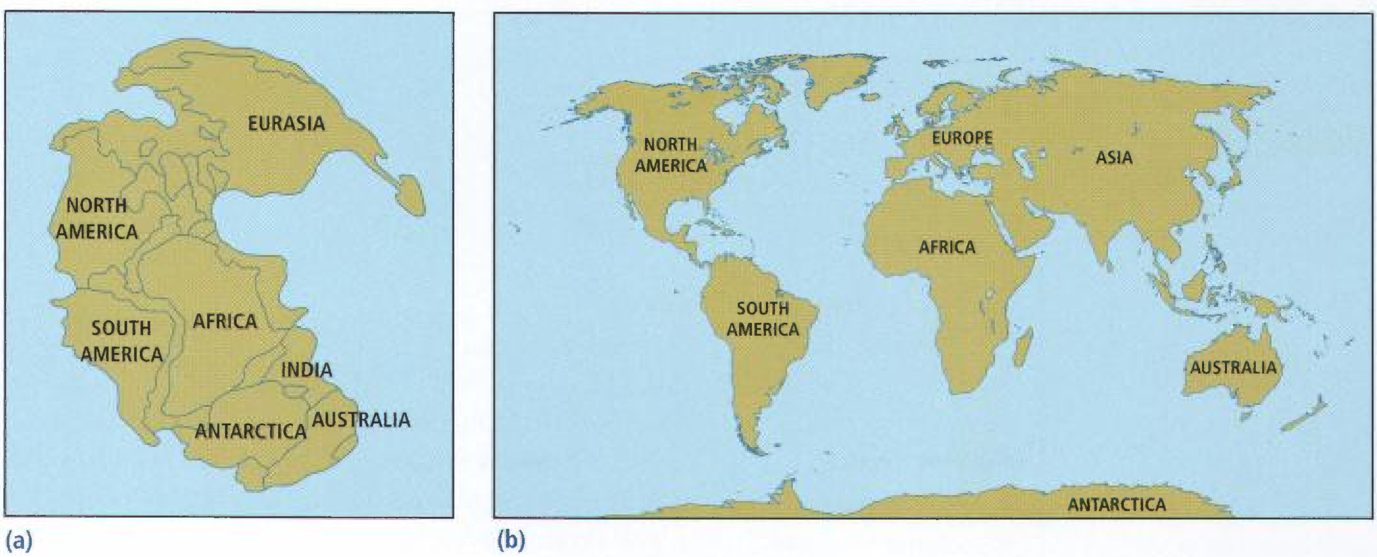


Figure 1 (a) Alfred Wegener suggested that about 270 million years ago, all of the continents formed a single landmass he called Pangaea. (b) The continents today.

Wegener proposed a radical idea to explain this evidence: **continental drift theory**. This theory argues that the continents have moved slowly since Earth formed, and were once joined together in a landmass called Pangaea.

The Fossil Record

Jigsaw puzzle fit is not the only reason to think the continents have moved. Some rare plant and animal fossils are found in distant parts of the world (Figure 2). For example, *Mesosaurus* was an aquatic reptile that lived during the early Permian era, more than 250 million years ago. Its fossilized remains have only been found in two places: on the southwest coast of Africa, and the southeast coast of South America. *Mesosaurus* was a fresh-water animal, so it would not have been able to migrate across the Atlantic Ocean. Wegener asked, had the continents been closer together so the animals could travel between them? As ridiculous as that may sound, Wegener felt that it was no more ridiculous than the common belief that many species migrated via "land bridges" that might once have existed between the continents. There was no evidence of such bridges.

STUDY TIP

You can use a table to help you organize information for studying. Make a three-column table with the following headings: Fossil Record, Matching Mountains, and Ancient Glacial Evidence. Under the appropriate heading, record important information in point-form notes. Include the words in bold in your notes.

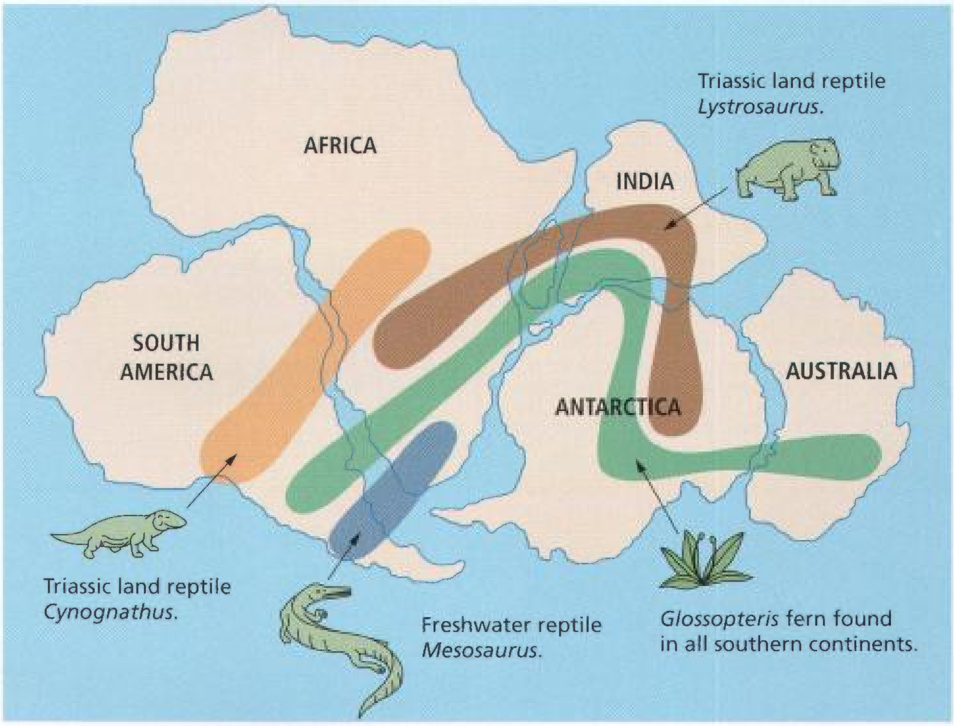


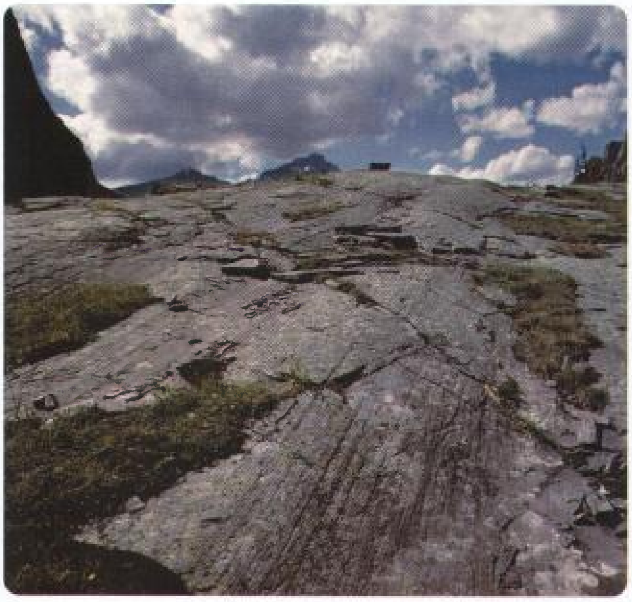
Figure 2 Certain land-animal fossil specimens like *Cynognathus* have been found only in small areas, but on both sides of the Atlantic ocean. *Glossopteris* was a giant fern that existed for only a short time. Even though it was a tropical plant, its fossils are found on every continent, including Antarctica.

Matching Mountains

Certain geologic features like mountain chains and ancient lava flows line up across distant continents. Folded mountains such as the Appalachians in the northeast United States have very distinct patterns of rock layers. This same pattern can be found in Britain and Norway as well as in South America and Africa. Large coal deposits (formed from lush tropical forests 350 million years ago) have been found far from the tropics, in Antarctica. For Wegener, this provided strong evidence that the continents had changed position.

Ancient Glacial Evidence

Glaciers scour the rock in their path (Figure 3) providing evidence of **paleoglaciation**, the extensive periods in which glaciers covered most of the continents. Glaciers existed where they could not today, such as near the equator in southern India. Did Earth's axis change or did the continents move? Wegener felt that continental drift was the simpler explanation.



(a)

(b)

Figure 3 (a) Glaciers scratch grooves into Earth's crust as they move, showing us their direction of movement. (b) Patterns gouged by glaciers more than 250 million years ago match up on Pangaea, as Wegener hypothesized.

Challenges to Continental Drift Theory

Wegener's ideas faced a lot of opposition from prominent geologists of the early 1900s. Many scientists supported his ideas (including those who made the discoveries mentioned above). However, it was hard to shake the belief in older theories. The age of Earth, for example, was a hot debate at the time. Estimates ranged wildly from 6000 years to 400 million years. Continental drift theory required a much longer time than that. It was not until the 1950s that radioactive dating of rocks supported the hypothesis that Earth is more than 4600 million years old.

More importantly though, Wegener could not provide strong evidence for how the continents were able to move over the surface of Earth. While important science groups were resistant to these new ideas, oil exploration geologists knew that understanding the kind of motions in Wegener's theory helped them find oil. In the next section, you'll learn about critical evidence from the sea floor gathered later, during the Second World War. This contributed to theories of how Earth's crust could move.

LEARNING TIP

Think back over Section 17.2. Ask yourself, "What evidence did Wegener propose to support his continental drift theory? What was considered by critics to be the weakness in his theory?"

17.2 CHECK YOUR Understanding

1. (a) Describe Wegener's continental drift theory.
   (b) List the evidence that Wegener used to support his theory.
2. Explain how the presence of coal deposits in Antarctica supports the theory of continental drift. Figure 4 shows a current world map.

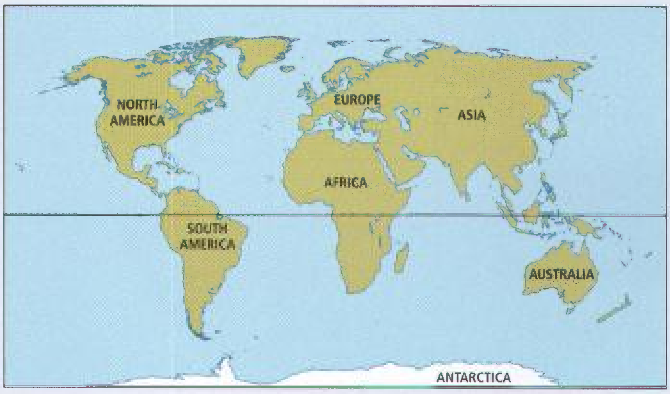


Figure 4

3. Wegener's critics argued that a much warmer climate in the past could explain the coal found in Antarctica. If Antarctica was once warm enough for coal-forming vegetation to thrive there, what do you think the equatorial regions would have been like?
4. (a) What kinds of evidence do glaciers leave behind?
   (b) Explain how the direction of motion of ancient glaciers can be determined.
   (c) What can explain evidence of ancient glaciers near the equator?
5. Explain why most geologists did not accept Wegener's continental drift theory at the time he proposed it.
6. (a) Name the landform in Figure 5.
   (b) How is this landform important to Wegener's theory?

Figure 5

7. (a) Pangaea can be used to explain the presence of similar fossils on opposite sides of the Atlantic Ocean. What other explanation was proposed?
   (b) Why did Wegener not accept this reason?
8. In Egypt, the Great Pyramids of Giza face slightly east of true north. Explain why the pyramids might not line up with true north as the builders likely intended. Assume that the builders 4500 years ago could determine directions accurately.

17.3 New Evidence of a Dynamic Earth

During Word War II, an American scientist named Harry Hess commanded a navy ship equipped with new technology that bounced sound waves off objects below to measure how deep they were. Hess realized that he could do some science at the same time as his military duty and kept the depth finder on at all times, even far out to sea. If the ocean floors were ancient and undisturbed, as was thought, then they should be flat and featureless. Instead, Hess found crevasses, trenches, mountain ridges, and volcanoes.

Undersea mountains were noticed by engineers laying the first trans-Atlantic telegraph cables, but the extent of the ridges was unknown. After World War II, oceanographers discovered a massive undersea mountain range running along the middle of the Atlantic Ocean. This Mid-Atlantic Ridge features a deep, wide canyon running the length of its centre. Other **mid-ocean ridges** were soon discovered, linking up and running 75 000 km throughout the world's oceans. Deep ocean trenches were also discovered along the edge of some continents. When plotted on a map, earthquakes and volcanoes line up along the ridges and trenches (Figure 1).

Did You KNOW?

Travel to the Ocean Floor

More people have been on the Moon than in the deepest place in the ocean. A crew of two reached the bottom of the Mariana Trench aboard the U.S. Navy research submersible *Trieste* in 1960. A Japanese remote submersible descended the 11 km in 1995, but no other submersible has since returned.

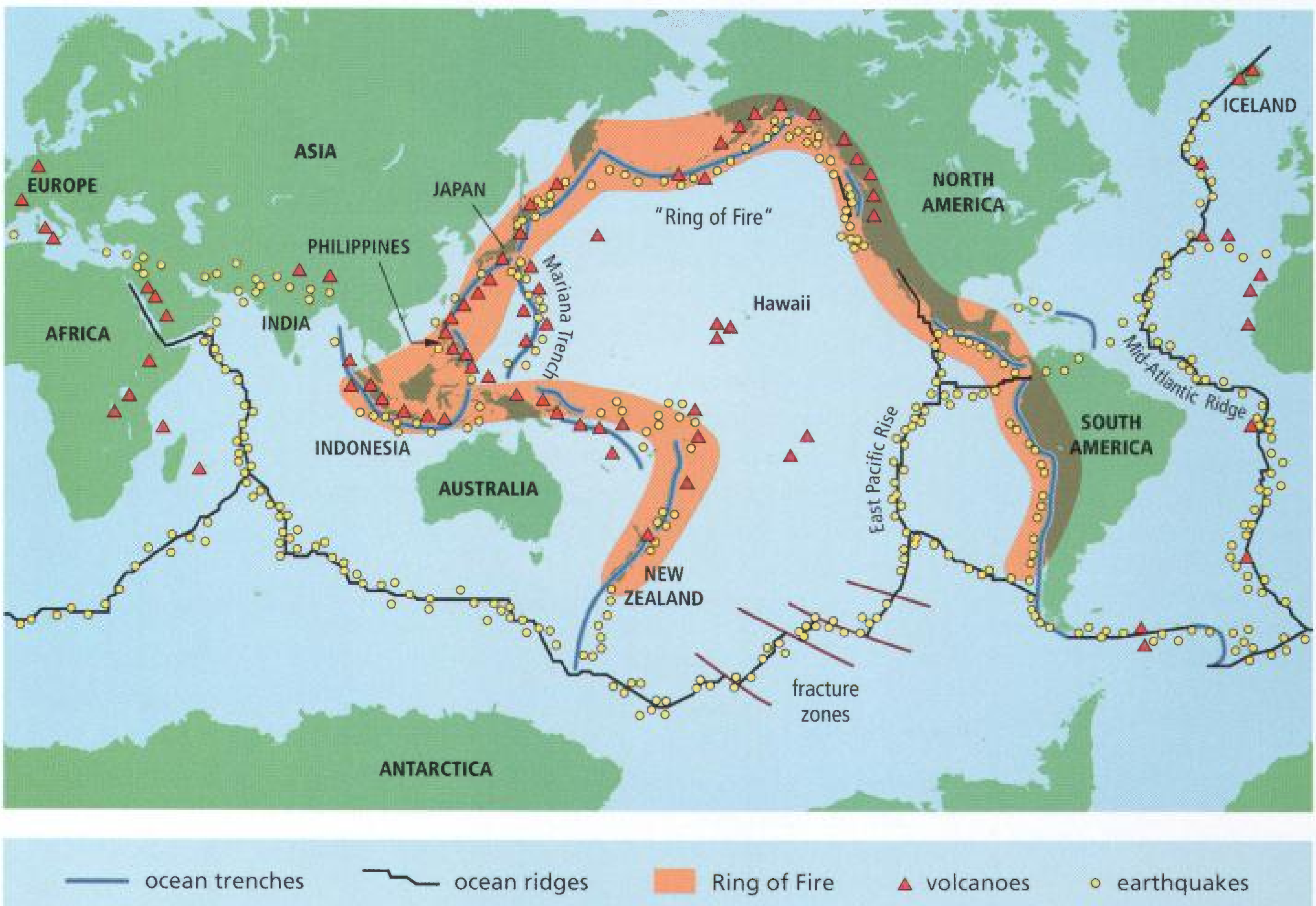


Figure 1 This world map shows how the distribution of volcanoes and earthquakes lines up with the network of ridges and trenches.

LEARNING TIP

Headings summarize primary topics within the section, while subheadings expand upon the topics. As you read pages 502 and 503, set a purpose for your reading by turning headings and subheadings into questions. Then read to answer the questions.

Sea-Floor Spreading

In 1960, Hess hypothesized that the sea floor was widening at the mid-ocean ridges (also called a spreading ridge). He called this process **sea-floor spreading** (Figure 2). Later work by Canadian Tuzo Wilson and others led to the understanding that the sea floor also cycled back into Earth at **ocean trenches**, the extensive elongated depressions where two plates converge. Molten magma from within Earth rises up and cools, filling the gap in the ridge with new rock. Hess thought convection currents in the mantle, proposed much earlier by British geologist Arthur Holmes, caused the spreading and forced the magma up. Chapter 18 examines this process in more detail.

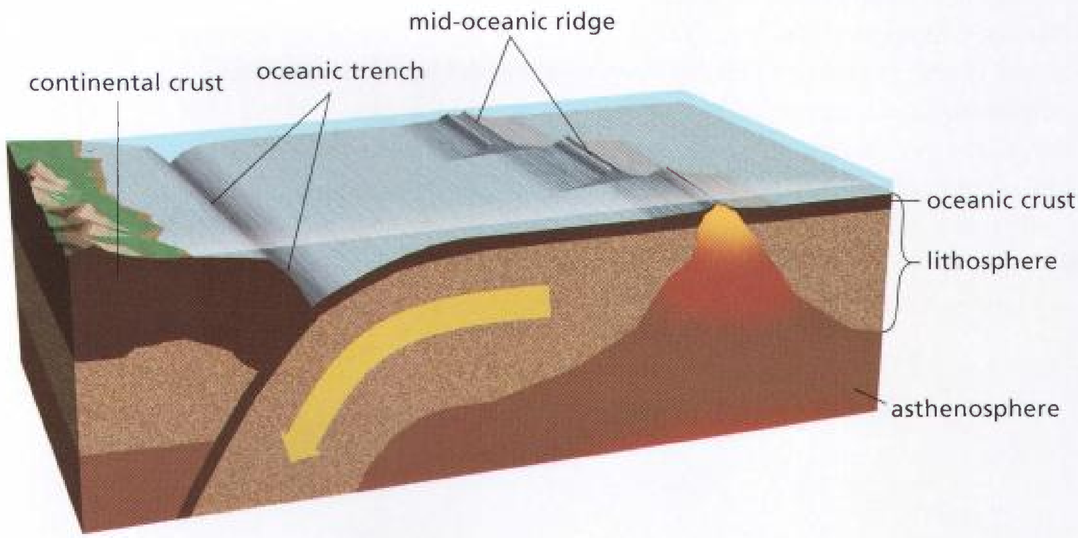


Figure 2 Sea-floor spreading happens when magma rises from the mantle, filling the crack left by the parts of the sea floor moving apart. In this example, the other edge of the sea floor is pushed beneath the continent. As it descends, it pulls the oceanic crust back into the mantle.

Did You KNOW?

Heat Measures Age

Between 1862 and 1897, the respected scientist Lord Kelvin calculated Earth to be about 24 million years old. He calculated the rate at which Earth would have lost the heat present from its formation and compared that to the current temperature. Unfortunately, he did not account for the heat that has been generated by natural radioactive decay, which was not discovered until 1898. Based on half-life measurements of certain substances, we now believe Earth to be about 4600 million years old.

Earth's Heat Source

Temperature increases closer to Earth's core, but where does this heat come from? Some heat is left over from the initial creation of the planet. Additional heat comes from naturally occurring radioactive substances as they break down and turn into other substances. By 1944, Arthur Holmes completed calculations showing that radioactive decay within Earth could provide the energy necessary for convection currents in the mantle.

Radioactive Dating

Radioactive substances decay (and turn into other substances) at a specific rate called the half-life, as discussed in Unit C. By comparing the amount of the original and new substances in a sample, the age of the sample can be determined. Ernest Rutherford demonstrated this technique in 1904, but it wasn't until the 1950s that the technique was sophisticated enough to give the age of rock drill core samples. Radioactive dating of core samples confirmed evidence that the sea floor is older the further it is from the ridges.

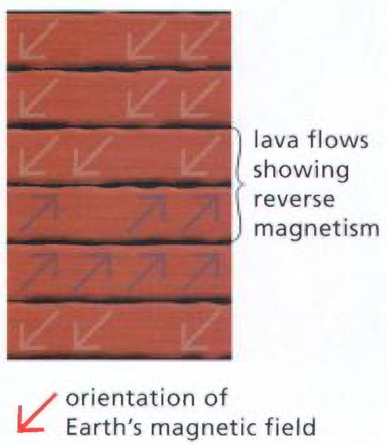
Magnetic Evidence

Basalt rock is rich in iron. When basalt lava cools and solidifies, the iron particles in the rock align with Earth's magnetic field, like a compass needle. Basalt lava flows record the orientation of Earth's magnetic field as the lava solidifies. In 1906, French physicist Bernard Brunhes examined layers of successive basalt lava flows and showed that Earth's magnetic field has reversed polarity repeatedly (approximately every 500 000 years). In the 1950s, British scientists Patrick Blackett and S.K. Runcorn studied the ancient magnetic patterns in British rock formations, which indicated that Britain had spun around and moved north in the past. Finally, in 1963, Drummond Matthews and Fred Vine of Cambridge University (and Canadian geologist Lawrence Morley, working independently) used measurements of the magnetic orientation of the sea floor to show a regular pattern of magnetic striping that was similar on both sides of the ridge. The mirror image pattern of magnetization (Figure 3) on the sea floor supported the theory that new ocean floor was being created at the mid-ocean ridges, and then slowly moving away from the ridge on both sides.

LEARNING TIP

Check your understanding. Use Figure 3 to describe to a partner how magnetic reversals were used to argue that the sea floor is spreading.

To find out more about the reversal of Earth's magnetic field, listen to the audio clip at **www.science.nelson.com**



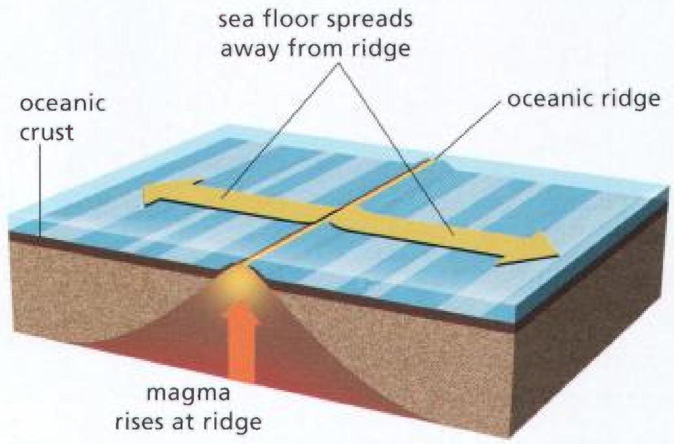


Figure 3 (a) By examining successive layers of ancient lava flows, we can see that Earth's magnetic field reversed many times, about every 500 000 years. (b) This is shown dramatically in the alternating bands of magnetic orientation, shown in different shades of blue, that radiate outward from the Mid-Atlantic Ridge.

Observations of the features of the ocean floor, radioactive dating of the ocean floor rock, patterns of magnetic striping in the rock, and radioactive decay providing an energy source to drive the process, all provided compelling evidence of sea-floor spreading. Earth's lithosphere was shown to be in motion.

17.3 CHECK YOUR Understanding

1. Describe the landscape of the ocean floor.
2. (a) What is the Mid-Atlantic Ridge?
   (b) What is the relationship between an ocean ridge and an ocean trench?
3. What new technologies allowed scientists to confirm that the sea floors are spreading?
4. Hess hypothesized that new sea floor was produced at ocean ridges.
   (a) Why are deep ocean trenches important to his hypothesis?
   (b) What would happen to the dimensions of Earth if the sea floor did not descend into the mantle at ocean trenches?
5. Which layers of Earth are involved in sea-floor spreading?
   A. crust and core
   B. core and mantle
   C. crust and asthenosphere
   D. lithosphere and asthenosphere
6. (a) List the sources of heat within Earth.
   (b) How does this heat contribute to mantle convection?
7. How do convection currents in the mantle contribute to sea-floor spreading?
8. Why does the sea floor bulge up at a spreading ridge?
   A. Rising mantle pushes up on the crust.
   B. Magma piles up as it rises from the mantle.
   C. Heated crust is less dense, so it floats higher.
   D. Friction curls up the edges of the crust as it moves.
9. Explain how the magnetic orientation of lava layers demonstrates reversals of Earth's magnetic field.
10. Describe how each of the following was used to argue that the sea floor is spreading.
    (a) magnetic reversals
    (b) age of rocks
    (c) mid-ocean ridges
    (d) deep ocean trenches
11. What evidence shows that the rock further from ocean ridges is older than rock closer to the ridges?
12. The colour coding in Figure 4 shows the age of the sea floor around the Juan de Fuca spreading ridge.

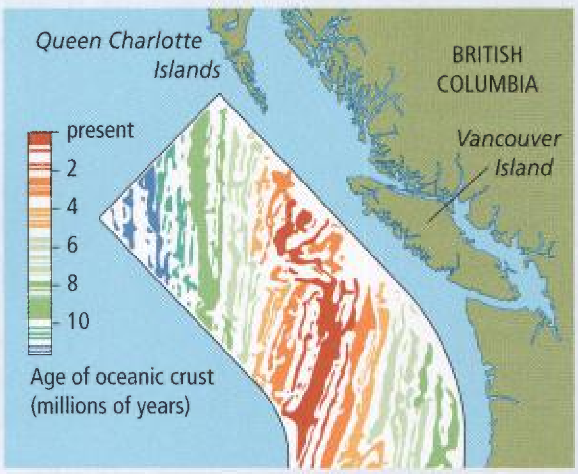


Figure 4

    (a) Which colour represents the current location of the spreading ridge?
    (b) The white regions indicate rocks with reversed magnetic polarity. Explain how the age and polarity of the rock suggests the ocean floor on either side of the ridge has moved.
    (c) In what direction is the sea floor spreading? How do you know?

17.4 Theory of Plate Tectonics

Over time, more evidence was gathered, and support grew for the idea of continental drift. But the theory that emerged said the continents weren't the only part of Earth's lithosphere that moves.

Plates that Make Up Earth

The **theory of plate tectonics** states that the lithosphere is divided into 12 large sections (plates) and about 20 smaller ones (Figure 1). These tectonic plates "float" on the more dense, fluid-like asthenosphere. Each plate moves in a different direction, so that some plates are moving away from each other, and others are moving toward each other. Some are moving past each other in opposite directions. Tectonic plates meet at three types of plate boundaries, defined by the movement there: divergent, convergent, or transform.

Did You KNOW?

Planetary Architecture

The word "tectonics" comes from the Greek word *tektonikós*, which means "relating to construction." You might think of plate tectonics as the construction of Earth's features.

To see an animation of the movement at plate tectonic boundaries, go to **www.science.nelson.com**

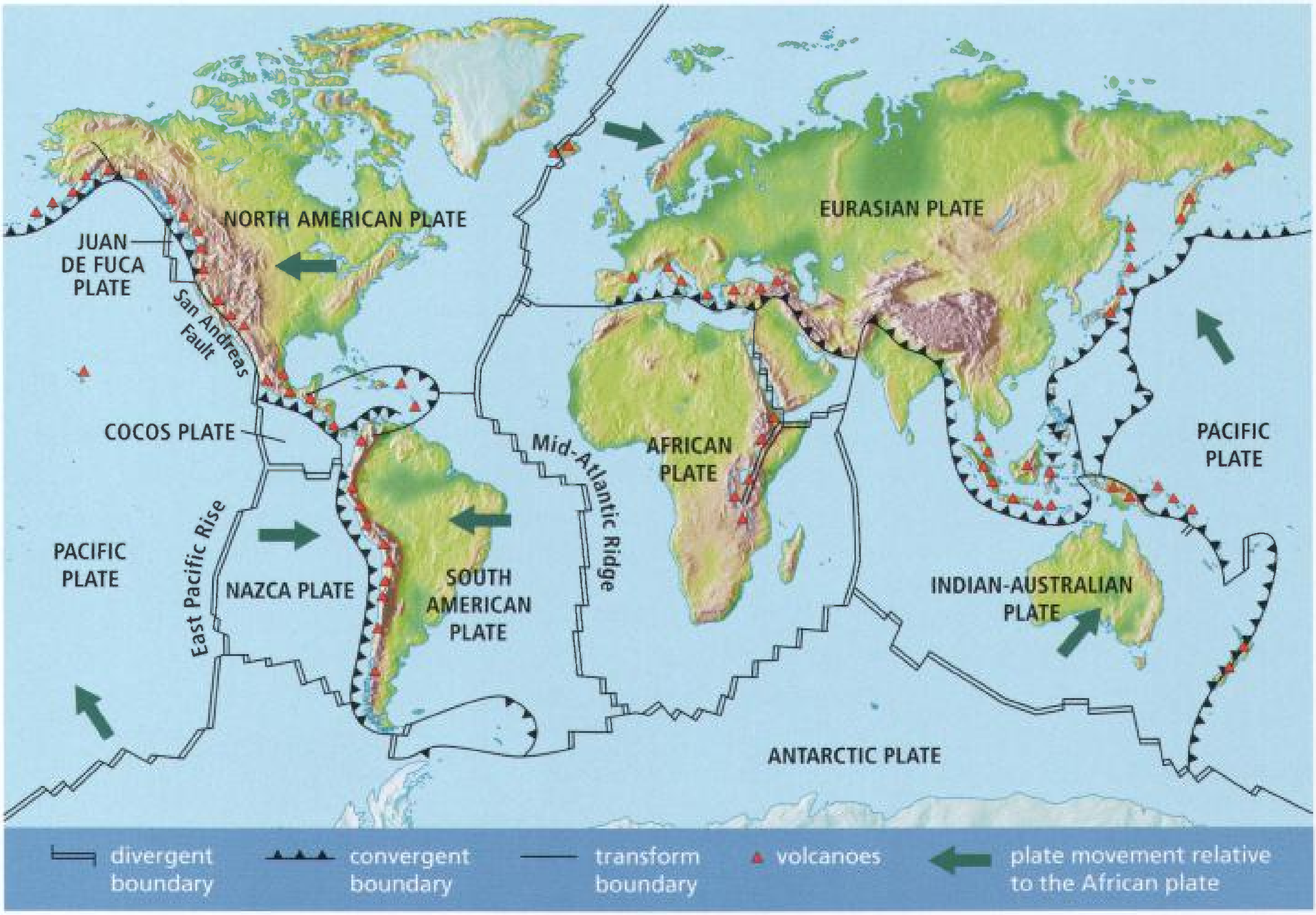


Figure 1 The symbols on this tectonic map tell us a lot about the movement of the tectonic plates. Since all the plates are in motion, their direction is given relative to the African plate, as if that plate were standing still. At a convergent boundary, the triangles point to the plate that is riding up and over the other. That means that the Juan de Fuca Plate is being pushed beneath the North American Plate.

Divergent Boundaries

The point where two plates move away from each other is called a **divergent boundary** (Figure 2). This creates shallow valleys or rifts. Most rifts are under the ocean (at mid-ocean ridges) and cover Earth like seams on a baseball. When a divergent boundary cuts across land, as it does in Iceland, it is called a **rift valley**. Small volcanoes and shallow earthquakes occur along these boundaries.

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

(a) (b)

Figure 2 Iceland lies on the divergent boundary between the Eurasian Plate and the North American Plate. (a) The road in this picture lies on the flat bottom of the rift. Elsewhere along the rift there are volcanoes. (b) At a divergent boundary, the plates are moving away from each other.

Convergent Boundaries

Plates moving toward each other collide at a **convergent boundary**. In some cases, the surface of one plate is scraped up, creating mountains (Figure 3). In other cases, one plate is pushed beneath the others creating a deep ocean trench at the boundary and a **subduction zone** where the two plates overlap. What happens at a convergent boundary depends on the types of plates involved:

- **oceanic–oceanic convergent boundaries** creates islands such as the Philippines
- **oceanic–continental convergent boundaries** create deep ocean trenches and parallel mountain chains such as that along the coast of B.C.
- **continental–continental convergent boundaries** create inland mountain ranges such as the Himalayas

STUDY TIP

There is lots of new vocabulary in this section. As you read, write unfamiliar words on study cards. Then read the section again, and write a definition for each word on the back of the card.

How high could a mountain get before it sinks into the ground? To find out, listen to the audio clip at www.science.nelson.com **www.science.nelson.com**

(a) (b)

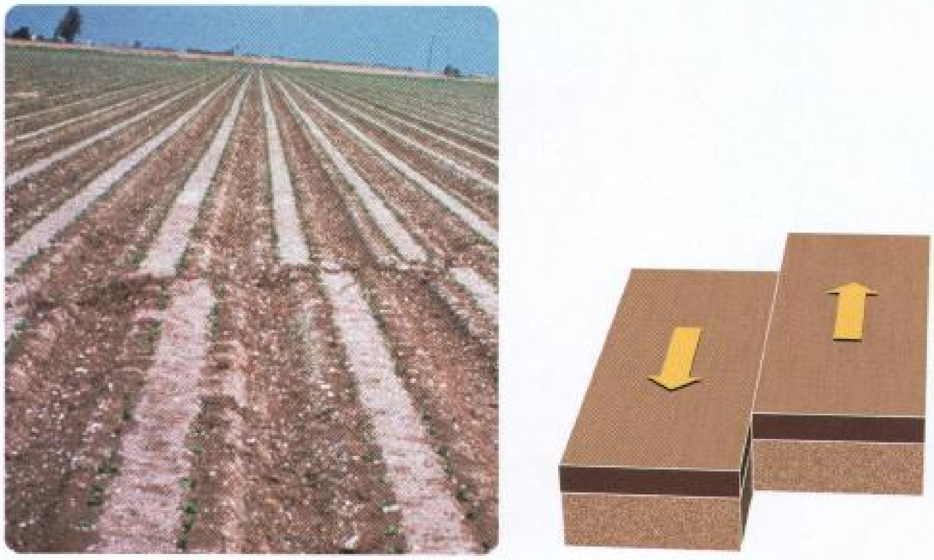
Figure 3 (a) Vancouver Island is an ancient layer of Earth's crust scraped up by the collision of the Juan de Fuca Plate with the North American Plate along a convergent boundary. (b) At a convergent boundary, tectonic plates are moving toward each other, and one plate will subduct beneath the other.

Transform Boundaries

At a **transform boundary**, plates move past each other in opposite directions (Figure 4). These are seen as **strike–slip faults**, where the land on either side of the fault line is moving in opposite directions parallel to the fault. Neither plate rides over the other, but the slip is not smooth; earthquakes often result.

LEARNING TIP

Active readers know when they have learned something new. After reading this section, ask yourself, "What have I learned about the theory of plate tectonics that I didn't know before?"



(a) (b)

Figure 4 (a) The tectonic plates beneath this farm moved after the field was ploughed, so the rows are now offset. (b) This farm lies above a transform boundary, where the plates are sliding past one another.

Note that each of these boundary types is related to the other. When one side of a plate is converging, the other side is diverging. Other areas of the plate may form a transform boundary with part of another plate. In Chapter 18, you will learn more about the effects of these tectonic movements. 17A ***Investigation***

17A ***Investigation***

Clocking Tectonic Plates

To perform this investigation, turn to page 510.

In this investigation, you will analyze evidence in the Hawaiian Islands to calculate the speed and direction of the Pacific plate over the past 300 million years.

TRY THIS: Simulate Plate Tectonics

Skills Focus: communicating, creating models, evaluating

You can use household materials to demonstrate your understanding of what happens at plate boundaries.

Possible Materials: pieces of paper, foam rubber, jelly-filled layer cake, lasagna

1. Using common materials, build a model of convergent boundaries.

A. Present your demonstration to a family member or classmate. Can they see how mountains and trenches are formed when tectonic plates collide?

B. Evaluate your model, identifying how it is like and how it is not like plate tectonics.

17.4 CHECK YOUR Understanding

1. Outline the theory of plate tectonics.
2. If all the tectonic plates are moving, why doesn't the African plate in Figure 5 have an arrow on it?

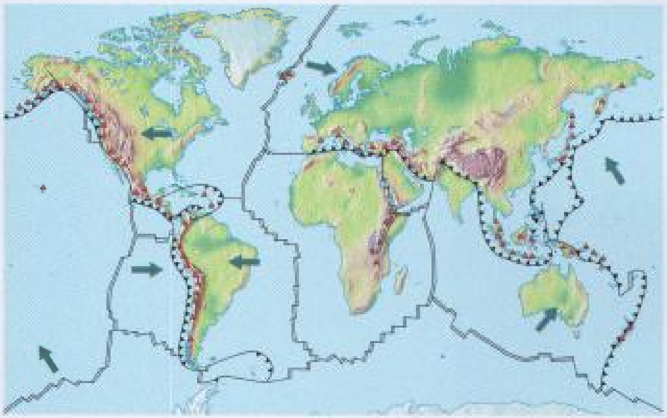


Figure 5

3. Describe where on Earth there is a
   (a) transform boundary
   (b) divergent boundary
   (c) convergent boundary
4. Draw diagrams to illustrate the type of movement that occurs between tectonic plates at a
   (a) divergent boundary
   (b) convergent boundary
   (c) transform boundary
5. What geological feature do you expect to find at a divergent boundary?
6. What kind of plate boundary is related to the formation of a mountain range?
7. Based on the theory of plate tectonics, how are mountains built?
8. Do tectonic plates slip smoothly by each other? Describe what you might experience at a transform boundary.
9. (a) What is a strike–slip fault?
   (b) At what kind of plate boundary would you find one?
10. Consider what happens at a convergent boundary, where the sea floor subducts beneath the crust of the continent. Which type of crust do you think is denser? Explain.
11. How is a subduction zone associated with a convergent boundary?
12. (a) Figure 6 shows the Cocos Plate. In which direction is the plate moving?
    (b) At the convergent boundary, is the Cocos Plate sinking beneath the continent or rising over the top? How do you know?

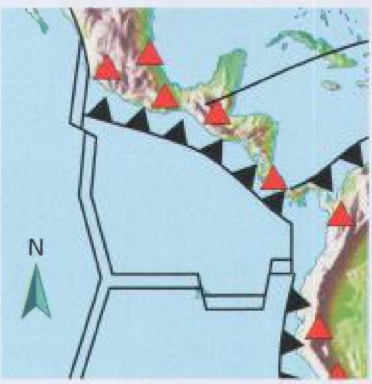


Figure 6

13. Draw the tectonic map symbol you would see at a
    (a) mid-ocean ridge
    (b) strike-slip fault
    (c) subduction zone

Tech **CONNECT**

MORE THAN A MAP, GPS CAN HELP PREDICT EARTHQUAKES

With satellite technology and a GPS receiver, anyone can know their location on Earth to within a few metres. This same technology may help predict earthquakes.

Global Positioning System (GPS) receivers are familiar items in cars, boats, and airplanes as well as in the hands of wilderness adventurers. They can help people find where they are, or where they're going. They can also help businesses track their vehicles around the world.

GPS uses a receiving unit that gets information from a network of more than 24 satellites. The receiver measures signals from at least three satellites to determine its own location, a process called triangulation. Other applications help it calculate speed and direction, create maps, and give directions.

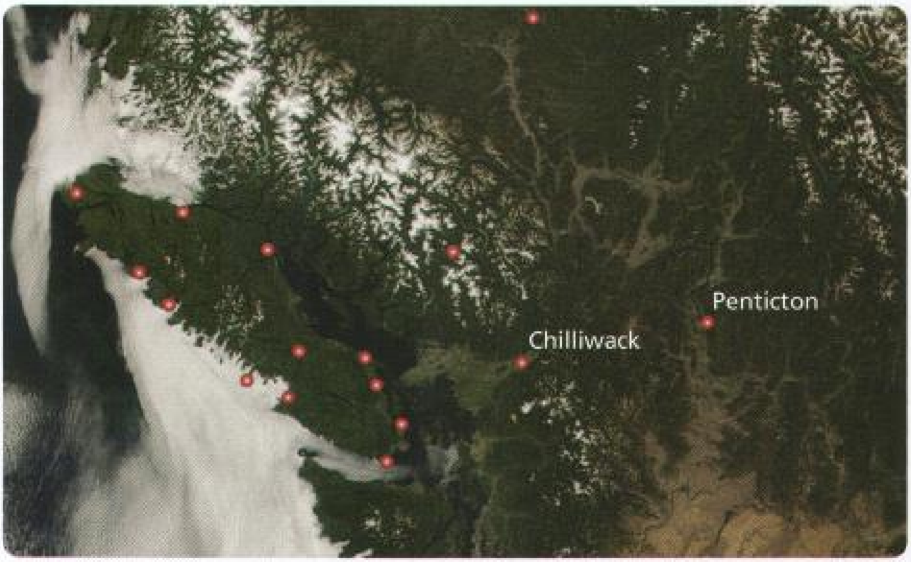
You might think that tracking an ocean tanker is a big application, but nothing is bigger than tracking the movement of Earth's tectonic plates. Scientists are using GPS to track movements and deformations in Earth's crust. While they gain understanding today, they hope that in the future this technology will help predict earthquakes.

Twelve GPS receivers are mounted in the bedrock throughout British Columbia to monitor movement of Earth's crust (Figure 1). The U.S. Geologic Survey has another network in the Pacific Northwest, including some on the ocean floor. GPS data helps track changes in the location and height of each station relative to the base station in Penticton, B.C. This gives scientists an idea of how the crust is compressing and bending due to the movement of tectonic plates.

Recently, Vancouver Island was measured to be moving toward Penticton at 10 cm per year, but towards Chilliwack at only 7 cm per year. The crust is bulging and building up tension. During two weeks in the summer of 1999, GPS receivers detected that Vancouver Island moved about 4 mm away from Penticton; about a 20 mm change at the plate boundary. Had this happened quickly, this could have caused a magnitude 6.7 earthquake.

There is considerable evidence that "mega-thrust" earthquakes have occurred on the Pacific coast at regular intervals. In 1946, there was a magnitude 7.3 earthquake near Courtenay, and the oral history of coastal First Nations recorded a massive earthquake and tsunami in the 1700s. Archeological evidence confirmed this tsunami. By tracking the deformation of the continental coastline, scientists hope to be able to predict a dangerous build-up of stress, and the next massive earthquake.

(b)



(a)

Figure 1 (a) The locations of the GPS receivers in B.C. that make up the Geological Survey of Canada's Western Canada Deformation Array (WCDA). (b) GPS receiver stations sit on cement columns secured to Earth's crust. They use solar power to collect data.

17A Investigation

Clocking Tectonic Plates

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

The speed at which tectonic plates move can be measured by several techniques. Global Positioning System receivers anchored to bedrock can track today's movement, but how can you learn about earlier movement?

Chains of volcanoes can be created when a tectonic plate moves over a spot of hot rising mantle. The distance between the volcanoes depends on how fast the plate moved. When combined with the known age of each volcano (by radioactive dating), you can plot the past speed and direction of a plate.

Questions

How fast, and in what direction, has the Pacific Plate been moving?

Prediction

Write a prediction based on the question asked above.

Experimental Design

You will measure the distance between the volcanoes in the Hawaiian Islands and combine this with the known age of the islands to calculate the historical movement of the Pacific Plate.

Materials

- ruler, marked in millimetres
- calculator
- scale map of the Hawaiian Islands (Figure 1)

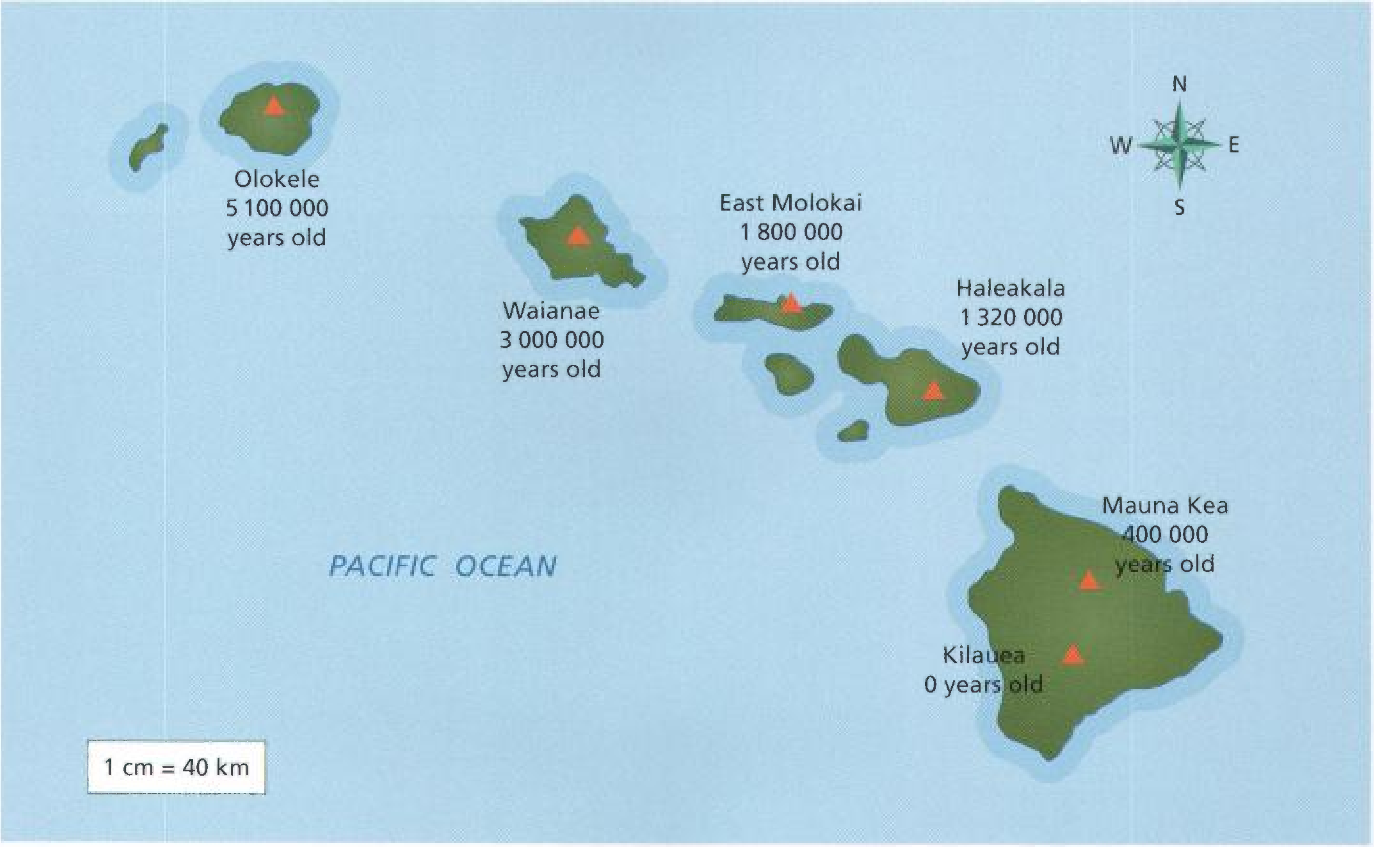


Figure 1 The Hawaiian Islands

Procedure

1. Copy Table 1 into your notebook.

Table 1

Volcano	Distance to next volcano (km)	Time until next volcano (yr)	Speed (cm/yr)
Olokele			
Waianae			
East Molokai			
Haleakala			
Mauna Kea			
Kilauea	0	0	0

2. Using the scale map provided in Figure 1, measure the distance between Olokele and Waianae. Measure from the centre of each volcano, marked by a triangle. Record the distances in centimetres, to one decimal place. Measure the distances between each of the remaining volcanoes.
3. Convert your measurements to kilometres using the scale shown on the map. Record this value in the table.
4. Calculate the difference between the ages of the volcanoes. How many years passed between the formation of each island in the chain? Record these values in the table.
5. Calculate the speed at which the plate moved between the formation of each island using the equation

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

A sample calculation has been done for you.
Sample calculation:

$$\text{distance} = 50 \text{ km, time} = 400\,000 \text{ yr}$$

$$\text{speed} = \frac{50 \text{ km}}{400\,000 \text{ yr}}$$

$$= 0.000125 \text{ km/yr}$$

6. Convert the speed to centimetres per year. Remember that 1 km = 100 000 cm. Record this value in the table.

Sample calculation:

$$\text{cm/yr} = \text{km/yr} \times \frac{100\,000 \text{ cm}}{1 \text{ km}}$$

$$= 0.000125 \text{ km/yr} \times \frac{100\,000 \text{ cm}}{1 \text{ km}}$$

$$= 12.5 \text{ cm/yr}$$

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation

Analysis

(a) Which volcano is the oldest? Which is the youngest?

(b) When was the Pacific Plate moving the fastest? The slowest?

(c) Explain how you could calculate the average speed of the Pacific Plate over the past five million years, then calculate the value.

(d) In what direction is the Pacific Plate moving? Explain how you know.

Evaluation

(e) Identify possible sources of error.

(f) Evaluate carefully how you measured the distance between volcanoes. How does the method or accuracy of this measurement affect the calculation of the distance and speed?

(g) If the distance between volcanoes is measured in kilometres, why is speed given in cm/yr?

(h) What major assumption is made about the spot of rising mantle when plate speed is calculated this way? If this assumption is incorrect, how might this change your results?

To perform this investigation with an interactive map of the Hawaiian Islands, go to **www.science.nelson.com** GO

CHAPTER 17

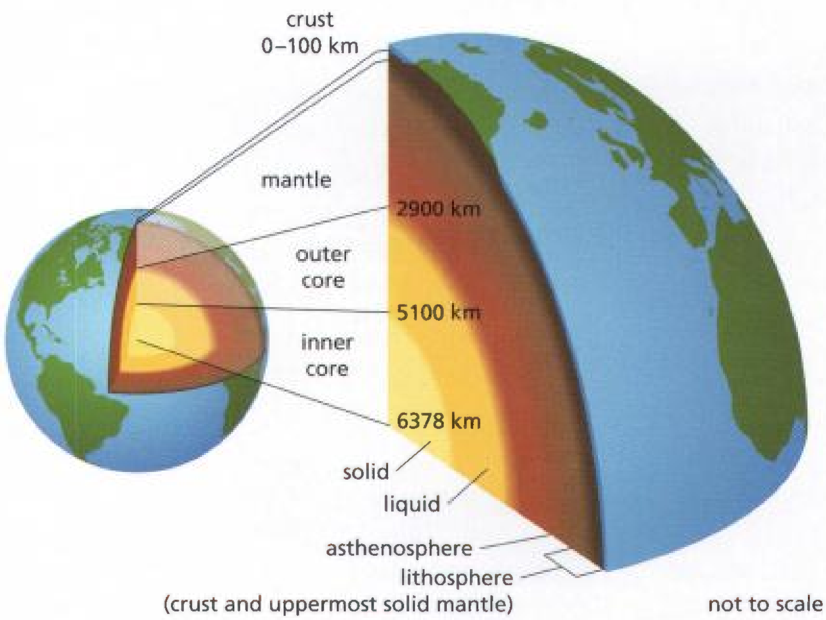
Review

The Dynamic Earth

Key Ideas

Earth is composed of layers.

- Distinct properties define Earth's three main layers: crust, mantle, and core.
- The crust is the rigid outer layer that makes up the continents and sea floors.
- The lithosphere is a region formed by the crust and the rigid outer layer of the mantle.
- The asthenosphere is the fluid-like layer of mantle beneath the lithosphere.
- Earth's centre has two layers: a liquid outer core and a solid inner core.



Earth's outer layer has moved.

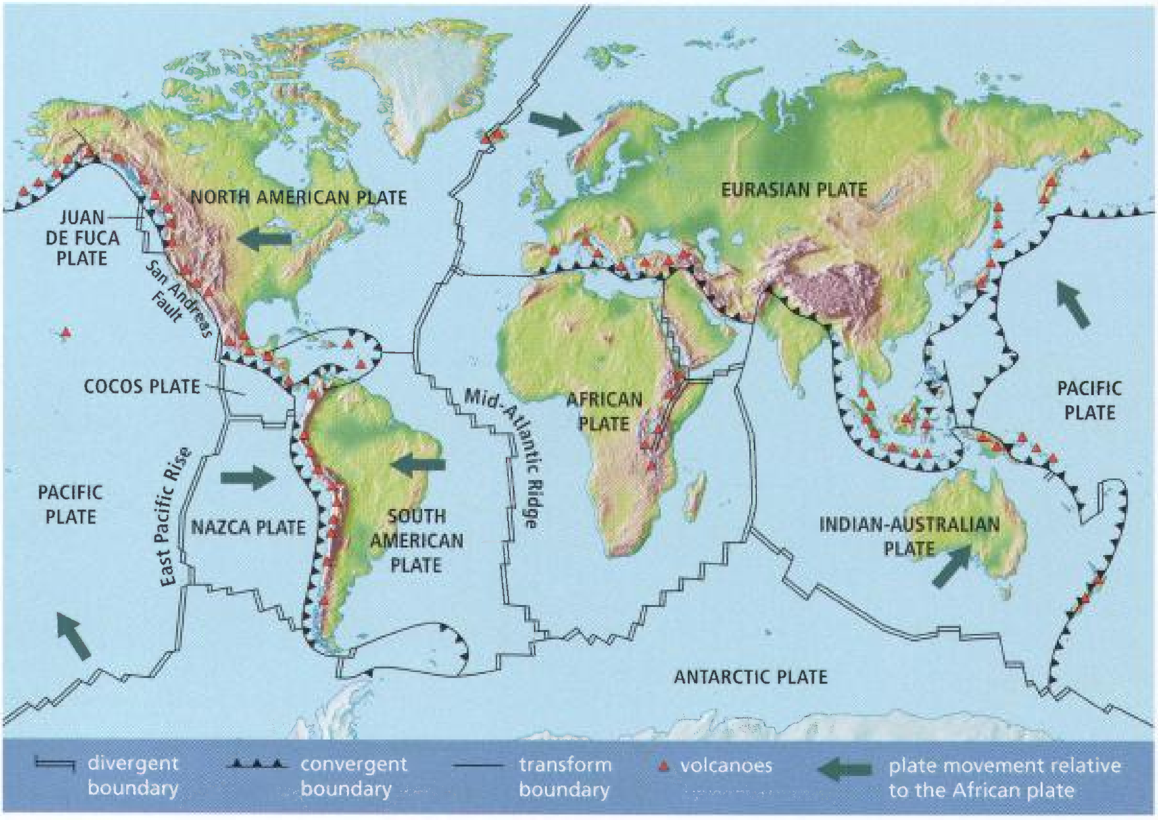
- Continental drift theory argues that the continents have moved slowly since Earth formed.
- Continents on either side of the Atlantic fit together like puzzle pieces.
- Fossil and geologic evidence shows the continents have been in other locations.
- At one time, the continents formed Pangaea, a single huge landmass.

Vocabulary

crust, p. 493
mantle, p. 493
lithosphere, p. 493
asthenosphere, p. 493
outer core, p. 493
inner core, p. 493
seismic wave, p. 495
tectonic plate, p. 497
continental drift theory, p. 498
paleoglaciation, p. 499
mid-ocean ridge, p. 501
ocean trench, p. 502
sea-floor spreading, p. 505
theory of plate tectonics, p. 505
divergent boundary, p. 506
rift valley, p. 506
convergent boundary, p. 506
subduction zone, p. 506
oceanic–oceanic convergent boundary, p. 506
oceanic–continental convergent boundary, p. 506
continental–continental convergent boundary, p. 506
transform boundary, p. 507
strike–slip fault, p. 507

Plates of the outer layer move continuously.

- Plate tectonic theory explains the mechanisms by which tectonic plates move over the asthenosphere.
- The lithosphere is divided into massive tectonic plates that are pushed and pulled over the asthenosphere.
- Heat within Earth creates convection currents in the mantle that help move the plates.
- Sea floors are spreading at mid-ocean ridges and subducting at deep ocean trenches.



This movement explains Earth's geologic features and events.

- Three types of boundaries exist where tectonic plates meet. These create Earth's geologic features and events.
- Ridges and rifts, volcanoes and earthquakes, are created at divergent boundaries, where plates are moving away from each other..
- Earthquakes and strike-slip faults are created along transform boundaries, where plates move past each other in opposite directions.
- At convergent boundaries (where plates move toward each other), we find mountains, trenches, subduction zones, volcanoes, and earthquakes, depending on the types of plates involved.

Many of these questions are in the style of the Science 10 Provincial Exam.
The following icons indicate an exam-style question and its cognitive level.
K Knowledge **U** Understanding and Application **HMP** Higher Mental Processes

Review Key Ideas and Vocabulary

K **1.** Which layer of Earth is liquid?
A. outer core
B. lithosphere
C. outer mantle
D. asthenosphere

K **2.** Which layer of Earth is most dense?
A. crust
B. inner core
C. outer core
D. lower mantle

K **3.** What separates Earth's layers?
A. hard crust
B. flexible membranes
C. measures of distance
D. distinct set of properties

K **4.** The temperature increases closer to Earth's core. Where does this heat come from?
A. radiation from nuclear testing
B. absorbed heat from burning coal
C. the Sun's radiation trapped by atmosphere
D. radioactive decay and heat remaining from planet formation

K **5.** Which of the following did Wegener use as evidence of continental drift?
A. location of earthquakes
B. presence of mid-ocean ridges
C. magnetic striping on ocean floor
D. similar rock types on different continents

K **6.** At what location does mantle rise up, creating new crust that wedges plates apart?
A. subduction zone
B. divergent boundary
C. transform boundary
D. convergent boundary

K **7.** Which layer(s) of Earth make up the tectonic plates?
A. lithosphere
B. continental crust only
C. continental crust and ocean crust
D. asthenosphere and top layer of mantle

K **8.** At which type of plate boundary are mid-ocean ridges found?
A. divergent
B. transform
C. convergent
D. inconsistent

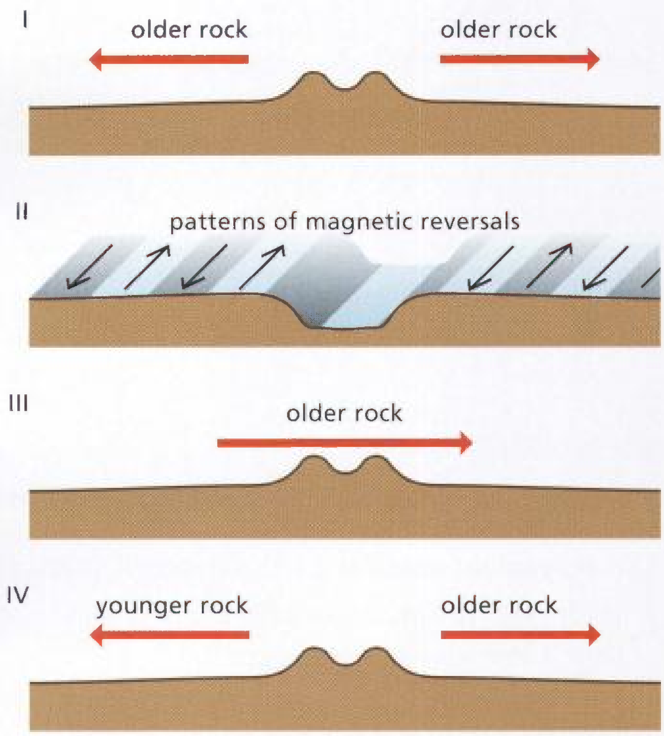
K **9.** What type of plate boundary creates a deep ocean trench along the edge of a continent?
A. oceanic–oceanic transform
B. continental–oceanic convergent
C. continental–continental divergent
D. continental–continental convergent

10. Draw labelled diagrams to compare the three main types of plate boundaries.

11. What is Pangaea? How was it used in the development of the continental drift theory?

Use What You've Learned

U **12.** Which of the following diagrams provide evidence for sea–floor spreading?



A. I only
B. I and II only
C. II and III only
D. IV only

U 13. What kind of plate boundary is circled on the map in Figure 1?

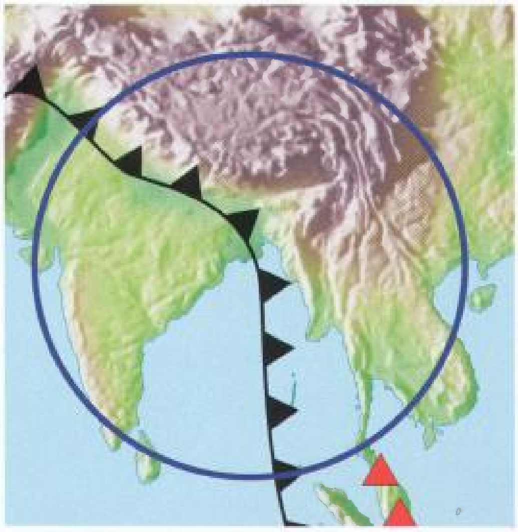


Figure 1

A. divergent boundary
B. transform boundary
C. convergent boundary
D. congregate boundary

14. How did Wegener's continental drift theory explain the evidence of glaciers on land that is near the equator today?

15. While visiting the town of Hollister, California, your friend notices some of the sidewalk curbs are broken and shifted offline. She notices the same misalignment on the other side of the street. What kind of plate boundary is the town built on? Explain the evidence to your friend.

16. (a) Name the process that Harry Hess believed caused the movement of the sea floor, as shown in Figure 2.
(b) What layers of Earth are involved in this process?
(c) What do the arrows represent?
(d) Name two geological features this produces.

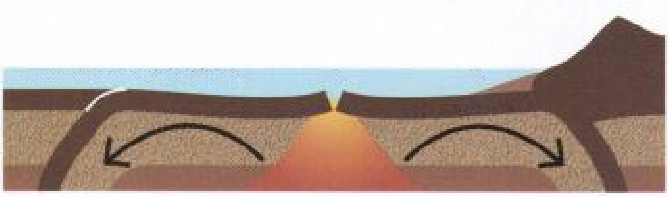


Figure 2

17. Using print and electronic resources, create a timeline of technologies and discoveries that contributed to the continental drift theory and the plate tectonic theory. Highlight the contributions of Canadian scientists and technologies.

www.science.nelson.com GO

Think Critically

HMP 18. What would happen if Earth expanded at the same rate that new sea floor was created?
A. Mantle convection would stop.
B. Subduction zones would not exist.
C. A new super-continent would be created.
D. The continents would get closer together.

HMP 19. Pangaea formed about 270 million years ago, and Earth is nearly twice that old. Which of the following statements is true?
A. Continental drift started around 250 million years ago.
B. The asthenosphere formed continents before Pangaea.
C. The lithosphere did not break into plates until Pangaea separated.
D. Pangaea is just one formation made by the tectonic plates since Earth was created.

Reflect on Your Learning

20. Most scientists who supported the continental drift theory faced significant opposition and even ridicule from their colleagues. Can you think of situations where you have been dismissed lightly, only to be proven correct later? Or maybe you dismissed someone else's idea. What do you think contributed to the initial disbelief?

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

CHAPTER 18

Plate Tectonics

Chapter Preview

Most geologic processes take millions of years to shape Earth: glaciers creep across the continents, rivers erode deep canyons, lakes fill and empty, and tectonic plates create mountains and rift valleys. When geologic change happens quickly, it endangers people nearby. How can people assess the risks of a volcanic eruption or an earthquake where they live? Is it possible to predict when and where these will happen? Investigating tectonic processes and understanding the underlying mechanisms that shape Earth will help answer these questions.

KEY IDEAS

- Three factors cause the movement of Earth's tectonic plates.
- Forces at plate boundaries produce landscape features.
- The interactions of tectonic plates cause volcanoes and earthquakes.
- Earthquakes send waves through Earth.

TRY THIS: Simulate an Earthquake

Skills Focus: creating models, observing, evaluating

Friction between tectonic plates can pause the motion, but the tectonic forces that cause the movement continue to build. Eventually, the tectonic forces overcome the friction, resulting in an earthquake.

Materials: 2 foam rubber blocks (about 10 cm × 20 cm × 5 cm)

1. Place two foam rubber blocks flat on a table, long edges together.
2. Keeping a slight pressure toward the seam, slowly slide the blocks in opposite parallel directions. If the blocks slide smoothly, push harder toward the seam.
3. Observe the behaviour of the blocks on each side of the seam.

A. What happened along the seam? Describe the motion.

B. Did the foam on either side ever distort?

C. If these were sections of Earth's lithosphere, what would you see and feel as they moved?

18.1 Causes and Effects of Plate Movement

In the previous chapter, you learned about the role convection currents in the mantle play in sea-floor spreading. Can that alone explain the movement of tectonic plates? Consider that the Pacific Plate is moving at 10 cm per year, almost five times faster than the North American Plate. This suggests other forces are at work.

STUDY TIP
As you read, "think like a teacher" and try to predict exam questions for Chapter 18. Ask yourself, "In preparing an exam for this chapter, what questions would I include?"

Moving Tectonic Plates

Scientists now believe that three forces work together to move the tectonic plates: mantle convection, ridge push, and slab pull (Figure 1). Just how much each force contributes to the process is not yet known.

Mantle Convection

Hot mantle rises at one place, then cools and falls at another. This creates convection currents within the mantle known as **mantle convection**. Friction between the mantle and lithosphere moves the crust along, similar to how floating herbs are moved to the sides in a pot of boiling soup.

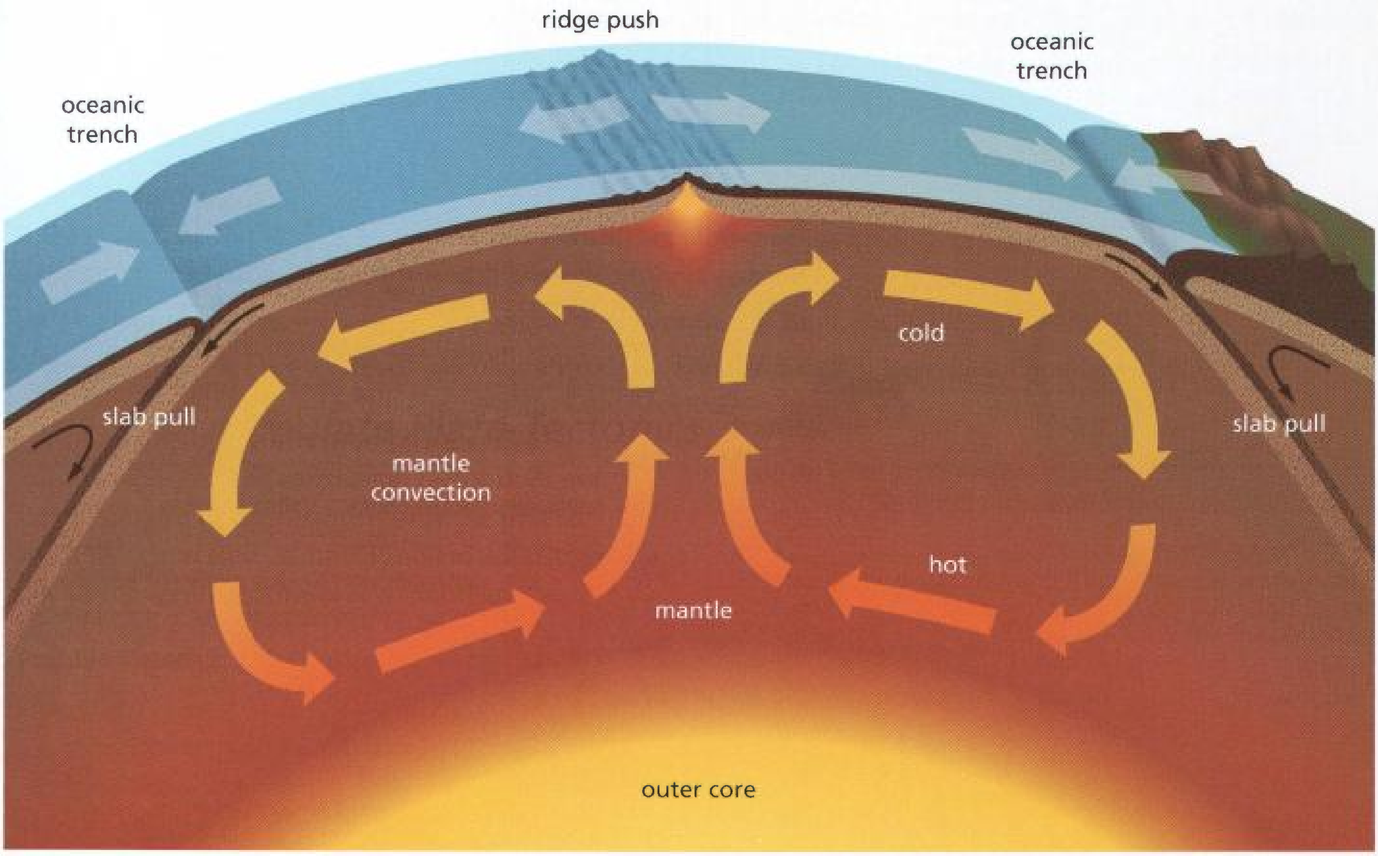


Figure 1 Ridge push, mantle convection, and slab pull combine to move tectonic plates.

LEARNING TIP
Check your understanding. Use Figure 1 to explain to a partner how mantle convection, ridge push, and slab pull work together to move tectonic plates.

Ridge Push

Where hot mantle rises, it heats the crust until it expands and floats higher. This makes a ridge and pulls the crust thinner, like pushing up on a slab of moulding clay. Cracks open in the thinner area and magma comes to the surface. As it cools, the magma wedges the plates apart. As the new sea floor cools, its density increases and it sinks down and away from the mid-ocean ridge, pushing the rest of the plate ahead of it. This push originating from the ridge is called **ridge push**.

Slab Pull

Lithosphere continues to cool as it is moved away from a spreading ridge. An oceanic plate sinks beneath the less dense continental plate when they collide. Convection currents in the mantle then act on both surfaces of descending plate, increasing the force pulling the entire plate along. Like a rope sliding off a table, the oceanic plate descends into the mantle, pulling the rest of the plate with it. This is called **slab pull**. About 700 km down, the temperature and pressure soften the plate, recycling it into the mantle.

TRY THIS: *Slab Pull*

Skills Focus: creating models, observing, evaluating

Materials: 1 m × 10 cm strip of paper, two 100 g masses, tape

It is thought that the weight of a descending tectonic plate will pull the rest of the plate along behind it. In this activity, you will model this event.

1. Tape the masses on either end of the paper strip.
2. Lay the paper strip flat on a table, with one mass just over the edge.
3. Give the hanging mass a slight tug. Observe the effect of this change.

A. Describe what happened to the paper strip and masses.

B. What provided the force to move the paper strip?

C. Do you think this demonstration is suitable to model slab pull? Why or why not?

Shaping Earth

You know from Chapter 17 that mountains, trenches, and rifts can be explained by the theory of plate tectonics. The way these are thought to work can be modelled, but can't be tested directly; the time and size involved are just too big. This makes them the subject of much debate by Earth scientists.

Mountains

When tectonic plates converge, the plate with higher density may descend beneath the other, or subduct. The overriding plate bulldozes the material on top of the subducting plate (the one being pushed back into the mantle). At an oceanic–continental convergent boundary, the leading edge of the overriding continental plate is compressed, causing folding, faulting, and uplift of mountains along the coast. The St. Elias Mountains along the Alaska–B.C. border formed this way. They are among the fastest-rising mountains in the world. At a continental–continental boundary, the sedimentary rock in-between the two plates is squeezed, lifted, and folded into mountains (Figure 2).

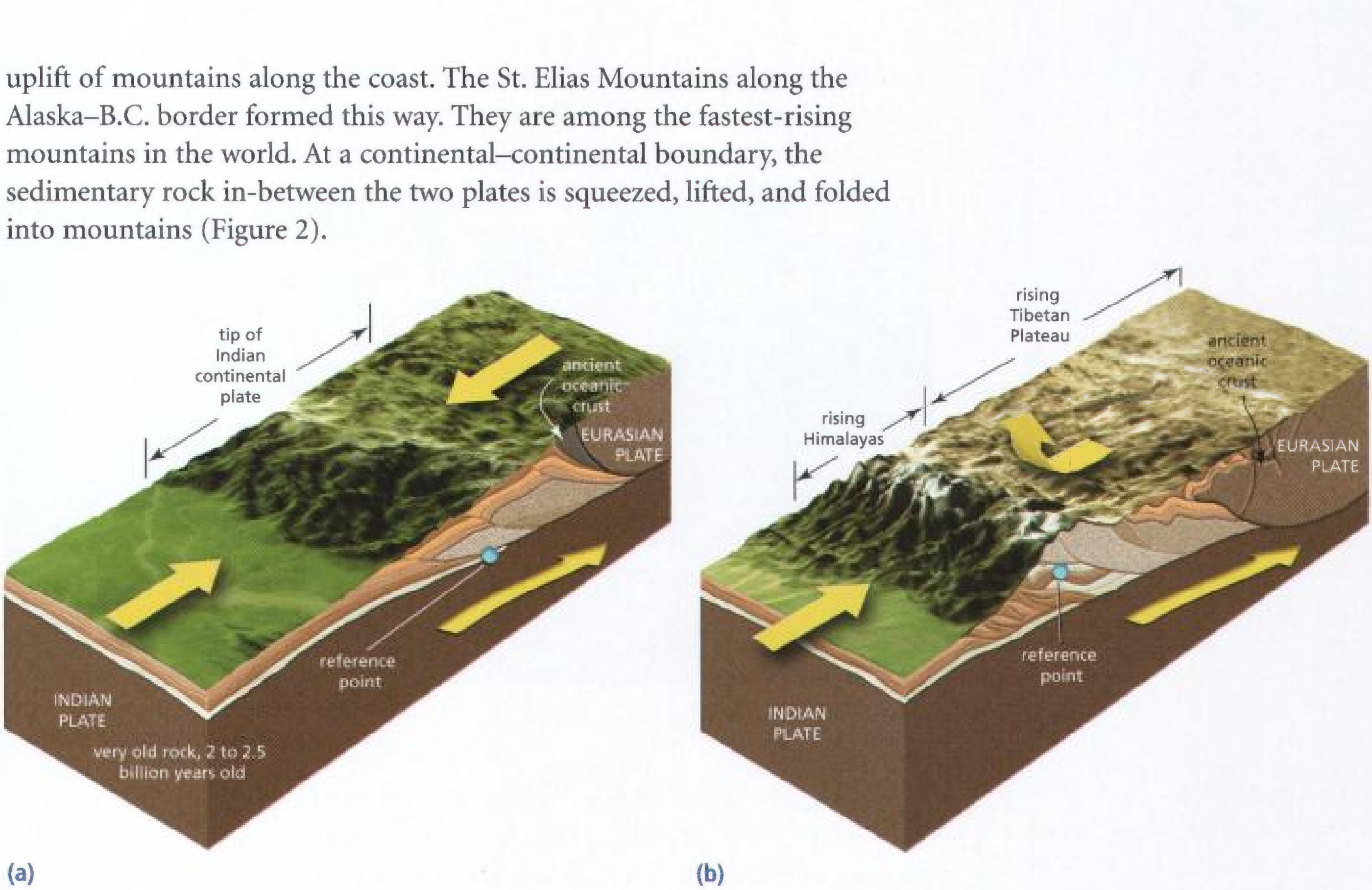


Figure 2 (a) The Eurasian Plate acts like a bulldozer as it pushes into the Indian Plate. The top layer of the Indian Plate is pushed up, forming the Himalayan Mountain Range. (b) The Himalayas continue to rise about 5 mm per year.

Marine Fossils in the Mountains

The oceans were never as high as the mountains in Yoho National Park, but you'll find fossils of marine organisms high up in the Rockies near Field, B.C. (Figure 3). The Burgess Shale found in Yoho is fossil-bearing rock that was laid down underwater more than 500 million years ago at the edge of an oceanic plate. (That's about 230 million years before the continents formed Pangaea.) About 200 million years ago, as the North American Plate moved over an oceanic plate, the fossil-bearing rock was pushed up and formed part of the Rocky Mountains.

Figure 3 The Rockies' Burgess Shale is one of the most important fossil beds in the world, documenting the explosion of life forms during the Cambrian Period (543 to 490 million years ago). It preserved not only the bone outlines usually associated with fossils, but the imprints of soft tissues as well.

Rifts

At divergent boundaries, the lithosphere is tearing apart, driven by upwelling magma from the mantle. Earthquakes and volcanoes often occur along a rift. When these tears are beneath the ocean, magma emerges from the mantle to form new sea floor. Long mid-ocean ridges form on either side of the rift as the cooling crust bulges up because of the upwelling magma.

Where the divergent boundary crosses the thicker lithosphere of a continent, blocks of the crust collapse as the crust stretches apart, creating rift valleys. As with undersea rifts, the edges of the rift bulge up, forming ridges.

In Africa, the 4800 km long Great Rift Valley (Figure 4) runs down the eastern side of the continent. This rift contains some of Africa's deepest lakes and highest mountains.

Figure 4 The Great Rift Valley near Lokichar, Kenya

LEARNING TIP

After you finish reading the section on trenches, ask yourself, "How can I put what I have just read into my own words (paraphrase)?" Try explaining to a classmate how trenches are formed.

In Asia, an ancient rift filled with water to form Lake Baikal, also known as the Blue Eye of Siberia. At 1637 m deep, it is the deepest lake in the world. Though its surface area is less than half that of Lake Superior, its depth makes it the largest freshwater lake in the world. It holds approximately 22 % of Earth's liquid fresh water.

Trenches

At an oceanic–continental convergent boundary, the margin of the subducting plate forms a deep ocean trench. The trenches are nearly parallel to a chain of volcanoes and the subduction process causes earthquakes. At an oceanic–oceanic convergent boundary, a deep ocean trench is also formed, parallel to a chain of volcanic islands. Trenches are the deepest places in the oceans, descending over 3 km below the ocean floor (Figure 5). GO

If you would like to learn more about the Mariana Trench, **www.science.nelson.com** GO

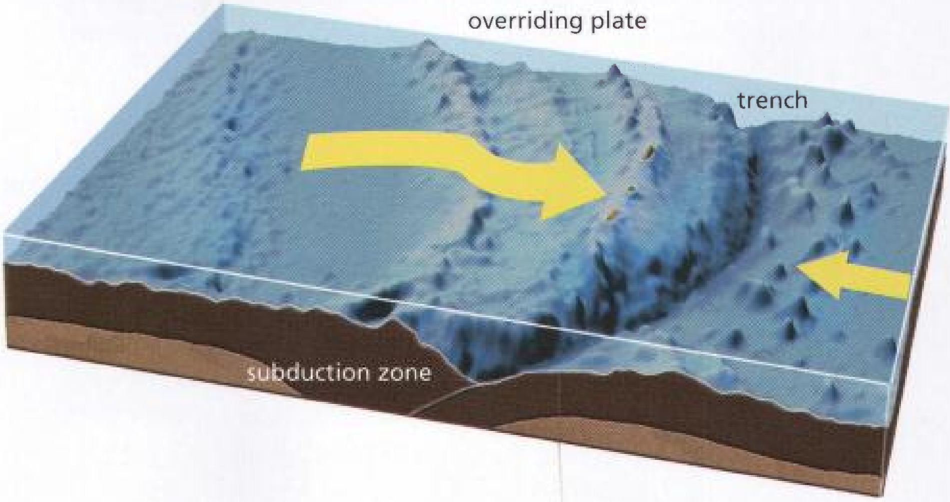


Figure 5 The Mariana Trench between Japan and Indonesia is Earth's deepest trench, sinking nearly 11 km below the surface of the Pacific Ocean. If you could put Mt. Everest in the trench, its peak would still be more than 2 km below sea level.

18.1

CHECK YOUR Understanding

1. Define the following terms:
   (a) density
   (b) convection current
2. Describe the changes in the mantle and the resulting effect at each location labelled in Figure 6.

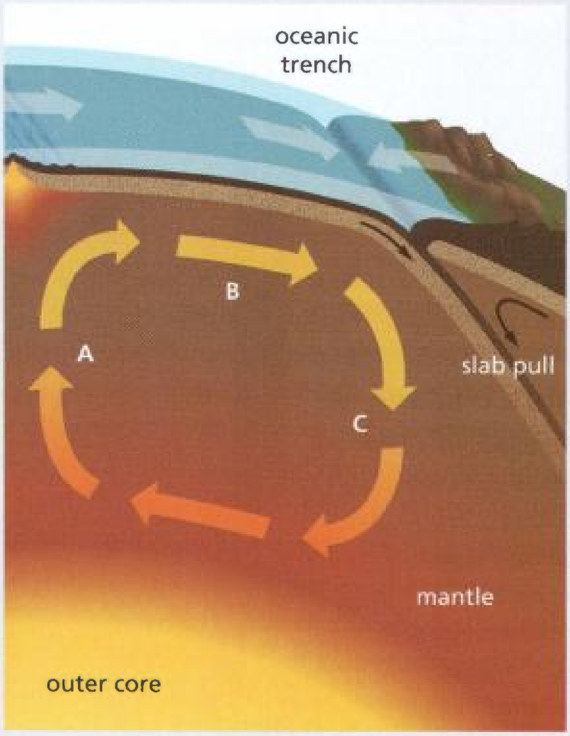


Figure 6

3. What part(s) of Earth's interior are involved in a convection current? Explain.
4. Draw and label a diagram that illustrates ridge push.
5. How does gravity contribute to plate movement?
6. What happens to the oceanic plate as it descends below 700 km in the mantle?
7. At what type of convergent plate boundary is each feature created?
   (a) ocean trench
   (b) mountains containing marine fossils
8. Draw diagram (c) to show the next step in this process shown in Figure 7.

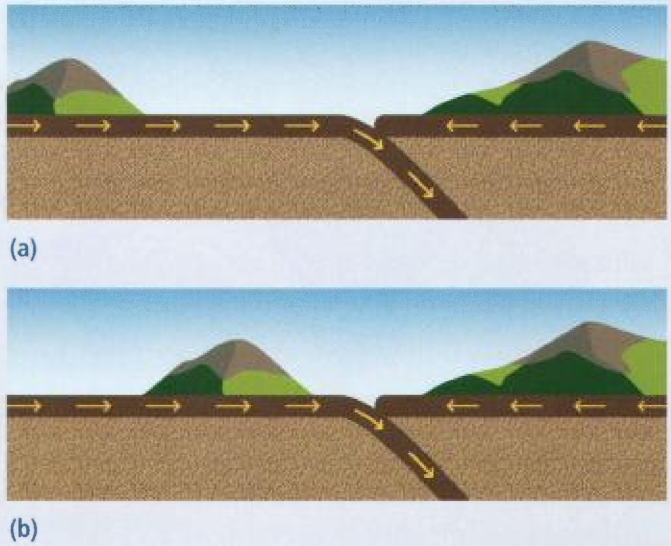


Figure 7

9. Why are ocean trenches the deepest parts of the ocean?
10. Examine the mountains in Figure 8. At which location would you expect to find the following?

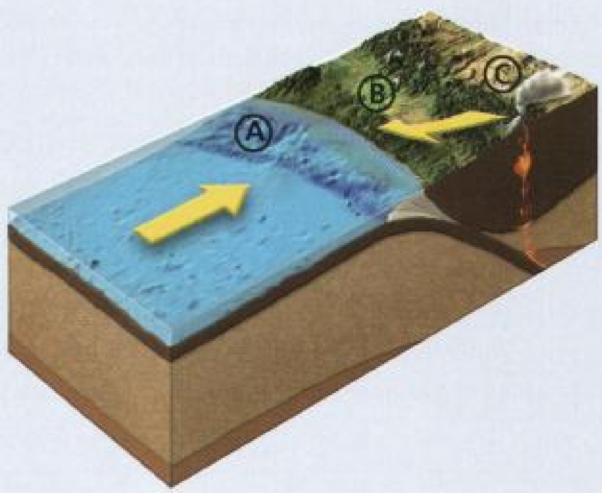


Figure 8

   (a) sedimentary rock containing marine fossils
   (b) ocean floor rock that has been folded and uplifted
   (c) continental rock that has been folded and uplifted

18.2 Geological Events

Landforms are not the only effect of plate tectonics. Volcanoes and earthquakes (Figure 1) are effects that can happen so quickly and with such drama that they make international news headlines. You learned that many volcanoes and earthquakes line up along plate boundaries. Are they related? Do they happen in other places? Read on to find out.

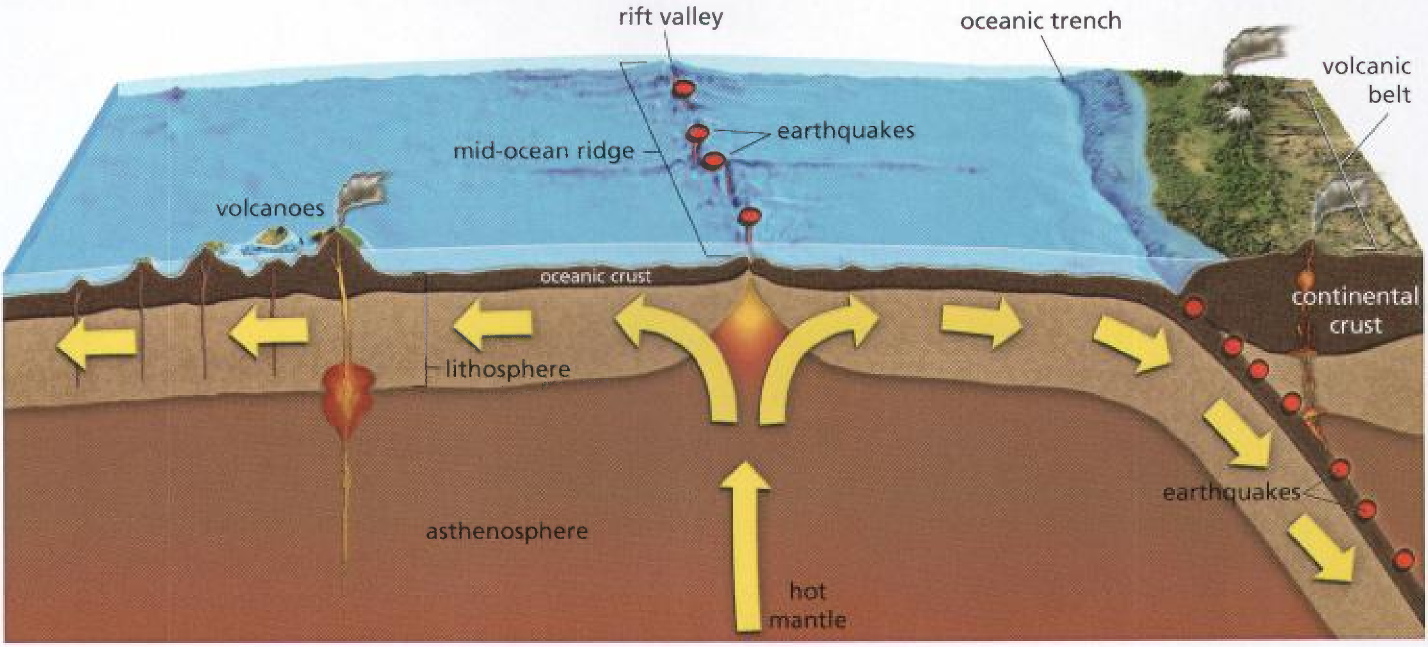


Figure 1 Volcanoes are found where fractures in the lithosphere give magma a path to the surface; or where a hot spot in the mantle has melted through the lithosphere. Earthquakes occur as plates bump past each other.

Volcanoes

A **volcano** marks a crack in the lithosphere where magma (molten rock) and gases reach Earth's surface. Once magma reaches the surface, it is called lava. Magma forms deep underground when the (mostly) solid rock of the asthenosphere experiences at least one of three things, all of which lower the melting point of the rock:

- a drop in pressure (e.g., at a crack in the crust);
- a change in composition (e.g., in the subduction zone); or
- an increase in temperature (e.g., above a hot spot or convection upwelling).

Volcanoes at Mid-Ocean Ridges

The energy in tectonic movements stress the lithosphere, creating cracks and crevices. When the crust tears, it relieves pressure on the mantle below and magma expands into the path to the surface (Figure 2). Along the thin crust of mid-ocean ridges, the magma reaches the surface with much of the same properties it had in the mantle. It is very hot and flows easily as lava, building volcanoes.

Figure 2 In the news, we learn of the dramatic and destructive force in a volcanic eruption. However, most volcanoes are not explosive, due to the low gas content of their magma. Eruptions can take many forms and last for long periods of time.

Hot Spots and Volcanic Island Chains

Hot spots are small regions of very hot mantle, thought to be heated by a concentration of radioactive substances near Earth's core. This heat creates very hot columns of rising mantle, which cause the lithosphere to thin out and crack as it bulges up. Eventually, magma bursts through the weakened lithosphere over the hot spot, forming a volcano (Figure 3).

LEARNING TIP

Active readers adjust their reading to fit the difficulty of the text. If you find a topic difficult to understand, take note of the subheadings (as they divide the topic into smaller chunks), read more slowly, and reread.

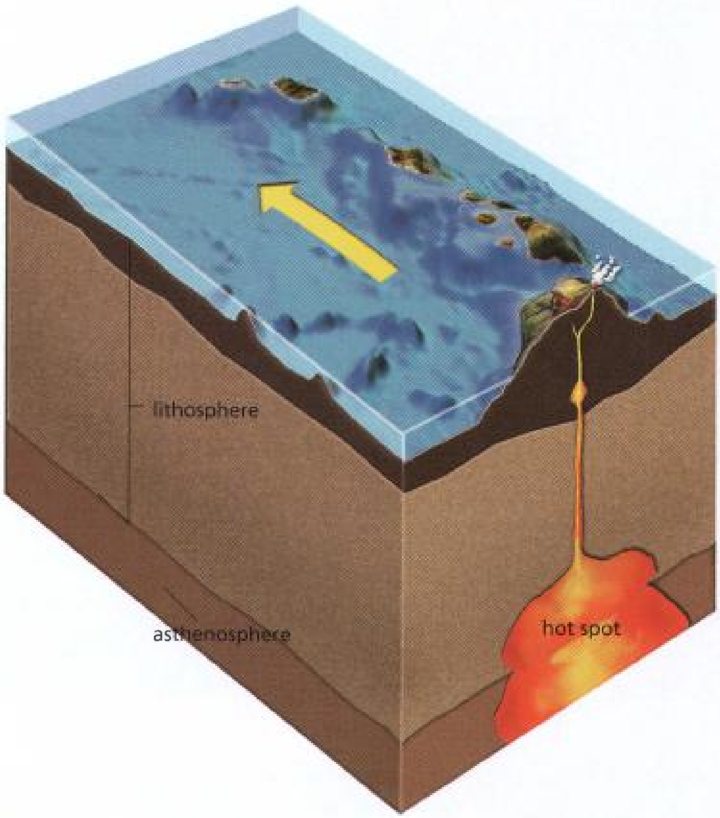
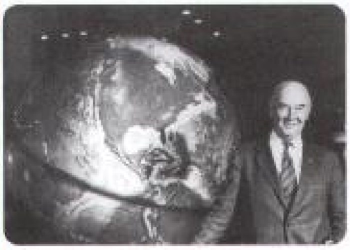


Figure 3 Hot spots can form enormous volcanoes. Measured from the ocean floor, the island of Hawaii is taller than Mt. Everest.

Did You KNOW?

A Canadian Idea

Hot spots were first proposed by Canadian geophysicist J. Tuzo Wilson in 1963 to explain the chain of Hawaiian Islands and seamounts that extend all the way to the North Pacific. Wilson was one of the founders of the plate tectonic theory, along with Hess, Deitz, Matthews, and Vine.

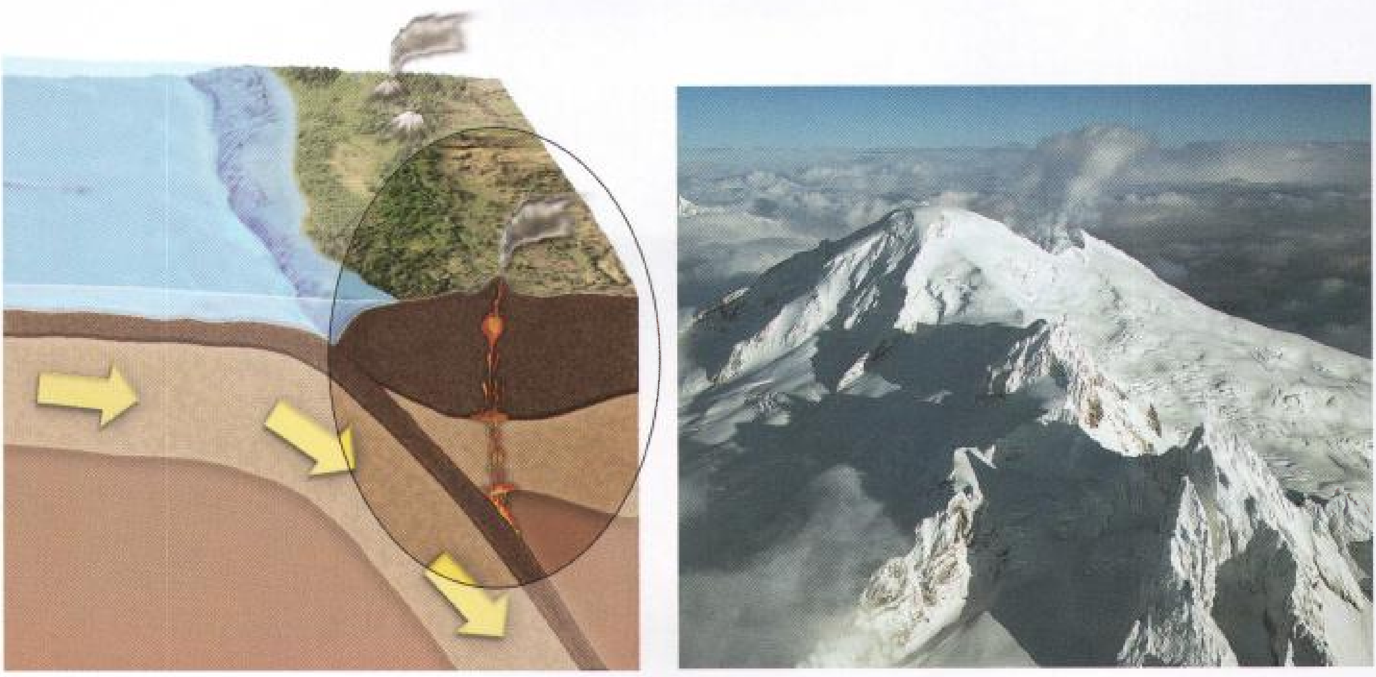


The hot spot stays in place as the lithosphere moves over it. As the plate moves away from the hot spot, the volcano becomes less active. Eventually the hot spot forms a new volcano. This creates a chain of volcanoes stretching away from the hot spot in the direction of plate motion. If the hot spot is beneath ocean, it creates a chain of islands (like the Hawaiian Islands examined in Investigation 17A). If the hot spot is beneath a continent, it creates a chain of volcanoes such as the Anahim Belt in central B.C., which contains the Nazko Cone right over the hot spot.

Volcanic Belts and Island Arcs

The crust pulled into the mantle at a subduction zone contains a significant amount of trapped water. The increasing temperature releases water as steam, which lowers the melting point of the mantle rock (like salting ice on the road), and generates magma along the boundary between the descending lithosphere and the asthenosphere. This magma then melts its way upward, following cracks and crevices caused by stress in the subduction zone. Between 100–300 km from the ocean trench, the magma reaches the surface of the overriding plate, creating a row of volcanoes roughly parallel to the boundary:

- A **volcanic belt**, or chain of inland volcanoes, is created on an overriding continent parallel to a convergent boundary (Figure 4).
- A **volcanic island arc**, or line of volcanic islands, is created on an overriding oceanic plate parallel to an oceanic–oceanic boundary.

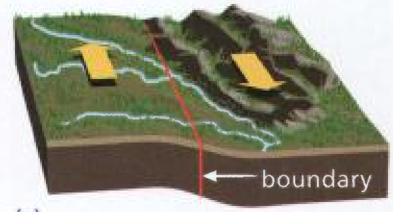


(a) (b)

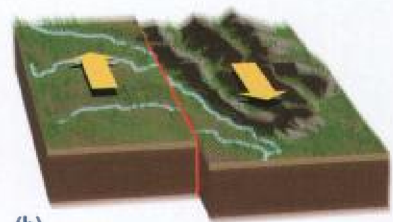
Figure 4 (a) Inland from the subduction zone, magma percolates up through cracks in the overriding plate, forming volcanic belts on continents, and volcanic island arcs in oceans. (b) Mt. Baker is an active volcano in the Cascade volcanic belt whose magma is generated by the subducting Juan de Fuca Plate.

Earthquakes

Boundaries between Earth's tectonic plates are the source of many **earthquakes**, vibrations through Earth's crust caused by volcanoes and movement along plate boundaries (tectonic activity). You will never feel the vast majority of earthquakes that happen continually throughout the world; a passing bus causes more vibration.



(a)



(b)

Figure 5 (a) When plates move past one another, friction at the boundary deforms the lithosphere. (b) Eventually, tectonic forces build up and overcome the friction, releasing the stored energy as an earthquake.

The Shuddering Slide

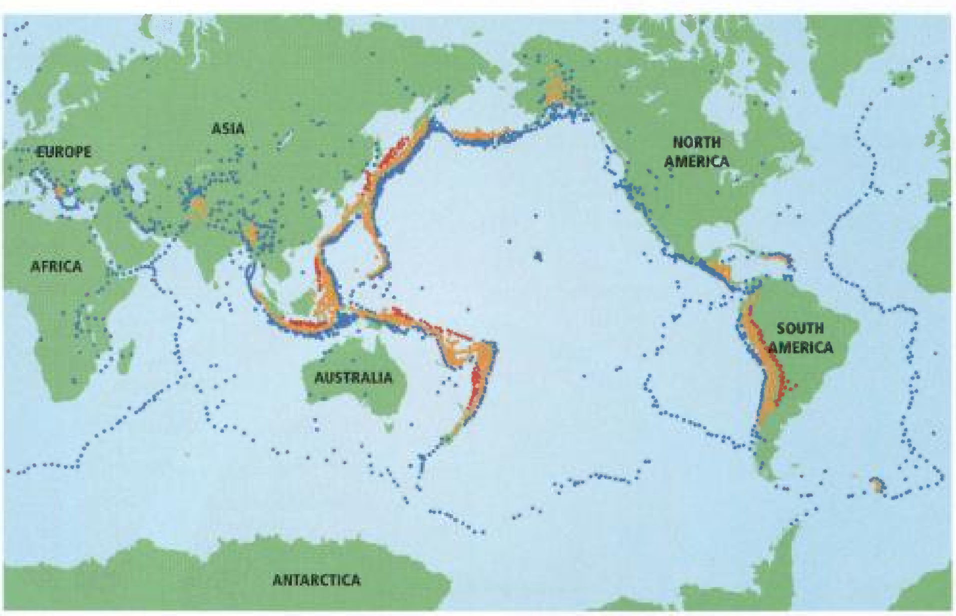
The movement of tectonic plates along boundaries is not smooth; the plates are enormous, made of solid rock, and subjected to tremendous compression and stretch. The edges of plates are not even, and friction causes them to deform, bend, lift, and crack. Earthquakes occur at all types of plate boundaries, whether the plates are sliding one under the other in a subduction zone, sliding past one another along a transform fault, or being pulled apart at a divergent boundary. Energy is stored in the deforming plates, like the energy in a compressed spring. Eventually, the tectonic forces are strong enough to overcome the friction, and the plates lurch ahead (Figure 5), releasing the stored energy as earthquakes. A **fault** is a displacement of the lithosphere (vertically, horizontally, or both) created by the movement of tectonic plates.

Earthquake Locations

The source of an earthquake within the lithosphere is called the **focus**. The **epicentre** is found on the surface, directly above the focus. Most earthquakes occur along tectonic plate boundaries, due to the movement of the plates themselves (Figure 6).

LEARNING TIP

Examine Figure 6. How do the parts of the map relate to each other? How do the symbols in the legend help to explain the information in the map?



shallow intermediate deep

Figure 6 Plotted on a map, earthquake epicentres for 1980–1996 clearly outline some plate boundaries.

Earthquakes are categorized according to how far beneath Earth's surface the focus occurs: **shallow-focus**, **intermediate-focus**, or **deep-focus** (Table 1 and Figure 7).

Table 1 Earthquake Categories

Category	Depth of Focus (km)	Region within Earth
shallow-focus	0–70	crust
intermediate-focus	70–300	subduction zone
deep-focus	300–700	mantle

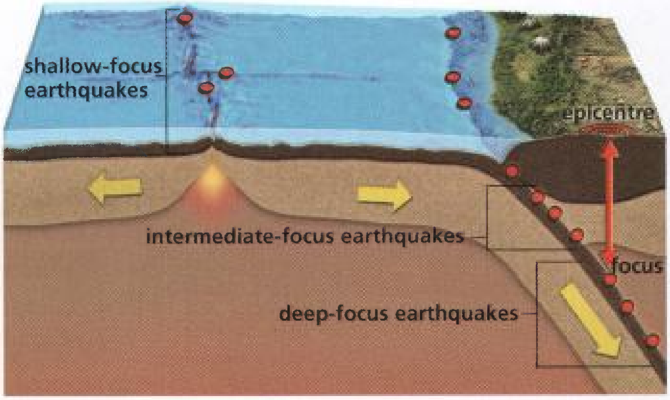


Figure 7 Earthquakes are categorized by the depth at which they occur.

Seismic Waves

Earthquakes transmit mechanical energy in the form of **seismic waves**, mechanical waves or vibrations in Earth. There are two main types of seismic waves: body waves and surface waves.

Body waves travel through a medium, such as sound waves travelling through air. Earthquakes cause two types of body waves: primary and secondary (Figure 8).

Primary waves (P–waves) are compression waves: the particles in the medium vibrate forward and backwards along the path of the wave. P–waves can travel through solids, liquids, or gases; they pass through all the layers of Earth. **Secondary waves** (S–waves) are shear waves: the particles in the medium vibrate perpendicular to the direction of the wave. S–waves travel more slowly and can only travel through solid rock, not through Earth's liquid core. Both P– and S–waves vibrate through Earth from the earthquake's focus. Measuring the changes in a wave's speed and direction has provided evidence about the internal structure of the planet (Figure 9).

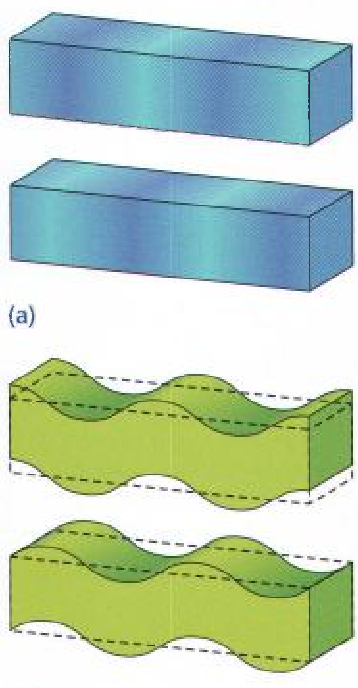


Figure 8
(a) Primary waves (P–waves) cause motion parallel to the direction of travel, like a worm crawling. (b) Secondary waves (S–waves) cause perpendicular motion, like a snake slithering.

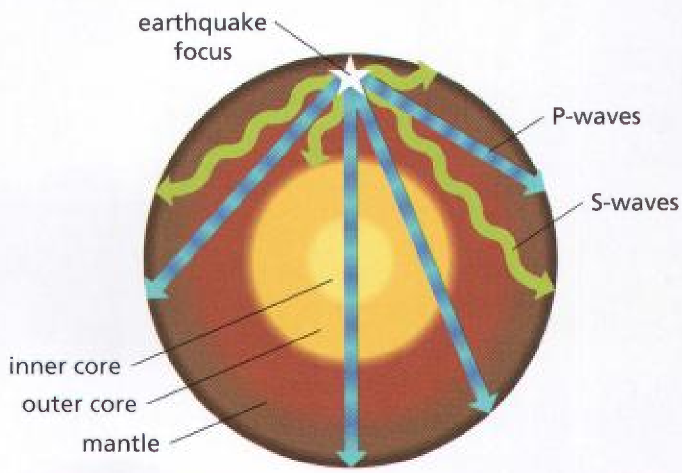


Figure 9 P– and S–waves can be detected around Earth, but surface waves (not shown) fade over a few hundred kilometres even in the largest earthquakes.

Surface waves travel along the outside of Earth, causing the most destruction (Figure 10). They are created when body waves reach the surface. These waves travel more slowly than body waves, and their range is limited to a few hundred kilometres. Like waves in the water, the motion of surface waves decreases significantly with depth.

Scientists use devices called seismographs to detect earthquake waves. With data from seismograph stations around the globe, triangulation is used to find the epicentre. 18A *Investigation*

18A *Investigation*

Where Was That Earthquake?

To perform this investigation, turn to page 532.

(a)

(b)

Figure 10 (a) Earthquakes can be very destructive. (b) Water recedes from the shoreline as the first tsunami wave approaches shore.

TRY THIS: *Making Waves*

Skills Focus: analyzing, creating models, evaluating, observing

Materials: long toy spring, 5 cm string, 20 L tub of water, rectangular pan of gelatin

1. Flag a single coil in the middle of the spring by tying the string around it. Now stretch the spring out.
2. Simulate P–waves by bunching up several coils near one end, then releasing. How does the flagged coil move? Record your observations.
3. Simulate S–waves by quickly jerking one end of the spring upward or sideways. How does the flagged coil move?
4. Place your hand underwater on the bottom of the tub of water then quickly raise one finger. This will simulate P–waves travelling toward the surface, causing surface waves.
5. Rhythmically press down and forward at one end of the gelatin slab.
6. At the same spot, shake the surface of the gelatin from side to side. Steps 5 and 6 simulate surface waves.

A. Describe how the spring's coils moved during the P– and S–wave simulations.

B. Explain why water cannot be used to show how S–waves cause surface waves.

C. Can gelatin simulate surface waves? Explain.

D. What can seismic waves tell us about Earth's structure?

CHECK YOUR Understanding

1. Describe how the magma is generated for volcanoes parallel to a subduction zone.
2. What two factors result in a volcano at a plate boundary?
3. Why are volcanoes found at mid-ocean ridges but not at ocean trenches?
4. What causes a hot spot in the mantle?
5. Explain why hot spot volcanoes appear as volcanic chains in the middle of an oceanic plate (Figure 11).

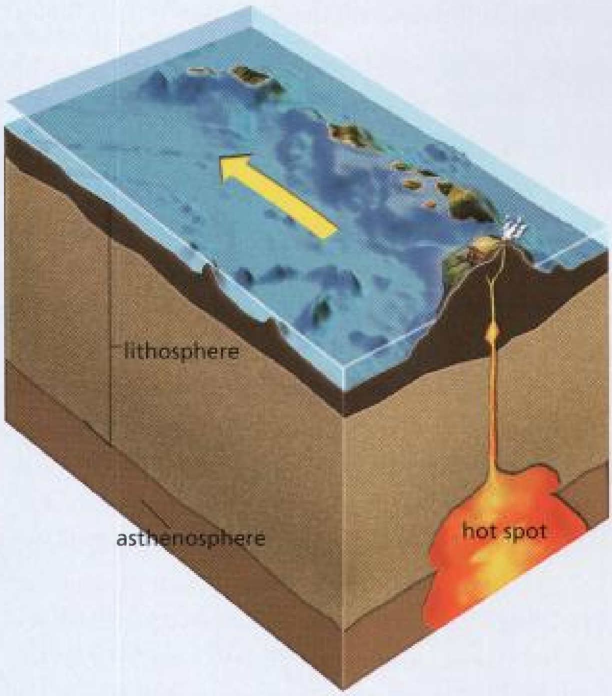


Figure 11

6. How are the terms "focus" and "epicentre" linked?
7. Draw a graphic organizer to compare the three categories of earthquake: shallow-focus, intermediate-focus, and deep-focus.
8. (a) At what type of plate boundary are deep-focus earthquakes likely to occur?
   (b) What causes them?
9. The three largest earthquakes in recorded history have occurred in subduction zones. How does the plate tectonic theory explain this? Consider the processes that occur along all three types of plate boundaries.
10. (a) What are the two main types of seismic waves?
    (b) Explain the difference between the two types.
11. Which type of seismic wave travels farthest through Earth? Why?
12. In 2005 and 2006, several major earthquakes occurred in Pakistan and Iran, located to the north and west of India (Figure 12).
    (a) Why does the theory of plate tectonics support the occurrence of earthquakes in these countries?
    (b) What type of plate boundary exists near these two countries?

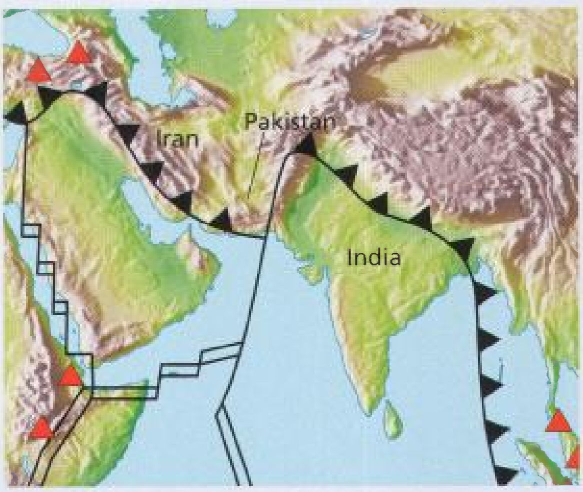


Figure 12

REMOTE TECHNOLOGY: VOLCANIC EXPLORATION AND CONSTRUCTION

New technologies are making volcanoes safer for the people who study them or live nearby.

Active volcanoes are treacherous; their eruptions endanger people as well as ecosystems. While volcanic activity can be predicted by scientists, gathering information can be difficult and deadly. Tragically, dozens of volcanologists (scientists who study volcanoes) have been injured or killed while collecting data and studying volcanoes in the field. To prevent this, remote-control technology has been developed to allow for safe exploration of volcanic activity.

To survey and collect samples from Mount St. Helens, volcanologists used a remote-control drone (Figure 1). The drone was equipped with nozzles to collect ash and gas, an infrared camera to detect heat, and a video camera to aid manoeuvring. The data collected has been used to make accurate predictions about the volatility of the volcano.

Figure 1 The "Silver Fox" sends real-time images of Mount St. Helens back to scientists with laptops monitoring from a safe distance.

Another interesting remote technology is being used on the slopes of Mount Fugen in Japan. Mount Fugen has been active ever since it first erupted in 1990, killing many people. The flow of boiling hot ash and gases from the volcano (Figure 2) also caused considerable damage to the surrounding area. To prevent this, a plan was developed to build giant check dams or barriers on the slopes of the volcano. However, the location for the barriers was too hazardous for humans to work there.

A Japanese technology company eliminated the hazard from this important work by creating remote-controlled construction tools for the project. With this technology, construction operators for each backhoe, dump truck, or other machine sit safely in a master control room kilometres away from the volcano. As operators receive live video feed from the machine, they send directions via the Internet or radio waves to a radio vehicle on site, which then individually controls each construction machine.

Two check dams have already been completed, and more are scheduled. Imagine doing a lifesaving job by remote control.

Figure 2 The flow of hot ash and gases expelled by Unzen (Mount Fugen) is a danger to the town below.

Explore an Issue

DECISION MAKING SKILLS

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

Living Near a Volcano

The Fraser Valley lies within the reach of at least two volcanoes: Mt. Rainier near Seattle and Mt. Baker just south of the Canada–U.S. border. Both volcanoes have the potential to erupt, emitting a variety of destructive elements. Volcanic eruptions can be catastrophic, yet around the world more than 500 million people live on or near active volcanoes.

The Issue: Volcanoes Pose Severe Risk to Nearby Inhabitants

A large volcano near a city recently became more active. Small tremors indicate magma movement beneath the mountain, and scientists believe there will be an explosive eruption. The eruption may occur within weeks, years, or not for many years. The provincial government has asked for input from a panel of experts concerning possible evacuation of the city.

Statement

Because of the potential cost to life and livelihood, communities should be moved away from volcano hazards.

Background to the Issue

There are many reasons to live near a volcano, including valuable farmland and fisheries, access to shipping routes, and interest in nearby ecology. The risks, on the other hand, are significant (Figure 1):

- Carbon dioxide gas from volcanic vents can smother people and livestock.
- Boiling hot gases and ash flow from the volcano, suffocating living things.
- Melting snowcaps high atop the volcanic mountain cause massive landslides and flash floods that can travel several kilometres.
- Seismic waves from eruptions damage property and can trigger tsunamis that travel across the ocean.
- Ash and acid rain from the eruption cloud fall metres deep, several kilometres wide.
- After an eruption, more people die due to starvation and pollution.

Take a Position

1. Carefully read the background information, then pick a volcano for discussion.

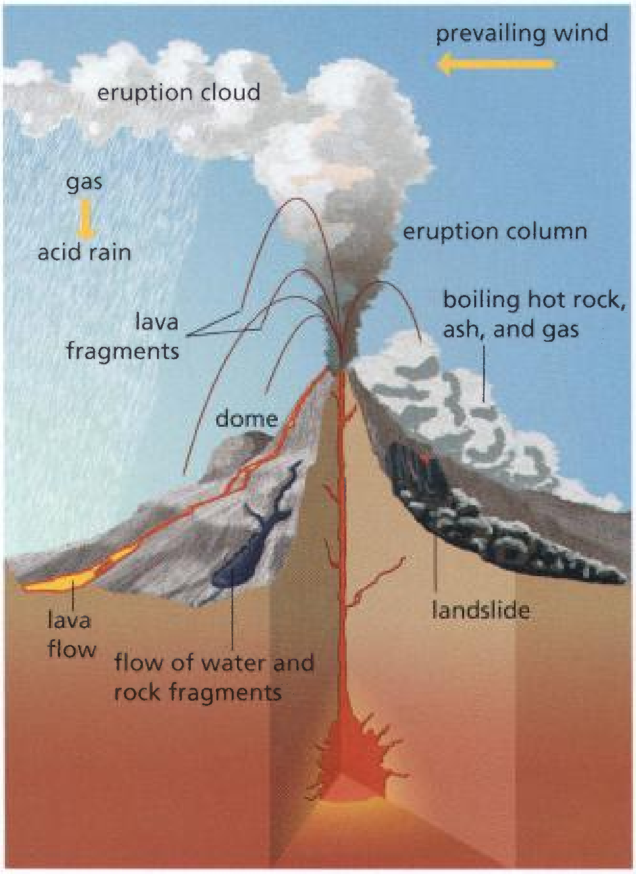


Figure 1 The numerous deadly hazards posed by a volcano.

2. Choose a role to play in presenting an opinion (for example, a volcano specialist, a local leader, an insurance company representative, or an emergency response director).
3. Research specific risks that this volcano poses. Consider the feasibility of a large evacuation, and the effect on the local economy and people's livelihoods.
4. Gather relevant information and prepare a multimedia presentation for the class. You should include a summary statement in the form of a short speech or a letter.

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Communicate Your Position

Your teacher will organize an expert panel to present the arguments. What facts and theories support your position? Which ones oppose it?

After considering the arguments, each member of the class will vote on the issue. Be open-minded and consider taking a different position from the one you researched. Will the solution be appropriate for the long term, the short term, or both? Do the risks outweigh the benefits, or vice versa? Your teacher will conduct the class vote and announce the results.

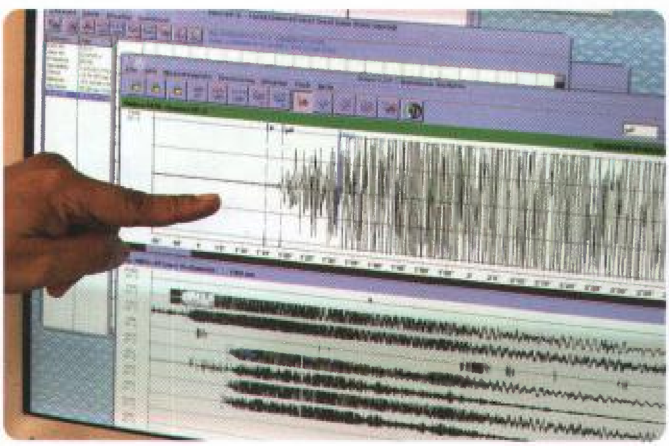
18A **Investigation**

Where was that Earthquake?

Seismology is the study of how seismic waves (vibrations in Earth) travel through the planet. These waves give us clues about movement at plate boundaries as well as providing information on the composition of Earth. A seismograph is used to detect the waves from earthquakes, even those that cannot be felt by people (Figure 1).

The primary and secondary waves caused by an earthquake travel at different speeds. Therefore, the difference in arrival time at a seismograph can be used to calculate the distance to the epicentre (and focus) of the earthquake.

(a)



(b)

Figure 1 (a) In ancient China, as an earthquake shook the ground, the pendulum movement caused a ball to fall out of the dragon's mouth and into the toad's mouth below. (b) Today's computers translate ground movement into a graph similar to that created by a seismograph (a seismogram).

INQUIRY SKILLS

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

Question

How can seismograms be used to locate the epicentre of an earthquake?

Experimental Design

This investigation is called a retrospective study. It is the type of investigation in which you take available data, analyze it, and extract new information: the earthquake's epicentre. You will need to design your own procedure for this investigation.

Materials

- ruler
- compass
- seismograms
- scale map of Western Canada handout
- distance–time graph for P– and S–waves

Procedure

1. Work with a partner. Examine the data. On the map, identify the location of each seismograph station.
2. Examine each seismogram in Figure 2 and determine the time difference between the arrival of the first P–waves (labelled P) and the first S–waves (labelled S).

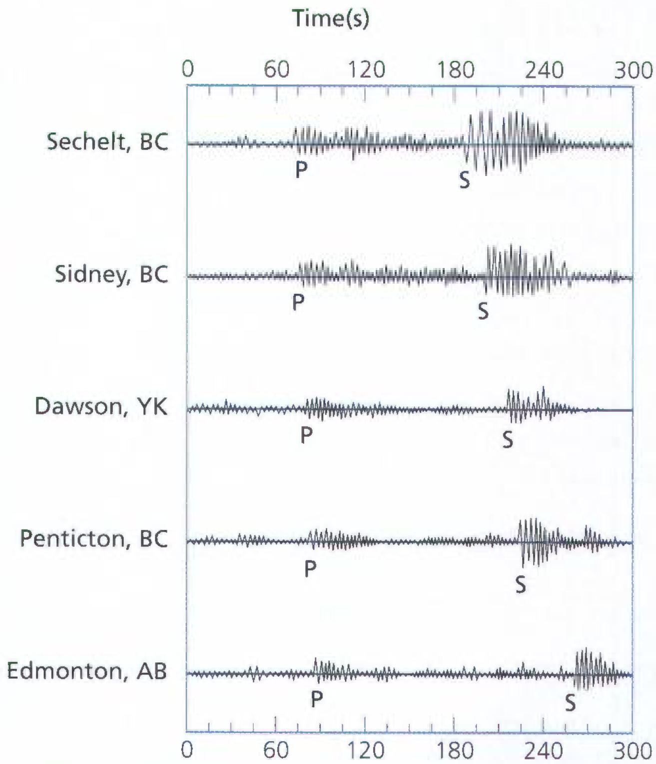


Figure 2 Seismograms from an earthquake felt on Vancouver Island and the lower mainland in October 2001.

3. Use the distance–time graph in Figure 3 to determine the distance of each seismograph station from the earthquake.

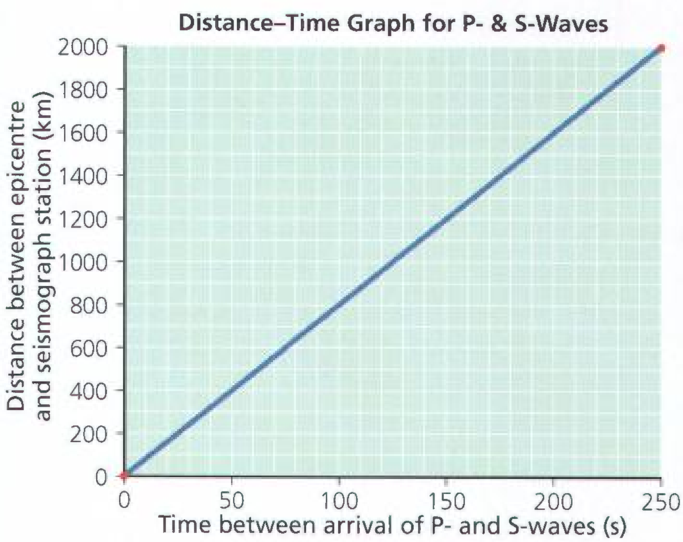


Figure 3 This distance–time graph is calibrated to find the distance between the epicentre and the seismograph station based on the time lapse between the arrival of P– and S–waves.

4. Write out the rest of the procedure you will use to find the earthquake's epicentre.
5. Carry out your procedure and record your findings.

Conclusion

Complete the following items to answer the question posed at the beginning of the investigation.

Analysis

(a) Which seismograph was furthest from the epicentre? Which was closest?

(b) Where was the epicentre of the earthquake?

Evaluation

(c) Were you able to locate the earthquake using your experimental design? If not, how would you change your method?

(d) How many seismograph stations are needed to locate an epicentre?

(e) How could you improve the accuracy of your location?

Synthesis

(d) If zero on the seismograms indicates 5:00 a.m., determinate the time that the earthquake occurred, to the nearest minute.

(e) Currently, scientists all over the world share their seismographic data over the Internet. Computers analyze data from hundreds of seismographs. Describe how this amount of data sharing changes the speed and accuracy with which earthquakes can be located.

CHAPTER 18

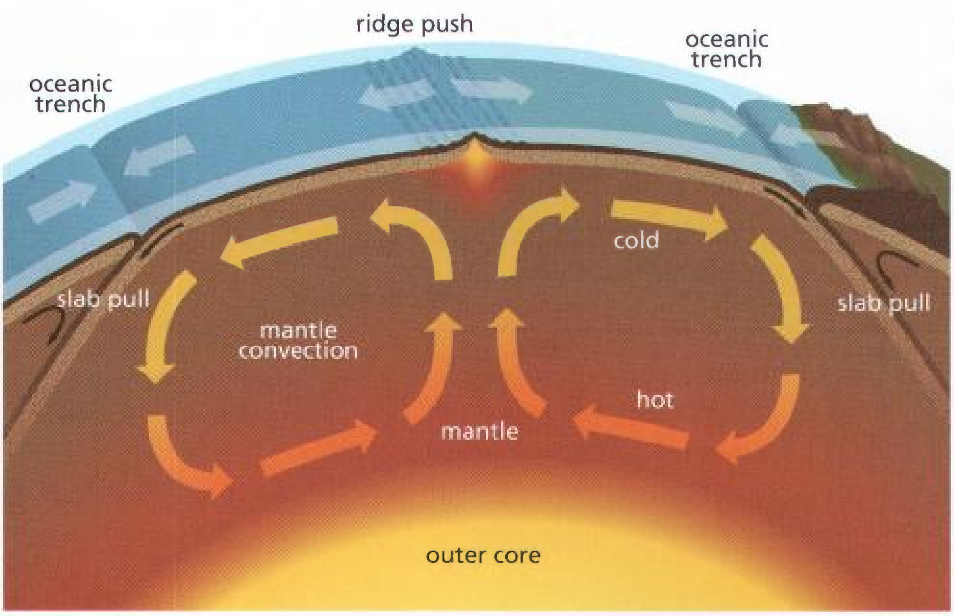
Review

Plate Tectonics

Key Ideas

Three factors cause the movement of Earth's tectonic plates.

- Mantle convection—hot mantle rises, then cools and sinks at another location. Friction between the moving mantle and the lithosphere pushes the plate along.
- Ridge push—hot rising mantle bulges the edges of a divergent boundary. Magma rising into the gap creates a wedge as it cools, pushing the plates apart.
- Slab pull—denser plate sinks beneath a less dense plate when they are pushed together. The sinking plate pulls the rest of the plate with it into the asthenosphere.



Forces at plate boundaries produce landscape features.

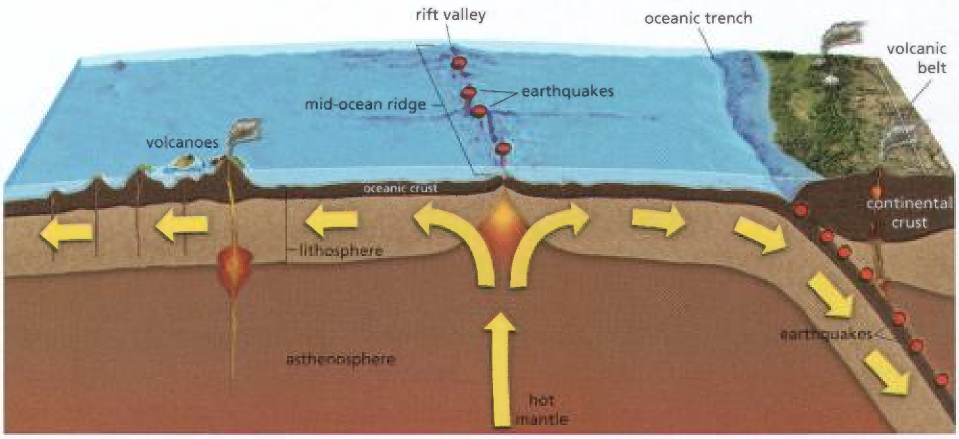
- Uplifted mountains, volcanic belts, and island arcs are found parallel to convergent boundaries.
- Ocean trenches lie along convergent boundaries.
- Mid-ocean ridges and rift valleys mark divergent boundaries.
- Strike-slip faults mark transform boundaries.

Vocabulary

mantle convection, p. 517
ridge push, p. 518
slab pull, p. 518
volcano, p. 522
hot spot, p. 523
volcanic belt , p. 524
volcanic island arc, p. 524
earthquake, p. 525
focus, p. 525
epicentre, p. 525
shallow-focus earthquake, p. 526
intermediate-focus earthquake, p. 526
deep-focus earthquake, p. 526
seismic wave, p. 526
body wave, p. 526
primary wave (P–wave), p. 526
secondary wave (S–wave), p. 526
surface wave, p. 527

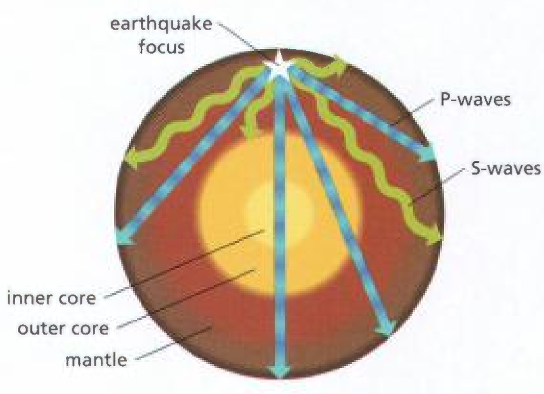
The interactions of tectonic plates cause volcanoes and earthquakes.

- Earthquakes result when tectonic forces overcome the friction between plates.
- Earthquakes are categorized by how deeply within Earth they occur: shallow-focus, intermediate focus, or deep-focus.
- Volcanoes are produced over lithosphere cracks and mantle hot spots.
- Volcanic island chains and volcanic belts are created on the overriding plate, parallel to a convergent boundary.
- Hot spots are rising plumes of hot mantle magma. As tectonic plates move over the hot spot, a chain of progressively younger volcanoes is formed opposite to the direction of plate movement.



Earthquakes send waves through Earth.

- The sudden movement of the lithosphere during an earthquake sends seismic waves (vibrations) through Earth.
- Primary and secondary body waves travel through Earth, starting at the focus, the site of the earthquake within Earth.
- Secondary waves radiate from the earthquake focus, but cannot pass through Earth's liquid outer core.
- Body waves cause surface waves that travel over the surface of Earth.
- An earthquake's epicentre is the location on the surface directly above the focus.



Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K 1. What does *not* contribute to the motion of tectonic plates?
   A. slab pull
   B. ridge push
   C. centrifugal force
   D. mantle convection

K 2. Which of the following describes a volcanic island arc?
   A. an arc-shaped volcano in the ocean
   B. a chain of volcanic islands parallel to an ocean trench
   C. a line of volcanoes on a continent, parallel to a boundary
   D. a chain of active and extinct volcanoes formed over a hot spot

3. Which type of seismic wave can travel through Earth's liquid outer core?

4. What is the relationship between body waves and surface waves?

5. Describe how each of the following causes tectonic plates to move:
   (a) ridge push
   (b) slab pull
   (c) mantle convection

K 6. In which of the following locations can a volcano form?

I	along a mid-ocean ridge.
II	inland from a subduction zone along the edge of a continent.
III	at one end of an island chain leading to a hot spot.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II, and III

U 7. Refer to Figure 1 below. What type of plate boundary is indicated at the featured location?

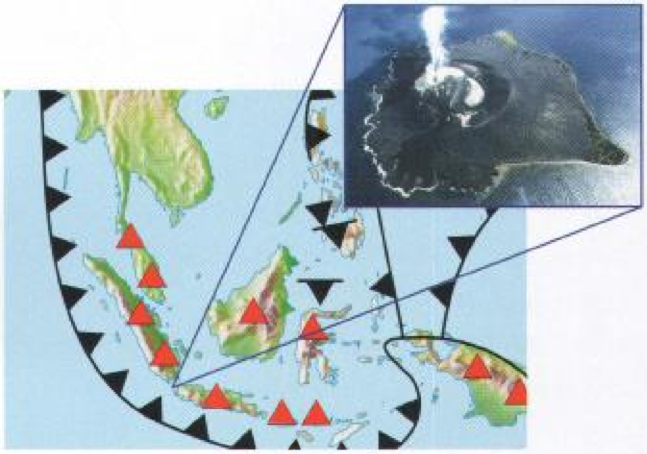


Figure 1

   A. oceanic–oceanic divergent
   B. oceanic–oceanic transform
   C. oceanic–oceanic convergent
   D. oceanic–continental convergent

Use What You've Learned

U 8. Which situation will produce a deep-focus earthquake?
   A. Lithosphere ruptures at a transform fault.
   B. Super-hot mantle rushes to the surface at a hot spot.
   C. Magma forces its way through cracks in the lithosphere.
   D. Tectonic plates pass each other in a subduction zone.

U 9. How are the focus and epicentre related?
   A. The epicentre is located on the surface directly above the focus.
   B. The earthquake occurs at the epicentre. The focus is the closest point on the surface.
   C. The epicentre is the source of the seismic waves, which travel toward the focus.
   D. An epicentre is an earthquake detection centre. The focus is the location of the earthquake.

10. Refer to the map in Figure 2. Name a location at which you would find

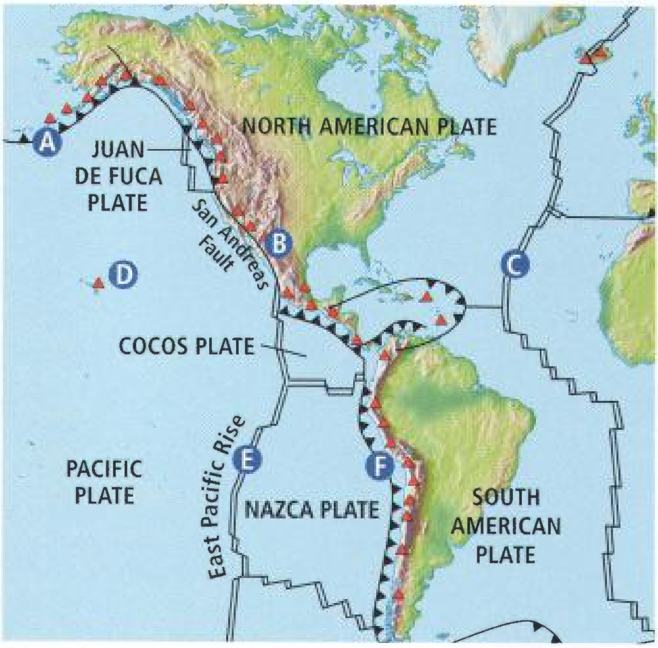


Figure 2

(a) shallow-focus earthquakes and volcanoes, but no deep-focus earthquakes
(b) a volcanic island arc
(c) earthquakes, but no volcanoes
(d) a chain of extinct volcanoes extending outward from an active one
(e) deep-focus earthquakes and a volcanic belt

11. What causes magma to form between converging plates?

12. Copy and complete Table 1 to compare and contrast types of seismic waves.

Table 1 Types of Seismic Waves

	P–Waves	S–Waves	Surface Waves
relative speed			
particle motion relative to direction of travel			
layers of Earth they travel through			
cause			

Think Critically

13. Examine the tectonic map (Figure 2) to answer these questions.
   (a) Why isn't there a mountain range on the east side of South America?
   (b) Which direction is the North American plate moving?
   (c) How does the location of mountains help you determine the direction of movement?
   (d) Why is there a parallel chain of volcanoes and mountains on the west coast of North America?

HMP 14. A chain of volcanic islands has only one active volcano, at the north end. The islands to the south get progressively older and more eroded. Which of the following best explains the formation of the island chain?
   A. Two plates are spreading east and west.
   B. Two plates are converging east and west.
   C. An ocean plate is moving southward over a hot spot.
   D. An ocean plate is moving northward over a hot spot.

15. Use print and electronic resources to explain what a "tectonic triple junction" is. Give two examples.

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16. Research the velocities of the Pacific, Juan de Fuca, and the North American Plates. Will the Juan de Fuca Ridge eventually subduct completely below the North American Plate? Create a diagram to explain.

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Reflect on Your Learning

17. Do you feel that your school or community is sufficiently prepared for a major earthquake or volcanic eruption? In what ways do you think preparations can be improved?

Visit the Quiz Centre at
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UNIT F

Review

Plate Tectonics

Unit Summary

In this unit, you learned about the continental drift theory and the theory of plate tectonics—the forces and processes that shape Earth's surface. The planet is made of layers, the outermost of which is broken into tectonic plates that are constantly in motion. This motion is caused by a combination of factors and results in tectonic activity such as volcanoes and earthquakes, as well as some landforms that contour the planet. List the key terms from this unit, then organize them into a mind map that shows how each of these features and activities are related to each other.

Many of these questions are in the style of the Science 10 Provincial Exam. The following icons indicate an exam-style question and its cognitive level.
K Knowledge U Understanding and Application HMP Higher Mental Processes

Review Key Ideas and Vocabulary

K **1.** Which of the following did Wegener use to support the continental drift theory?

I	oddities in the distribution of fossils and paleoglaciation evidence
II	the geographic fit of the continents and distant matching geologic features
III	measurements showing that North America and Africa were getting farther apart

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

K **2.** Which of the following describes the bands of alternating magnetic orientation on the sea floor?
A. stripes parallel to transform faults
B. stripes that run perpendicular to mid-ocean ridges
C. alternating stripes mirrored on either side of a mid-ocean ridge
D. stripes that parallel continental margins ending at mid-ocean ridges

K **3.** Where does the theory of plate tectonics predict earthquakes and volcanoes will occur?
A. along continental margins
B. mostly in deep ocean trenches
C. evenly distributed around Earth
D. primarily along plate boundaries

K **4.** The San Andreas Fault in California is an example of a(n)
A. divergent plate boundary.
B. transform plate boundary.
C. convergent plate boundary.
D. amalgamate plate boundary.

K **5.** Which process occurs at an oceanic–continental convergent boundary?
A. hot spots are created
B. oceanic crust subducts
C. continental crust subducts
D. new oceanic crust is created

K **6.** Which of the following causes tectonic plates to move over Earth?
A. ridge push
B. subduction
C. Earth's rotation
D. strike-slip faults

K **7.** The process that creates earthquakes is described by
A. the theory of plate tectonics.
B. magnetic reversals.
C. the continental drift theory.
D. a seismograph.

K **8.** Which of the following are sources of heat within Earth?

I	excess radioactive decay
II	friction due to convection currents
III	heat remaining from Earth's formation

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

K **9.** Which of the following statements about the sea floor is always true?
A. Age is consistent.
B. Age decreases in all directions from a hot spot.
C. Age increases with distance from a mid-ocean ridge.
D. Age increases with distance from the continental margin.

K **10.** What determines which plate subducts at a convergent boundary?
A. relative speed of the plates
B. relative density of the plates
C. melting of the continental plate
D. magnetic reversals on the two plates

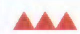
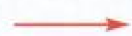
K **11.** What is the epicentre of an earthquake?
A. The point of origin of an earthquake.
B. The location of a seismograph that detects the earthquake.
C. A network of three or more seismographs used to detect an earthquake.
D. The location on the surface of Earth directly above the earthquake's origin.

12. Draw and label a cross-section of the internal structure of Earth. Include the three main types of plate boundaries and indicate the relative location of shallow- to deep-focus earthquakes.

13. Match the features on the left with the type of plate boundary on the right.

Feature	Type of Boundary
a) deep-focus earthquake **b)** fault **c)** volcanic island arc **d)** mid-ocean ridge **e)** rift valley **f)** subduction zone **g)** ocean trench	I. convergent II. divergent III. transform

14. Match each symbol on the left to its meaning on the right.

Tectonic Map Symbol	Meaning
a) 	I. transform boundary
b)	II. direction of travel
c) 	III. divergent boundary
d) 	IV. convergent boundary

15. The Indian–Australian Plate is colliding with the Eurasian Plate to create the Himalayan mountains. Which plate is subducting beneath the other? How can you tell?

16. Use a graphic organizer to compare oceanic crust and continental crust in terms of thickness, composition, and density.

Use What You've Learned

U **17.** Which of the following statements about tectonic plates is correct?

I	Pangaea was a gathering of the continental portions of tectonic plates.
II	Tectonic plates have moved over the asthenoshphere since Earth formed.
III	Pangaea is the only other formation the continents formed.

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

U **18.** What forces oceanic lithosphere into the mantle?

A. It curls under as it cools.
B. Its high-density materials make it sink.
C. It is magnetically attracted to the solid inner core.
D. It is pushed under by a plate that is less dense.

U **19.** Which plate boundary type is responsible for the formation of the Cascade volcanic belt just east of the Juan de Fuca Plate (Figure 1)?

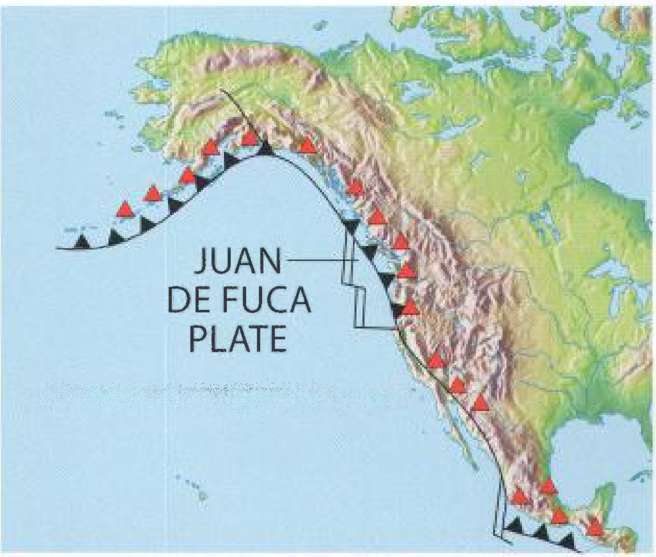


Figure 1

A. oceanic–oceanic convergent
B. continental–oceanic transform
C. oceanic–continental convergent
D. continental–continental divergent

20. There is no directional arrow on the Juan de Fuca Plate in the tectonic plate boundaries map shown in Figure 1. Explain how you can tell which direction it is moving.

U **21.** Which of the following is the result of a continental–continental convergent boundary?

A. Japanese islands
B. Great Rift Valley
C. San Andreas Fault
D. Himalayan mountains

22. Is the line of volcanic islands north of Australia the result of a hot spot? Explain how you know.

23. Which feature would you expect to be deeper: the rift valley along the spreading ridge of the East Pacific Rise, or the Puerto Rico Trench? Explain.

24. Copy and complete Table 1 to compare and contrast the continental drift theory and the theory of plate tectonics.

Table 1

	Continental Drift Theory	Theory of Plate Tectonics
Part(s) of Earth involved		
Description of movement(s)		
Cause(s) of movement		
Evidence		

25. Sketch Figure 2 in your notebook, and add the location of future volcanoes caused by the hot spot under the tectonic plate.

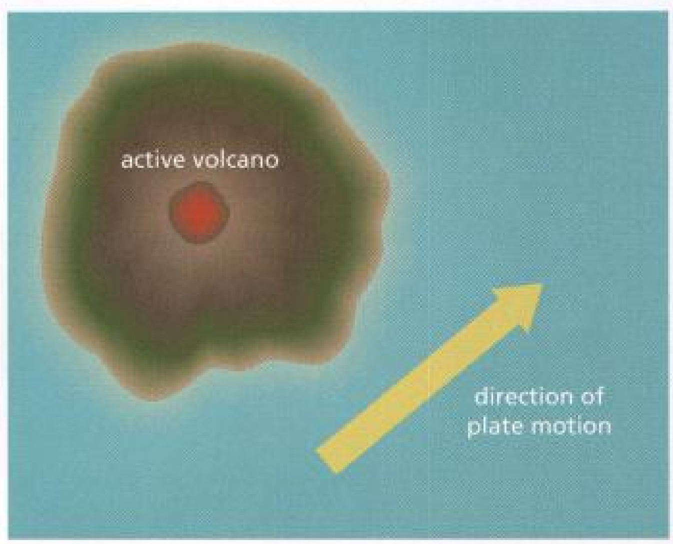


Figure 2

26. What is the correct tectonic map symbol for the type of plate boundary shown in Figure 3?

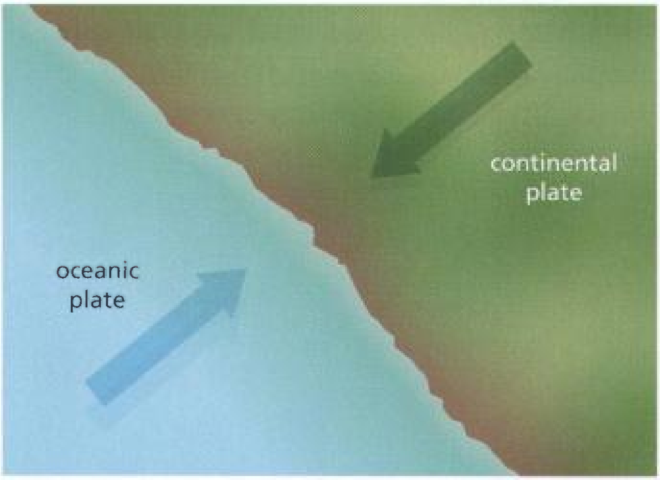


Figure 3

Think Critically

HMP 27. Why do deep-focus earthquakes occur only at a convergent boundary?
A. These boundaries stick with the greatest force.
B. Deep-focus earthquakes require the pressure of an overriding plate.
C. It's the only place lithosphere is found so deep below the surface.
D. Rising magma at other boundaries lubricates the lithosphere, preventing earthquakes.

HMP 28. Why don't earthquakes happen more than 700 km below Earth's surface?
A. Lithosphere in this area floats freely.
B. There is no friction within the liquid mantle.
C. They do, but the seismic waves can't be detected.
D. Tectonic plates become part of asthenosphere at this depth.

29. Why are older mountains and volcanoes smaller than younger ones, such as the Himalayas?

HMP 30. The portion of an ocean plate farthest from a spreading ridge is considered to be older. Why will this older portion of a plate move beneath a younger oceanic plate?
A. It is more dense.
B. It is made of denser minerals.
C. It has been pulled by gravity longer.
D. It has slowed more than the younger plate.

31. Hot spot volcanoes in the oceans (e.g., Hawaii) have a very different mineral balance than hot spot volcanoes on continents (i.e., Anahim Belt, Yellowstone). Explain why.

32. Explain why mantle convection alone is not likely the only force driving the motion of tectonic plates. Consider that ocean plates move faster than continental plates, in general.

33. Use print and electronic resources to map the location of active volcanoes in British Columbia. Which volcano poses the greatest hazard? Explain.

www.science.nelson.com GO

34. In December 2004, a large-magnitude earthquake occurred in the subduction zone off the coast of Sumatra. The resulting tsunami caused the death of over 200 000 people. Research the nature and cause of tsunamis. What other tsunamis have caused large destruction? Summarize your findings in a paragraph.

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Reflect on Your Learning

35. One benefit of the plate tectonic theory is a better understanding of how and when earthquakes occur. How has, or might, this understanding affect your life?

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

APPENDICES

Appendix A: Safety Knowledge and Skills

A1: Safety Rules

Science investigations can be a lot of fun—you have the chance to work with new equipment and materials. However, science investigations can also be dangerous, so you have to pay attention! As well, you have to know and follow special rules. Here are some important rules to remember, and the symbols to watch for, as you participate in science activities and investigations.

1. Follow your teacher's directions.

- 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.

2. Act responsibly.

- 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.

3. Be science-ready.

- 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.

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.

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 minutes. Inform your teacher.

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.

A2: Safety Conventions and Symbols

Caution Symbols

The activities and investigations in *B.C. Science Probe 10* 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.

Figure 1 Potential safety hazards are identified with caution symbols.

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).

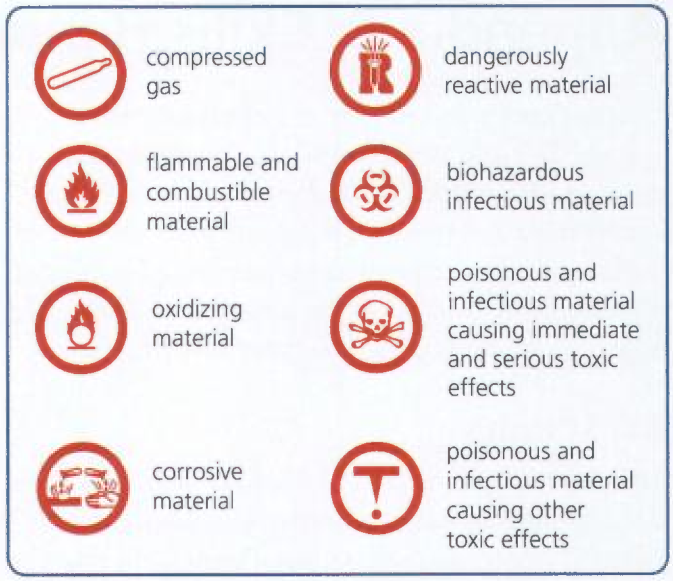


Figure 2 Workplace Hazardous Materials Information System (WHMIS) symbols

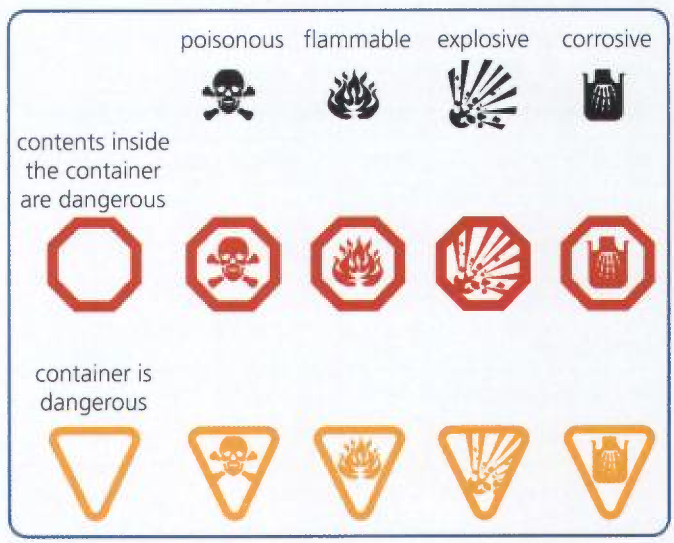


Figure 3 Household Hazardous Products Symbols (HHPS)

Appendix B: Skills Handbook

Effective communication is an important part of science. To avoid confusion when measuring and doing mathematical calculations, there are accepted conventions and practices regarding units of measurement, working with very large and very small numbers, and acknowledging uncertainty. The following appendices explain these conventions.

B1: 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 for 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 $m \cdot kg/s^2$. 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
time	*t*	minute	min
		hour	h
		year	a
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

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

1 km = 1000 m

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. Sample Problem 1 illustrates how to convert from one unit to another.

SAMPLE PROBLEM 1

Convert Units

A chemistry class of 30 students is performing an experiment in the laboratory. Each pair of students will use a volume of 125.0 mL of silver nitrate solution for a chemical reaction. Silver nitrate costs $56.25 per litre. Determine the cost of the silver nitrate for the class.

Solution

The first step is to determine the total volume required. Each pair of students requires 125.0 mL so the whole class will require 15 × 125.0 mL = 1875 mL.

The second step is to convert the volume from millilitres to litres.

There are two possible conversion factors between mL and L. They are

$$\frac{1 \text{ L}}{1000 \text{ mL}} \text{ and } \frac{1000 \text{ mL}}{1 \text{ L}}$$

You should always choose the form of the conversion factor that cancels the original unit. In this case, the original unit is mL, so the correct conversion factor is

$$\frac{1 \text{ L}}{1000 \text{ mL}}$$

$$1875 \cancel{\text{mL}} \times \frac{1\text{L}}{1000 \cancel{\text{mL}}} = 1.875 \text{ L}$$

Notice how the initial units, mL, cancel (divide to give 1), leaving L as the new unit.

Now that you have determined the volume in L, the solution to the problem is simple. Multiply the price per L by the volume in L.

$56.25/L × 1.875 L = $105.47

The cost of the silver nitrate for the class is $105.47.

Practice

Make the following conversions.

(a) Write 3.5 s in ms.

(b) Convert 3.5 cm to µm.

(c) Change 5.2 L to cL.

(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

$$\frac{1000\ \text{mm}}{1\ \text{m}} \quad \text{and} \quad \frac{1\ \text{m}}{1000\ \text{mm}}$$

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.

$$1\frac{\text{m}}{\text{s}} \times \frac{1\ \text{km}}{1000\ \text{m}} \times \frac{60\ \text{s}}{1\ \text{min}} \times \frac{60\ \text{min}}{1\ \text{h}} = 3.6\frac{\text{km}}{\text{h}}$$

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.)

B2: 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 $2.59 \times 10^1 \times 10^5$ km^2. Adding the exponents gives us 2.59×10^6 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 2.6×10^6 km^2.

B3: 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

	Example	
Guideline	**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 1 presents an analogy that uses the results of horseshoe tosses to explain precision and accuracy.

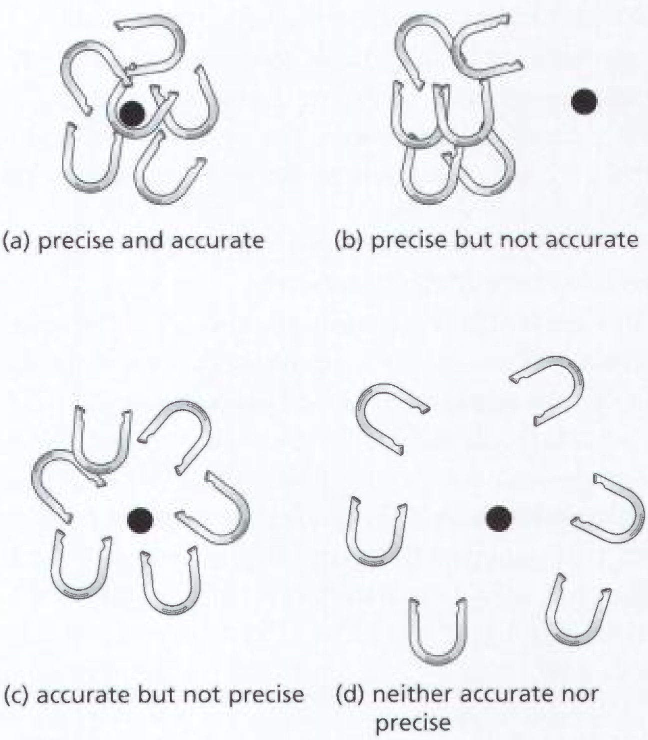


Figure 1 The patterns of the horseshoes illustrate the comparison between accuracy and precision.

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.

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).

B4: 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 Table 7.

Table 7 Effect of Different Fertilizers on Algae Growth

Aquatic system	Observations				
	Day 1	Day 2	Day 3	Day 4	Day 5
Fertilizer 1					
Fertilizer 2					
No fertilizer					

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 Table 8. (Remember that there can be more than one dependent variable in an investigation.)

Table 8 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

Follow these guidelines to make a data table:

- Use a ruler to make your table.
- Write a title that precisely describes your data.
- 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.

B5: 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 9 and Figure 2). 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 9 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

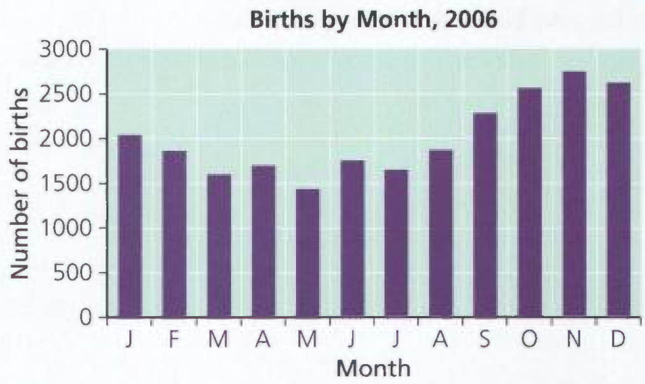


Figure 2

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 of its parts. For example, a circle graph can show the proportion of the gases that are found in air (Figure 3).

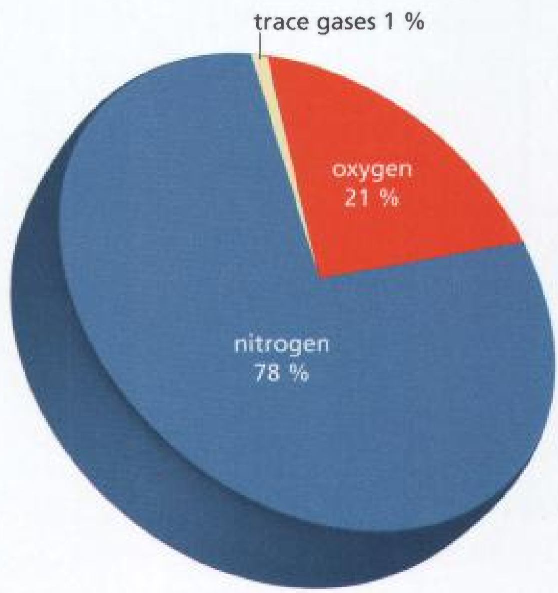


Figure 3 The gaseous components of air and their percentages.

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 10 to construct the point-and-line graph in Figure 4.

Table 10 A Running White-Tailed Deer

Time (s)	Distance (m)
0	0
1.0	13
2.0	25
3.0	40
4.0	51
5.0	66
6.0	78

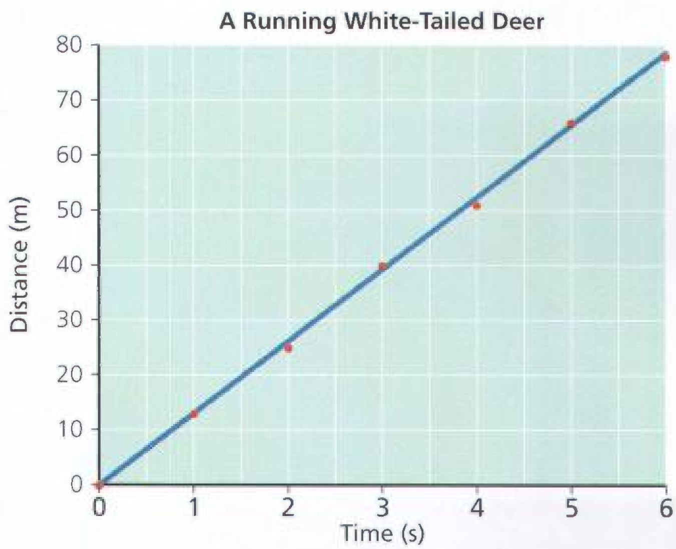


Figure 4

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 time in Table 10 ranges from 0 s to 6.0 s, but the x-axis in the graph in Figure 4 ranges from 0 to 7.0 s.
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 4, one line is used for every 1 s on the x-axis, and for every 10 m 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 4, the first set of points is 0 on the x-axis and 0 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 4 to predict that at 4.5 s the deer will have ran 60 m. Predicting values that lie between known values is called **interpolation**. You can also predict outside the plotted values. From the graph in Figure 4 you can predict that at 7.0 s the deer will have ran 90 m. 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.

Climatographs

Some graphs, such as climatographs, combine a bar graph and a point-and-line graph. In Figure 5, both precipitation and temperature are measured for each month of the year.

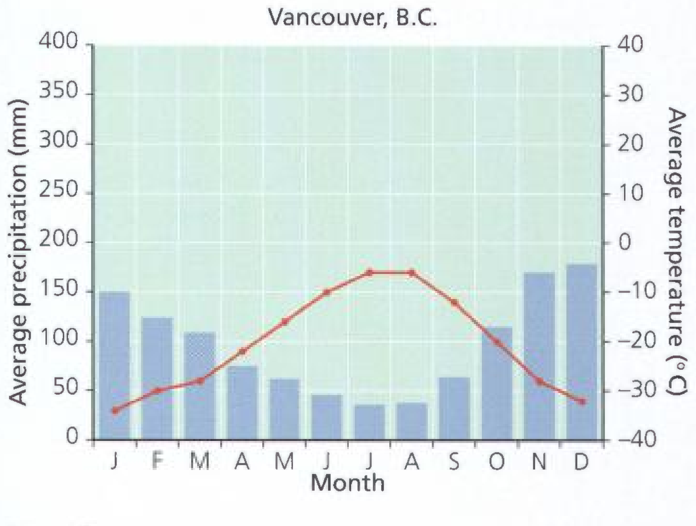


Figure 5

Appendix C: Reference

The following appendices provide information that you may need to refer to from time to time throughout the year. They are based on the data in the booklet that will be provided for the provincial science exam.

C1: Alphabetical Listing of the Elements

Based on mass of C_{12} at 12.00. Values in parentheses are the mass number of the most stable or best-known isotopes for elements that do not occur naturally.

Element	Symbol	Atomic number	Atomic mass
Actinium	Ac	89	(227)
Aluminum	Al	13	27.0
Americium	Am	95	(243)
Antimony	Sb	51	121.8
Argon	Ar	18	39.9
Arsenic	As	33	74.9
Astatine	At	85	(210)
Barium	Ba	56	137.3
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.0
Bismuth	Bi	83	209.0
Bohrium	Bh	107	(264)
Boron	B	5	10.8
Bromine	Br	35	79.9
Cadmium	Cd	48	112.4
Calcium	Ca	20	40.1
Californium	Cf	98	(251)
Carbon	C	6	12.0
Cerium	Ce	58	140.1
Cesium	Cs	55	132.9
Chlorine	Cl	17	35.5
Chromium	Cr	24	52.0
Cobalt	Co	27	58.9
Copper	Cu	29	63.5
Curium	Cm	96	(247)
Darmstadtium	Ds	110	(281)
Dubnium	Db	105	(262)
Dysprosium	Dy	66	162.5
Einsteinium	Es	99	(252)
Erbium	Er	68	167.3
Europium	Eu	63	152.0
Fermium	Fm	100	(257)
Fluorine	F	9	19.0
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.3
Gallium	Ga	31	69.7
Germanium	Ge	32	72.6

Element	Symbol	Atomic number	Atomic mass
Gold	Au	79	197.0
Hafnium	Hf	72	178.5
Hassium	Hs	108	(277)
Helium	He	2	4.0
Holmium	Ho	67	164.9
Hydrogen	H	1	1.0
Indium	In	49	114.8
Iodine	I	53	126.9
Iridium	Ir	77	192.2
Iron	Fe	26	55.8
Krypton	Kr	36	83.8
Lanthanum	La	57	138.9
Lawrencium	Lr	103	(262)
Lead	Pb	82	207.2
Lithium	Li	3	6.9
Lutetium	Lu	71	175.0
Magnesium	Mg	12	24.3
Meitnerium	Mt	109	(268)
Manganese	Mn	25	54.9
Mendelevium	Md	101	(258)
Mercury	Hg	80	200.6
Molybdenum	Mo	42	95.9
Neodymium	Nd	60	144.2
Neon	Ne	10	20.2
Neptunium	Np	93	(237)
Nickel	Ni	28	58.7
Niobium	Nb	41	92.9
Nitrogen	N	7	14.0
Nobelium	No	102	(259)
Osmium	Os	76	190.2
Oxygen	O	8	16.0
Palladium	Pd	46	106.4
Phosphorus	P	15	31.0
Platinum	Pt	78	195.1
Plutonium	Pu	94	(244)
Polonium	Po	84	(209)
Potassium	K	19	39.1

Element	Symbol	Atomic number	Atomic mass
Praseodymium	Pr	59	140.9
Promethium	Pm	61	(145)
Protactinium	Pa	91	231.0
Radium	Ra	88	(226)
Radon	Rn	86	(222)
Rhenium	Re	75	186.2
Rhodium	Rh	45	102.9
Roentgenium	Rg	111	(272)
Rubidium	Rb	37	85.5
Ruthenium	Ru	44	101.1
Rutherfordium	Rf	104	(261)
Samarium	Sm	62	150.4
Scandium	Sc	21	45.0
Seaborgium	Sg	106	(266)
Selenium	Se	34	79.0
Silicon	Si	14	28.1
Silver	Ag	47	107.9
Sodium	Na	11	23.0
Strontium	Sr	38	87.6
Sulphur	S	16	32.1
Tantalum	Ta	73	180.9
Technetium	Tc	43	(98)
Tellurium	Te	52	127.6
Terbium	Tb	65	158.9
Thallium	Tl	81	204.4
Thorium	Th	90	232.0
Thulium	Tm	69	168.9
Tin	Sn	50	118.7
Titanium	Ti	22	47.9
Tungsten	W	74	183.8
Uranium	U	92	238.0
Vanadium	V	23	50.9
Xenon	Xe	54	131.3
Ytterbium	Yb	70	173.0
Yttrium	Y	39	88.9
Zinc	Zn	30	65.4
Zirconium	Zr	40	91.2

C2: Names, Formulas, and Charges of Some Polyatomic Ions

Positive ions	Negative ions		
NH_4^+ Ammonium	CH_3COO^- Acetate	HCO_3^- Hydrogen carbonate, bicarbonate	NO_2^- Nitrite
	CO_3^{2-} Carbonate	HSO_4^- Hydrogen sulphate, bisulphate	ClO_4^- Perchlorate
	ClO_3^- Chlorate	HS^- Hydrogen sulphide, bisulphide	MnO_4^- Permanganate
	ClO_2^- Chlorite	HSO_3^- Hydrogen sulphite, bisulphite	PO_4^{3-} Phosphate
	CrO_4^{2-} Chromate	OH^- Hydroxide	PO_3^{3-} Phosphite
	CN^- Cyanide	ClO^- Hypochlorite	SO_4^{2-} Sulphate
	$Cr_2O_7^{2-}$ Dichromate	NO_3^- Nitrate	SO_3^{2-} Sulphite

C3: Common Isotope Pairs Chart

Isotope		Half-life of parent (years)
Parent	Daughter	
Carbon-14	Nitrogen-14	5730
Uranium-235	Lead-207	710 million
Potassium-40	Argon-40	1.3 billion
Uranium-238	Lead-206	4.5 billion
Thorium-235	Lead-208	14 billion
Rubidium-87	Strontium-87	47 billion

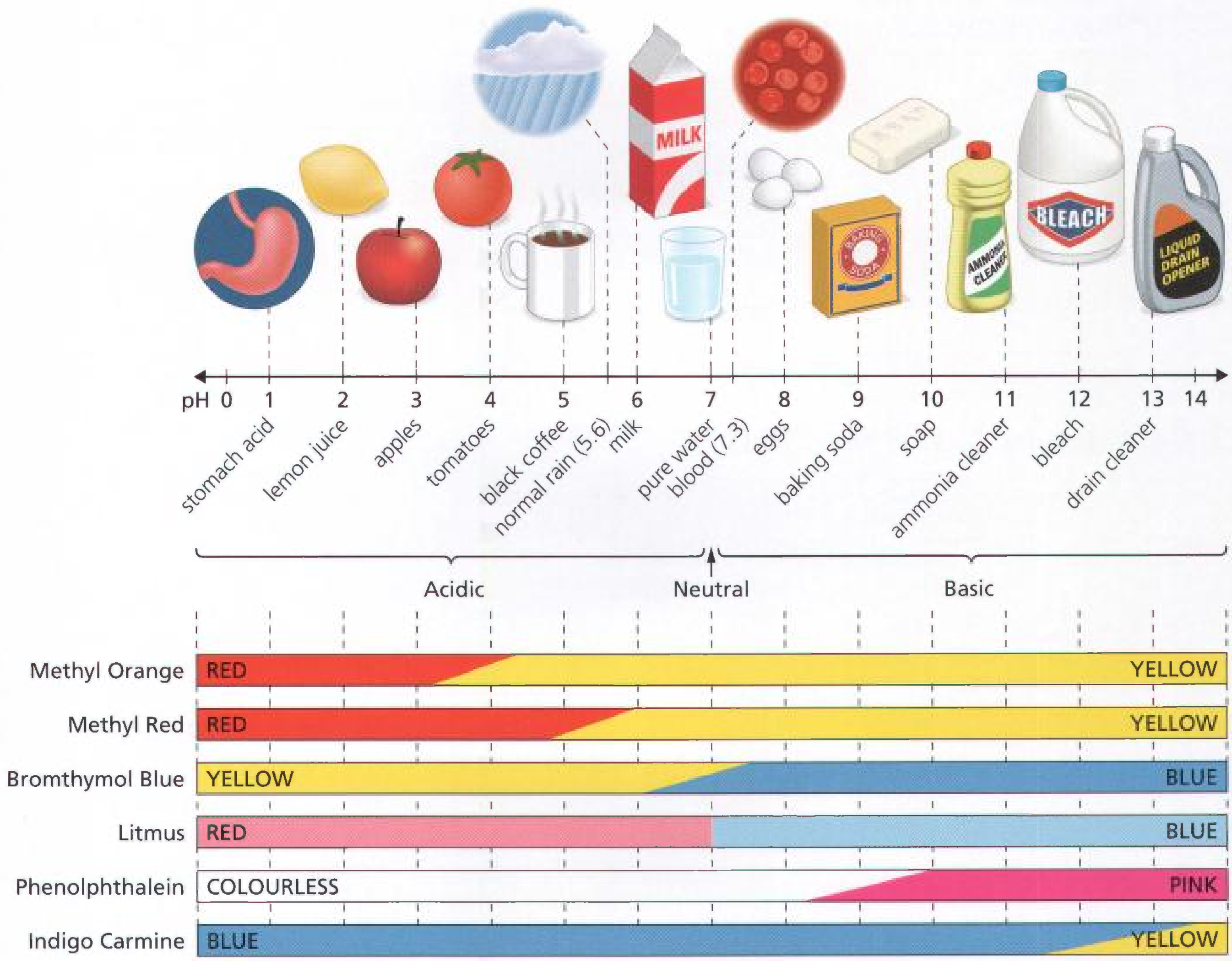
C4: Radioactivity Symbols

${}^4_2\alpha$, ${}^4_2He$	${}^{0}_{-1}\beta$, ${}^{0}_{-1}e$	${}^0_0\gamma$
${}^1_0n$	${}^1_1p$, ${}^1_1H$	

C5: Motion Equations

$v_{av} = \Delta d/\Delta t$	$a = \Delta v/\Delta t$	$\Delta v = v_f - v_i$
$\Delta d = v_{av}\Delta t$	$\Delta v = a\Delta t$	$v_i = v_f - \Delta v$
$\Delta t = \Delta d/v_{av}$	$\Delta t = \Delta v/a$	$v_f = v_i + \Delta v$

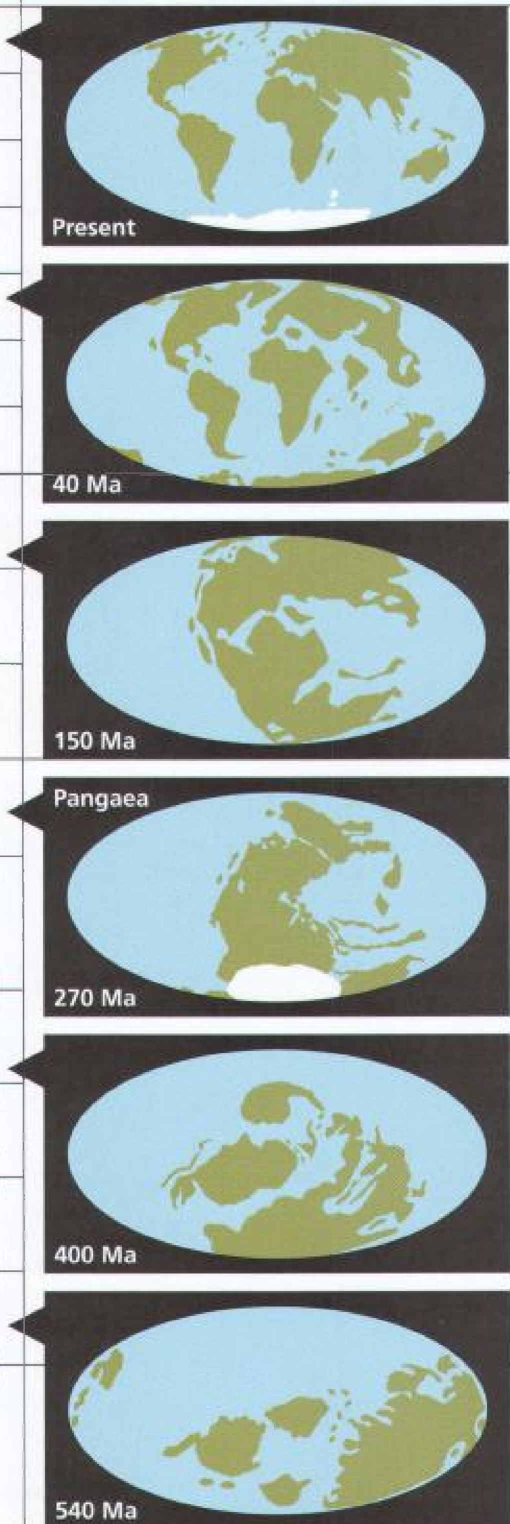
C6: pH Scale and Indicators



C7: Geological Time Scale

ERA	PERIOD	EPOCH	TIME (Ma)
CENOZOIC	Quaternary	Holocene	0.01
		Pleistocene	1.6
	Tertiary	Pliocene	5.3
		Miocene	24
		Oligocene	34
		Eocene	55
		Paleocene	65
MESOZOIC	Cretaceous		145
	Jurassic		200
	Triassic		251
PALEOZOIC	Permian		300
	Carboniferous		355
	Devonian		418
	Silurian		441
	Ordovician		490
	Cambrian		544
PRECAMBRIAN			4600

TECTONIC PLATE MAPS

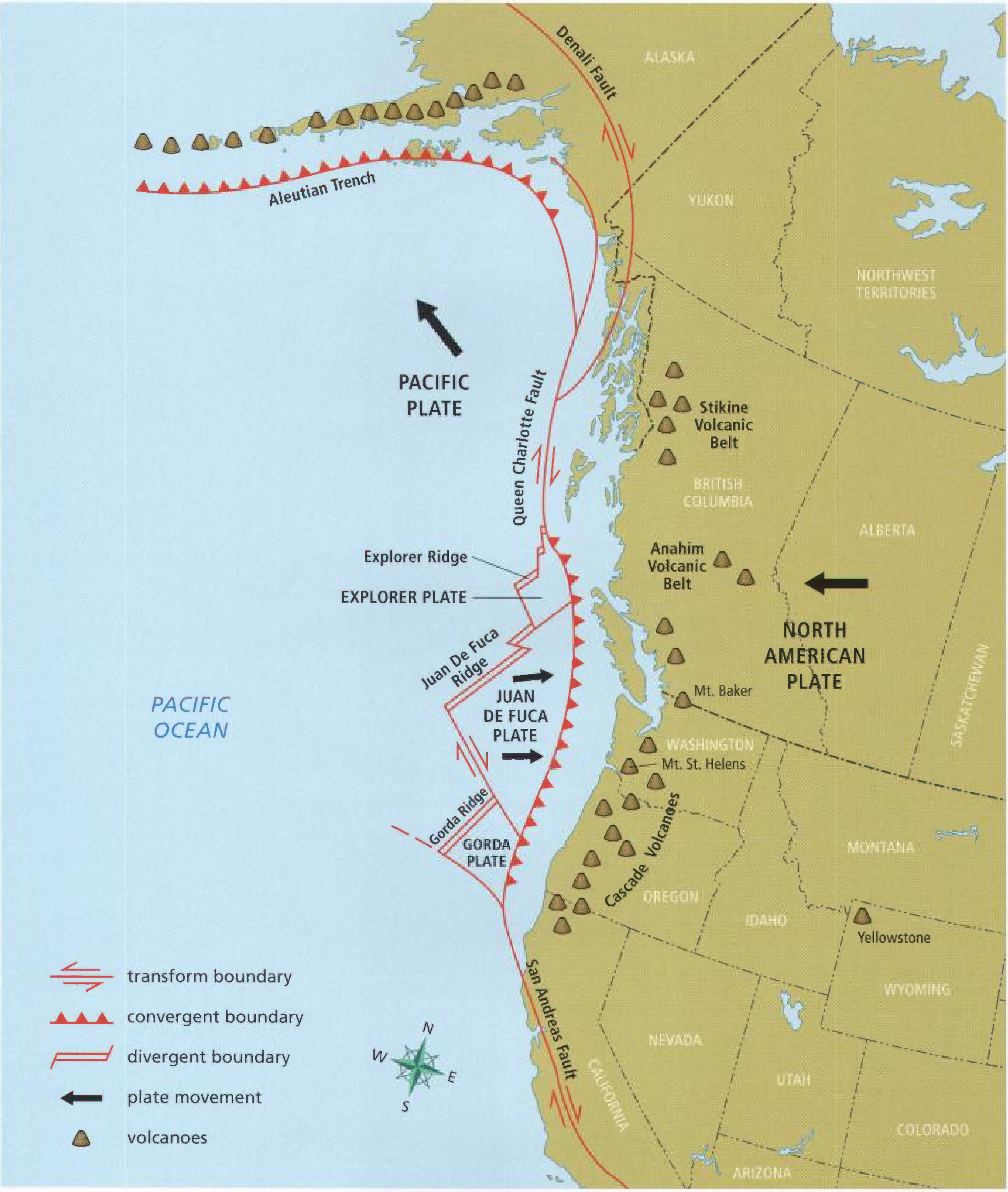


LITHOSPHERE

- ice sheets advance then retreat in Northern Hemisphere
- glaciation intensifies
- Grand Canyon forming
- beginning of modern ice ages
- Himalayan Mountains forming
- climate warmer than present causing higher sea level
- Rocky Mountains forming
- Atlantic Ocean forming
- Pangaea breaking apart
- glaciation in Southern Hemisphere
- Pangaea forming
- abundant deposition of organic material, source of future fossil fuels
- multicellular life on land
- glaciers retreat
- glaciers form at poles
- tropical climate at equator
- Burgess shale deposited
- abundant fossils appear in rock record
- multicellular aquatic life
- red iron oxide deposits
- single cell aquatic life
- Formation of Earth

Dates according to Geological Time Scale, 1999. Geological Survey of Canada Open File 3040. It is recognized that there is some variation in the dates given in the literature.

C8: Tectonic Plate Boundaries of the Pacific Coast of North America



Appendix D: Exam Preparation Strategies

One goal of your studies is to prepare for the assessments and evaluations that are a normal part of your science program. In addition, you should pay attention to preparing for the Science 10 Exam.

This section will provide some general strategies and tips that will help you to prepare for exams throughout the year and to perform your best on the Science 10 Exam. Of course, most of these strategies will only work if you have knowledge of the content and skills being tested, so your best strategy is to study hard.

D1: General Tips for Exam Taking

There are many ways to improve study skills and performance on exams. Different people learn and recall information differently. The following list provides some common-sense strategies that may help you improve your performance. Try each strategy. Find those that work best for you and ignore the rest.

Before the Exam—Preparation

- **Involve yourself in class.** Attend class regularly. Be active in your learning by asking questions and completing assignments on schedule.
- **Keep up-to-date with Science 10 material.** Make a study schedule that includes a regular review time every week. Use this time to organize your notes, review the material, and ask yourself questions about what you have learned.
- **Read and understand the exam scoring criteria.** Your teacher will explain the scoring criteria. Make sure you understand what they mean.
- **Find out what material the exam will be based on.** Ask your teacher to clarify which parts of the text and classroom activities the exam will be based on.
- **Form a study group.** If you work well with a partner or a few close friends, form a study group. You can help each other with material that you don't understand.
- **Practise writing old exams.** Use old exams to simulate the conditions of the exam, including the time constraints. This will also help you practise answering the types of questions on the exam. Afterward, compare your answers to the scoring criteria to see where you can improve.
- **Use online exams and quizzes.** Check www.science.nelson.com for online quizzes and other material that you can use to study and practise.
- **Practise relaxation techniques.** Exams are always stressful. Learning how to relax under pressure can help when you write the exam. There are many different methods of relaxing, including closing your eyes, breathing deeply, stretching, and/or visualizing success. Find a method that works for you.
- **Eat well and make sure that you are well rested.** Get a good night's sleep and eat a healthy breakfast, even if you don't feel hungry. You will perform better if you properly prepare your body.
- **Bring necessary supplies.** Bring at least two pens/pencils with good erasers, a calculator with enough batteries, and any other resources required.

During the Exam—Performance

- **Arrive early.** Get to the exam in plenty of time.
- **Stay relaxed.** Keep a positive attitude throughout the exam. If you're nervous, practise your relaxation techniques.
- **Read the instructions**: Make sure that you read all of the instructions very carefully. Many students lose marks because they didn't follow the instructions.
- **Scan through the exam.** When you receive the exam, quickly skim through the entire exam so that you can budget your time and get a sense of the kinds of questions on the exam.
- **Read the entire question carefully.** Don't make assumptions about what the question might be. Look for key words to help you understand what the question is asking.

- **Do the easiest questions first.** When time is limited, don't get stuck on a question that you are having problems with. Come back to it later if you have time.
- **Go for value.** Do questions that have the greatest values first.
- **Stay alert for clues.** Sometimes questions provide information that is a clue to the answer for other questions.
- **Keep track of the time.** Bring a watch to the exam with you so that you can better pace yourself. Don't worry if others finish the exam before you.
- **Review your answers.** If you have time, look over the exam to make sure that you've answered all the questions, put your name or student number on the paper, and check your answers.

After the Exam—Analysis

- **Ask questions.** Find out the correct answers to the questions that you had difficulty with. If a question is on one exam, it may appear on future exams.
- **Attend review sessions.** If there is an opportunity to go over the exam in detail, make sure that you attend. This will help you learn how to improve your performance on the next exam.
- **Plan for the next exam.** Recall your performance and note areas where you had difficulty. Be prepared for the next exam—physically and mentally.

D2: Types of Exam Questions

Multiple-Choice Questions

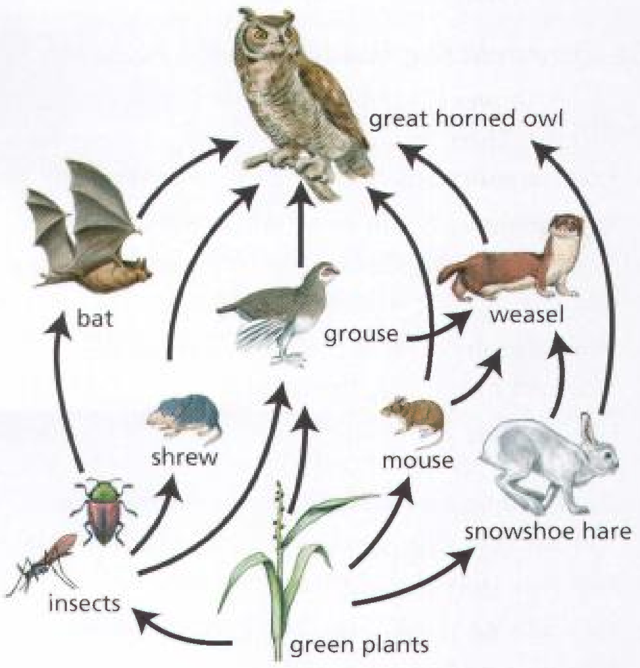
Multiple-choice exams contain questions that offer a number of possible answers from which you have to select the correct or best answer. Multiple-choice questions usually include a stem in the form of a question (or a phrase and a question) followed by a number of options called distracters, labelled A, B, C, and D. All questions are usually of equal value.

The Provincial Science 10 Exam

The Science 10 Exam will contain only multiple-choice questions. You have been provided opportunities to practise answering provincial exam-style questions in *B.C. Science Probe 10*. The Chapter and Unit Reviews contain multiple-choice questions that are modelled after the provincial exam. Additional exam-style questions are provided in the Student Workbook and online quizzes at www.science.nelson.com. Your teacher will also provide worksheets that will help you develop exam-taking strategies and provide practise with exam-style questions.

Many of the questions on the Science 10 Exam are context dependent. That is, they are based on additional information such as an illustration, a short article, a graph, or a table that is included in the exam. This information is preceded by a statement such as, "Use the following information to answer question 1." Question 1 below is an example of a context-dependent question.

Use the following illustration to answer question 1.



1. Which of the following is likely to occur if a large number of mice are removed from the area?
   A. an increase in the weasel population
   B. an increase in the owl population
   C. a decrease in the plant population
   D. a decrease in the shrew population

The remaining questions on the Science 10 Exam are not context dependent and are called discrete questions. For these questions you must rely on your understanding of concepts addressed in the Science 10 program. Question 2 below is an example of a discrete question.

2. Which statement explains how two members of the biotic community affect an abiotic factor?
   A. Pine trees and poplar trees affect the growth of grasses.
   B. Beavers and shrubs affect the number of poplar trees.
   C. Water temperature and pond oxygen levels affect the amount of plankton in the lake.
   D. Poplar trees and shrubs lose their leaves, which are decomposed and improve soil quality.

Additional examples of context-dependent and discrete questions can be found on the Nelson website www.science.nelson.com.

Tips for Answering Multiple-Choice Questions

- Try to answer the question before looking at the options. Then, read all the options and select the one that most closely matches your answer.
- Analyze the question stem and identify the key words or phrases that tell you what the question is asking.
- Eliminate any options that you know to be incorrect by crossing them out.
- Stay alert for key words in the stem: *always, must, most, least, NOT one of the following,* etc. These key words will usually be in bold print. For example, "Which of the following structures is **not** part of the respiratory system?"
- Stay alert for options that contain negative or absolute words such as *all, always, except, every, generally, however, may, must, never, none, not, often, only, perhaps, rarely, seldom, sometimes,* or *usually.* Absolute words tend to make an option false.
- Question any option that is totally unfamiliar to you or is not connected to the main idea in the stem.
- If you have narrowed the possible answers to two options, compare the options and look to the stem for a clue to the best answer.
- For questions where you have to calculate a numerical value, the formulas and other data will be provided in the data booklet. Solve the problem first, and then look for a match between your answer and one of the options.
- For numerical questions that require you to rearrange variables, events, or data into a specified order, pay particular attention to the instructions, which might specify, for example, "in the order in which they occur during convection."
- Don't waste time looking for patterns in the answers. The correct answers will be randomly distributed. So, don't become concerned or doubt your answers if you have three C answers in a row.
- Guessing is a last resort. Guess only after you have tried other strategies (e.g., eliminating incorrect options) and still have no idea what the correct answer might be. If you have to guess, the following guidelines **may** improve your accuracy:
  - If two options look similar, except for 1 or 2 words, usually one of these is the correct answer.
  - If two options have the same meaning, usually both are wrong.
  - If two options consist of words that look or sound the same (e.g., "displacement" vs. "replacement") one of these is often the correct answer.
  - If the options cover a wide range of numerical values, a value at or near the middle is often a good guess.
  - An option that is longer or more detailed than the other options is often the correct answer.

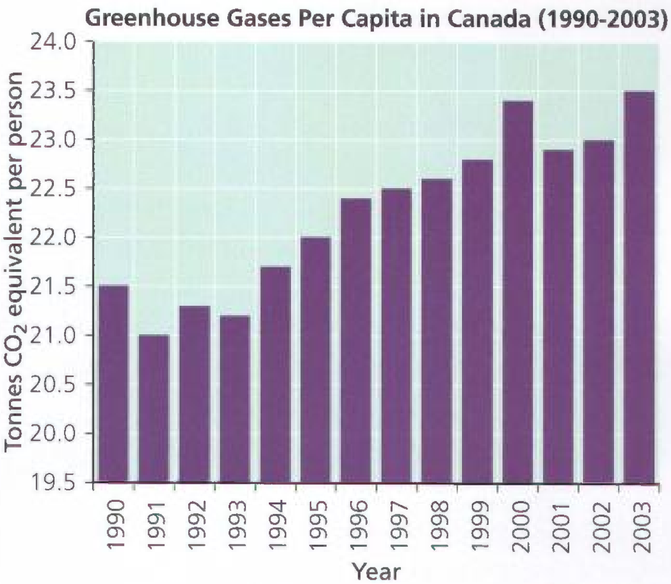
Written-Response Questions

There are two general types of written-response questions. One is the closed-response question, which has only one correct response, and the other is the open-response question to which there is more than one correct response. Learn to determine which type of question is being asked.

Closed-Response Questions

Closed-response questions have only one correct answer. These questions are generally presented as sections and subsections (question 1(a), (b), (c), etc.). They usually are based on current research or a scenario, and may provide data in graph or a table, as shown in the example below.

Use the following information to answer question 3.



3. (a) Describe any significant trends in the total per capita greenhouse gases in Canada from 1990 to 2003.
   (b) Propose an explanation for each of the trends you described in (a).
   (c) What is the percentage increase from 1990 to 2003? Does this figure give an accurate representation of what happened during the entire period? Explain.

Additional examples of closed-response questions can be found on the Nelson website www.science.nelson.com.

Open-Response Questions

Open-response questions have more than one possible answer. The question is asked as a series of bullets, and the answers are to be written in full sentences. Each bullet must be addressed and combined into the answer.

The questions are based on provided background information. Each bullet contains at least one directing word. Your final answer must address each bullet fully in order to get full credit. One of these bulleted questions may require you to make and defend a judgment or opinion. Your answer will be evaluated on the basis of its scientific aspects and on its technological, societal, and/or environmental aspects. Question 4 is an open-response question.

4. In 1989, one of the world's worst oil spills occurred in Alaska, when the oil tanker *Exxon Valdez* ran aground in Prince William Sound, spilling approximately 40 863 000 L of oil. The damage to the environment was severe. It has been estimated that up to 22 orcas, 250 bald eagles, 300 harbour seals, 2800 sea otters, 250 000 seabirds, and billions of salmon and herring eggs were killed.
   - Using an example food chain, **illustrate** how the food web in this ecosystem could be affected.
   - Based on what you know about the interactions with an ecosystem, **predict** the possible long-term consequences of this oil spill on the ecology of the region.
   - It has been suggested that oil tanker traffic should be banned from Prince William Sound. Take a position for or against this suggestion and **justify** your answer.

Additional examples of open-response questions can be found on the Nelson website www.science.nelson.com.

Tips for Answering Written-Response Questions

- Carefully read the information provided and make sure that you fully understand the material *and* all of the question parts before beginning to answer.
- Identify each key piece of information and make notes about the meaning and implications of that information. If it helps, mark key words and phrases.
- Identify the directing words in the question such as illustrate, analyze, explain, and predict. Directing words have specific meanings and are indicators of what is expected for an answer.
- Summarize your answers on scrap paper before writing them on the exam answer page.
- Once you have answered the question, review your answer and make sure that you have addressed all parts of the question.

Glossary

A

abiotic factor any of the non-living components of an ecosystem; a non-living environmental factor; such factors include the physical and chemical components in the environment (p. 22)

acceleration the rate of change of velocity; a vector quantity with both a magnitude and direction; symbol is $\vec{a}$ (p. 373)

accuracy how close a value is to its accepted value (p. 551)

acid a substance that releases H^+ ions in solution (p. 203)

acid–base neutralization reaction a chemical reaction in which an acid completely reacts with a base resulting in a neutral solution; products of this reaction are a salt and water (p. 243)

acidity a measure of the relative amounts of H^+ and OH^- in a solution; the higher the relative number of H^+ ions, the higher the acidity (the lower the pH) (p. 205)

acid precipitation results from air-borne pollutants, particularly sulfur dioxide and nitrogen monoxide, reacting with water vapour in the atmosphere to form acidic compounds that return to Earth in precipitation (p. 114)

adaptation any genetic trait that improves an organism's chance of surviving and reproducing (p. 61)

adaptive radiation occurs when species adapt differently to changes in the environment, and become specialized in order to exploit smaller parts of the ecological niche (p. 68)

aerobic respiration respiration that uses oxygen to release the energy in carbohydrates (p. 90)

albedo [al-BEE-doh] the degree to which a surface reflects light (p. 419)

alpha particle consists of two protons and two neutrons; emitted during alpha decay of a radioactive atom; symbol is α (p. 285)

anaerobic respiration respiration that does not require oxygen to release the energy in carbohydrates; respiration that occurs in the absence of oxygen; a process used by certain bacteria; also called fermentation (p. 90)

applied research research that is primarily focused on developing new and better solutions to practical problems (p. 13)

aqueous [AY-kwee-uhs] the term used to describe substances dissolved in water; such substances are given the designation (aq) (p. 203)

asthenosphere [as-THEN-uh-sfeer] the fluid-like layer of mantle over which the lithosphere drifts (p. 493)

atmosphere the layer of gases enveloping Earth (p. 417)

atmospheric pressure the pressure exerted by a column of air above any point; measured in pascals; also called air pressure (p. 431)

atom the smallest particle of an element that can exist by itself (p. 150)

atomic mass the average mass of the atoms of an element (p. 153)

atomic number the number of protons in the nucleus of an element; each element has a unique number (p. 153)

autotroph see **producer**

average speed the total distance an object travels divided by the total time taken (p. 346)

B

balanced equation a chemical equation in which the atoms are conserved; the number of atoms of each element is equal on both sides of the equation (p. 236)

base a substance that releases OH^- ions in solution (p. 203)

base units the seven SI units that can be used to express all physical quantities (p. 546)

basic research research that helps people learn more about how the natural world works (p. 13)

beta particle an electron emitted during beta decay of a radioactive atom; symbol is β (p. 286)

bioaccumulation the buildup of a substance within the tissues of organisms over time (p. 120)

biodegradation the decay process that makes the nutrients contained in waste and dead matter available to producers once again (p. 27)

biodiversity the variety of, and the variation among, organisms within a given ecosystem, biome, or the entire Earth (p. 64)

biomagnification the increase in concentration of a substance within the tissues of organisms that are at higher levels of the food chain (p. 120)

biome a large ecosystem with a specific range of abiotic and biotic factors such as temperature, precipitation, and characteristic organisms (including plants and animals) (p. 54)

biosphere the total area of Earth where living things are found; the narrow zone around Earth that supports life (p. 22)

biotic factor any of the living components of an ecosystem; such factors include organisms like bacteria, plants, and animals, as well as the interactions between them (p. 22)

body wave a type of seismic wave that travels through Earth, including primary (P) and secondary (S) waves (p. 526)

bond to join together; atoms have the tendency to bond with other atoms (p. 170)

bonding pair a single valence electron from an atom paired with a single valence electron from another atom; also called a shared pair (p. 210)

boreal forest the biome characterized by acidic soils, dry winters, moderate precipitation, and the growth of conifers; stretches across the northern parts of North America, Asia, and Europe; also known as taiga (p. 56)

C

canopy the upper layer of vegetation in a forest; often creates a dense layer, or cover, that prevents most sunlight from reaching the forest floor (p. 56)

carbon cycle the cycling of carbon through ecosystems (p. 86)

carbon dioxide equivalent (CO_2 eq.) the values used to compare the warming potential of other GHGs to the warming potential of carbon dioxide (p. 456)

carbon reservoir refers to locations on Earth that store and release organic carbon slowly (p. 86)

carbon sink a carbon reservoir that stores carbon for long periods or absorbs more carbon than it releases (p. 86; 456)

carbon source a carbon reservoir that releases more carbon than it stores (p. 86)

carnivore an organism (consumer) that eats other animals (consumers) (p. 26)

catalyst [KAT-uh-list] a substance that, when added to a reaction, increases the reaction rate without being consumed in the reaction (p. 255)

cellular respiration the reaction between carbohydrates and oxygen that produces energy, carbon dioxide, and water (p. 83)

chain reaction a reaction that initiates its own repetition (p. 318)

chemical bond any of several physical forces that join or connect atoms together (p. 176)

chemical equation a symbolic representation that uses chemical formulas to describe the reactants and the products in a chemical reaction (p. 232)

chemical family a group of elements that have a characteristic set of common physical and chemical properties (p. 157)

chemical formula describes the proportions of elements in a compound using chemical symbols (p. 183)

chemical property a property that describes a possible chemical change that a substance may undergo (e.g., reacts with water) (p. 149)

chemical reaction a process that involves a chemical change; a process in which a new substance(s) is/are formed (p. 233)

climate the long-term pattern of temperature and precipitation (p. 51)

climate change a shift in long-term average weather patterns, which includes changes in temperature, precipitation, and the frequency of extreme weather events such as hurricanes and tornadoes (p. 455)

climatograph a graph showing the monthly changes in temperature and precipitation throughout a year (p. 53)

climax community a complex, stable ecosystem reached during late successional stages (p. 71)

coevolution a type of interaction involving the adaptation of two species in response to each other (p. 63)

collision theory a theory that states that in order for moving particles to react, they must first collide with a certain minimum amount of energy (p. 251)

combustion reaction a chemical reaction in which an organic (carbon–hydrogen) substance reacts with oxygen to release heat, and perhaps light energy (p. 244)

commensalism [kuh-MEN-suhl-IZ-uhm] a symbiotic interaction in which one organism benefits while the other is unaffected (p. 30)

community all of the different populations in a particular area that interact with one another; the third level of organization that ecologists study (p. 22)

competition when two organisms make use of the same resource so that their niches overlap (p. 68)

compound a substance formed from two or more elements, in which the elements are always combined in the same fixed proportions (p. 150)

conduction the transfer of thermal energy by direct particle-to-particle contact (p. 411)

consumer an organism that consumes other organisms or biotic waste in order to survive; also called a heterotroph (p. 26)

continental–continental convergent boundary a convergent boundary where the continental portions of two tectonic plates meet (p. 506)

continental drift theory the theory that explains the movement of continents over Earth since it was formed (p. 498)

convection the transfer of thermal energy through the movement of particles in fluids; caused by differences in the density of particles in the fluid (p. 413)

convergent boundary the point of collision between two tectonic plates that are moving toward each other (p. 506)

core centre of Earth's internal structure; see also **outer core** and **inner core** (p. 493)

Coriolis [KOH-ree-OH-liss] **effect** explains a moving object's apparent change in horizontal direction due to the rotation of Earth (p. 442)

covalent bonding chemical bonding that results from a sharing of valence electrons; occurs when non-metals share their valence electrons with other non-metals to complete their valence shells (p. 177)

covalent chemical bond the type of bond formed by a bonding pair of electrons (p. 212)

covalent compound a compound formed when atoms join together through covalent bonding; also called a molecular compound (p. 177)

crust the rigid outer rock layer of Earth's internal structure, making up the sea floors and continents (p. 493)

D

daughter nucleus refers to the nucleus produced as a result of radioactive decay (p. 284)

DDT (dichloro, diphenyl trichloroethane) a synthetic pesticide that was widely used to control insect pests up until the 1970s, when it was discovered to have harmful effects on organisms (p. 121)

decay series occurs when a radioactive parent nucleus produces a daughter nucleus that is also unstable and the unstable daughter nucleus decays; process continues until a stable daughter nucleus is produced (p. 294)

decomposer a consumer that breaks down the complex molecules found in dead organisms and waste matter into simpler molecules (p. 27)

decomposition reaction a chemical reaction in which a compound breaks into its component parts (p. 241)

deep-focus earthquake an earthquake with a focus located at a relatively deep point (300–700 km) beneath Earth's surface (p. 526)

deforestation occurs when more trees are cut down than are replaced (p. 128)

denitrification the process that converts ammonia and nitrate back to nitrogen gas (p. 94)

derived units units of measurement that are formed using two or more base units (p. 546)

desert the biome characterized by less than 25 cm of precipitation annually and sparse vegetation of small plants specialized to conserve water; occurs in North Africa, central Australia, southwestern North America, eastern Asia, and the southeast tip of South America (p. 58)

detrivore a decomposer that feeds on the waste material in an ecosystem, including the bodies of other organisms that have died, plant debris, and animal feces (p. 27)

diatomic molecule a set of paired atoms; a small number of elements that only exist in pairs of atoms (p. 178)

discovery an observation of nature that no one has made before, or that no one has made in the same way before (p. 4)

displacement a vector quantity that indicates the change in position of an object; symbol is $\vec{d}$ (p. 359)

divergent boundary the area between two tectonic plates that are moving away from each other (p. 356)

double replacement reaction a chemical reaction in which two compounds (containing elements) react and two of the elements replace each other (p. 242)

dynamic equilibrium any system with constant change in which the components can adjust to the changes without disturbing the entire system (p. 23)

E

earthquake vibrations through Earth's crust caused by volcanoes or movement at tectonic plate boundaries (p. 525)

ecological pyramid a representation of energy flow in food chains and webs; also called a food pyramid (p. 39)

ecological succession a gradual change in the types of plants that represent the structure of a community (p. 71)

ecology the study of how organisms interact with each other and with their physical environment (p. 21)

ecosystem includes the living community as well as the physical environment in which the organisms live; the fourth and most complex level of organization that ecologists study (p. 22)

electron a negatively charged subatomic particle located outside the nucleus of an atom; has an electric charge of –1 (p. 154)

electron dot diagram see **Lewis diagram**

electron shell a specific region around the nucleus in which electrons are arranged; also called an orbital or an energy level (p. 154)

element a substance that cannot be broken down into simpler materials (p. 150)

elevation refers to height above (or below) sea level (p. 51)

El Niño [el NEEN-yo] a periodic shift in ocean currents, temperature, and atmospheric conditions in the tropical southern Pacific Ocean (p. 464)

empirical knowledge knowledge gained through observation and experimentation (p. 3)

endocrine-disrupting compounds (EDCs) chemicals that either mimic or disrupt the normal functioning of certain hormones; these chemicals often bioaccumulate and include DDT, PCBs, chlordanes, and PBDEs (polybrominated diphenyl ethers) (p. 124)

enhanced greenhouse effect caused by an increase in the concentration of GHGs above normal levels; leads to more heat being trapped in the atmosphere (p. 456)

epicentre the spot at Earth's surface directly above an earthquake's focus (p. 525)

extinction when a species is gone completely from Earth, or when so few individuals remain that reproduction is not possible (p. 64)

extirpation [EK-stur-PAY-shun] the phenomenon of local extinction, which occurs when a species ceases to exist in one area but still exists elsewhere in the world (p. 64)

extrapolation the prediction of values that lie outside known values (p. 555)

F

fault a displacement of the lithosphere (vertically, horizontally, or both) created by the movement of tectonic plates (p. 27)

fermentation see **anaerobic respiration**

focus the location of an earthquake's origin within the lithosphere (p. 525)

food chain a representation of the pathway taken by nutrients and energy through the trophic levels of an ecosystem (p. 34)

food pyramid see **ecological pyramid**

food web a representation of the nutrient and energy pathways in an ecosystem showing many cross-linked food chains (p. 36)

foreign species species that are not native to a particular ecosystem; they are often able to out-compete the existing native species for a particular niche (p. 69)

fossil fuels hydrocarbons found within the top layer of Earth's crust; include coal, oil, and gas (p. 86)

G

gamma ray a very high-energy type of electromagnetic radiation emitted during gamma decay of a radioactive atom; symbol is γ (p. 287)

global warming an increase in the long-term average temperature of Earth's surface and lower atmosphere (p. 455)

grassland the biome characterized by rainfall between 25–75 cm per year supporting the growth of grasses (p. 57)

greenhouse effect the warming effect created by the ability of Earth's atmosphere to trap thermal energy (p. 88; 455)

greenhouse gases (GHGs) gases in the atmosphere that allow solar radiation to pass through the atmosphere and be absorbed by Earth's surface, and then absorb and trap any thermal energy radiated from Earth; include carbon dioxide and methane (p. 88)

H

habitat the region in which an organism lives (p. 21)

half-life the average length of time for half of the parent nuclei in a sample to decay (p. 290)

heat the transfer of thermal energy from a cooler substance to a warmer substance because of temperature differences (p. 411)

heavy metals elements that are found in the middle of the periodic table and have relatively high densities; commonly used in industry; toxic or poisonous to organisms in relatively low concentrations (p. 123)

herbivore an organism (consumer) that eats plants (producers); also called a primary consumer (p. 26)

heterotroph see **consumer**

high-pressure cell a region of high-pressure at Earth's surface produced by the sinking of denser air (p. 433)

host the organism that is harmed in a symbiotic parasitic relationship; the other organism (parasite) benefits (p. 30)

hot spot a small region of very hot mantle heated by a concentration of radioactive substances near Earth's core (p. 523)

hydrocarbon an organic compound that contains only the elements hydrogen and carbon; the simplest of all organic compounds (p. 218)

hydrosphere all of the water, in all of its states, found in, on, or near Earth (p. 418)

I

inner core the solid centre of Earth, consisting mostly of very dense iron (p. 493)

innovation the modification of an existing technology to serve a new purpose (p. 6)

inorganic matter that is not of biological origin; it may or may not contain carbon and is often of mineral origin (p. 83)

inorganic compound any compound that is not an organic compound (p. 201)

instantaneous acceleration the acceleration of an object at a particular instant in time (p. 383)

instantaneous speed the speed of an object at a particular instant in time (p. 349)

insulator material that limits thermal energy transfer (p. 414)

intermediate-focus earthquake an earthquake with a focus located at a relatively intermediate point (70–300 km) beneath Earth's surface (p. 526)

interpolation the prediction of values that lie between known values (p. 555)

interspecific competition competition between different species (p. 68)

intraspecific competition competition between organisms of the same species (p. 68)

invention the creative development of a new device or process that helps people meet their needs or satisfy their wants (p. 6)

ion a charged atom; does not have an equal number of protons and electrons (p. 171)

ion charge balance in ionic compounds, the total positive ion charge is equal to or cancels the total negative ion charge; the total ion charge for the compound is zero (p. 183)

ionic bonding chemical bonding that results from a transfer of valence electrons; occurs when oppositely charged ions (metals and non-metals) strongly attract one another and are held tightly together (p. 176)

ionic compound a compound formed when atoms join together through ionic bonding (p. 176)

isobars lines on a weather map that join locations of equal atmospheric pressure (p. 433)

isotopes atoms of the same element that have different mass numbers; isotopes have the same number of protons, but a different number of neutrons (p. 281)

K

keystone species a species whose presence plays an important ecological role in determining the types and numbers of other species in particular ecosystems; when these species are eliminated, the effects on the ecosystem are dramatic (p. 64)

kilopascal (kPa) the unit of measurement for air pressure; 1 kPa = 1000 Pa (p. 431)

kinetic energy the energy that a substance has due to its motion (p. 405)

kinetic molecular theory the theory that matter is made up of tiny particles in constant, random motion; the more energy the particles have, the faster they move (p. 251; 405)

L

land breeze occurs because land cools faster than water overnight, creating higher air pressure over the land and lower air pressure over the water. The less dense air over the water rises, and more dense air blows off from the land to replace it (p. 438)

La Niña [lah NEEN-ya] a periodic shift to colder-than-average ocean temperatures in the eastern Pacific Ocean with effects opposite to those of El Niño (p. 466)

latent heat the energy needed to change a substance from one state to another without changing temperature (p. 415)

latitude the location of a place on Earth north or south of the equator, which is designated as zero (0) degrees (p. 51)

Law of Conservation of Mass the total mass of the reactants in a chemical reaction in a closed system is equal to the total mass of the products (p. 233)

legume [leg-YOOM] a plant whose root nodules host nitrogen-fixing bacteria; includes crops such as peas, peanuts, soybeans, clover, and alfalfa, and wild plants such as alders and lupins (p. 92)

Lewis diagram a simple model of the arrangement of valence electrons in atoms where single or paired dots represent the valence electrons; describes an atom as it prepares to bond with other atoms; also called an electron dot diagram (p. 210)

limiting factor the factor that is the most critical in determining the types of organisms that can exist in an ecosystem; an environmental factor that limits the growth, abundance, or distribution of a population of organisms in an ecosystem (p. 23)

line of best fit a smooth line that passes through or between the points on a graph so that there are about the same number of points on each side of the line; attempts to minimize the effect of random measurement errors (p. 555)

lithosphere [LITH-uh-sfeer] the region of Earth's internal structure formed by the crust and the rigid outer layer of the mantle (p. 417; 493)

lone electron pair a pair of electrons that are not a bonding pair, and thus do not form a chemical bond (p. 212)

low-pressure cell an area of lower air pressure at Earth's surface formed by a warmed air mass that is expanding and rising (p. 433)

M

mantle the middle, fluid-like layer of Earth's internal structure, nearly 3000 km thick (p. 493)

mantle convection convection currents that occur in the mantle because of uneven heat distribution within Earth (p. 517)

mass number the total number of protons and neutrons in the nucleus of an atom (p. 153)

mid-ocean ridge an undersea mountain range bracketing a divergent boundary; also called a spreading ridge (p. 501)

mimicry a strategy whereby one species resembles another that is poisonous, dangerous, or distasteful to avoid predation; also refers to situations where two harmful species have similar colouration (e.g., bees and wasps) (p. 63)

mixture formed when two or more substances are put together, but are not chemically combined (p. 150)

molecular compound see **covalent compound**

molecule a neutral particle that consists of two or more atoms that are covalently bonded together (p. 178)

multivalent metal elements that have more than one ion charge (p. 187)

mutualism [MYOO-choo-uhl-izm] a symbiotic interaction in which both species obtain some benefit from the interaction (p. 30)

mycorrhizae microscopic fungi that increase the solubility of phosphates in the soil, making them more readily available for plants (p. 99)

N

natural selection a process that favours the survival of organisms with traits that make them better adapted to the environment; tends to eliminate those individuals that are poorly adapted (p. 61)

negative acceleration occurs when an object undergoes a decrease in velocity, or the final velocity is less than the initial velocity (p. 376)

neutron an uncharged subatomic particle contained within the nucleus of an atom; similar in mass to a proton (p. 153; 281)

niche [neesh] the overall role of an organism in a community, including the range of biotic and abiotic conditions that the organism can tolerate (p. 68)

nitrate a highly soluble nitrogen compound containing both nitrogen and oxygen; produced from ammonium by bacteria in the soil (p. 93)

nitrification [NYE-trih-fih-CAY-shun] the process that produces nitrate from ammonium (p. 93)

nitrogen cycle the movement of nitrogen between the abiotic and biotic components of the biosphere (p. 92)

nitrogen fixation the first step in the nitrogen cycle, which occurs when nitrogen from nitrogen gas is "fixed" or combined with hydrogen to produce ammonia (NH_3) (p. 92)

nuclear fission the process of splitting a large atomic nucleus into two smaller nuclei (p. 313)

nuclear fusion the process of fusing, or joining of two small nuclei into one large nucleus (p. 327)

nucleus the dense centre of an atom; part of an atom containing all of the positive charge and almost all of the mass of the atom (p. 153; 280)

nutrients the elements and compounds that organisms must have in order to grow and live; includes water, oxygen, vitamins, and minerals, as well as foods that provide fats, proteins, and carbohydrates (p. 25)

O

oceanic–continental convergent boundary a convergent boundary where oceanic and continental portions of two tectonic plates meet (p. 506)

oceanic–oceanic convergent boundary a convergent boundary where the oceanic portion of two tectonic plates meet (p. 506)

ocean trench an extensive elongated depression of the sea floor where two tectonic plates converge (p. 502)

octet rule when bonding, each atom has a tendency to complete its valence shell to match its nearest noble gas (all noble gases have eight valence electrons except helium, which has two) (p. 212)

omnivore an organism (consumer) that eats both plants (producers) and animals (consumers) (p. 26)

organic describes matter that consists of compounds that always contain the elements carbon and hydrogen, although other elements may also be present; found in living organisms or the fossils of once living things (p. 83)

organic chemistry the chemistry of carbon compounds (p. 215)

organic compound a compound that has a high percentage of carbon by mass (p. 201)

organism a single living thing; the first and simplest level of organization that ecologists study (p. 21)

outer core the liquid outer portion of Earth's centre, consisting of iron and nickel (p. 493)

oxygen cycle describes the path of oxygen through ecosystems (p. 90)

ozone layer a layer about 24 km up in the atmosphere that contains a higher concentration of ozone (O_3) which absorbs harmful solar (UV) radiation (p. 457)

P

paired electrons two electrons together in an electron shell (p. 154)

paleoglaciation [PAY-lee-oh-GLAYS-ee-AY-shun] extensive periods in the past in which glaciers covered most of the continents (p. 499)

parasite the organism that benefits in a symbiotic parasitic relationship; the other organism (host) is harmed (p. 30)

parasitism [PEHR-uh-sih-TIZ-uhm] a symbiotic interaction where one organism (the parasite) benefits at the expense of another organism (the host), which is often harmed but usually not killed (p. 30)

parent nucleus refers to the nucleus that produces a daughter nucleus as a result of radioactive decay (p. 284)

parts per million (ppm) a notation used to denote low concentrations of chemical elements; denotes one particle of a given substance for every 999 999 other particles (p. 121)

permafrost the layer of permanently frozen sub-soil in polar regions (p. 55; 459)

pesticide a chemical substance used to control organisms humans consider to be pests (p. 121)

phase the physical property that describes the form in which matter can usually be found: solid, liquid, or gas; also called state (p. 178)

phosphate ions play an important role in the phosphate cycle due to their solubility in water; they can be dissolved out of rock into soil or water through the process of weathering, becoming available to producers and other organisms in the food chain (p. 98)

phosphorus cycle the path of phosphorus through ecosystems (p. 98)

photosynthesis the process whereby plants use the Sun's energy to convert carbon dioxide and water into carbohydrates and oxygen (p. 83)

pH scale a scale developed by chemists for measuring the acidity of solutions (p. 114; 205)

physical property a property of a substance that can be observed through the senses, measured, or calculated (p. 149)

pioneer species refers to the first species to arrive and colonize a new environment; over time, the presence of the pioneer species changes the environment, creating acceptable conditions for other species (p. 71)

polar ice the biome characterized by the presence of permanent ice and the absence of significant terrestrial vegetation; occurs at the North and South Poles (p. 58)

pollutant a substance introduced into the air, water, soil, or food in concentrations that threaten the health or survival of organisms; can affect natural population growth by destroying habitat and food sources or by killing organisms; can be natural or a result of human technology (p. 113)

polyatomic ion a group of atoms bonded together that act as a single ion (p. 189)

population all of the organisms of the same species that share a habitat; the second level of organization that ecologists study (p. 21)

precision the place value of the last measurable digit of a measurement; depends on the gradations of the measuring device being used (p. 551)

predation an ecological interaction that occurs when a predator captures and consumes prey (p. 28)

predator an organism that lives by preying on other organisms (p. 28)

predator–prey cycle describes the predator–prey relationship in terms of the effects on the size of both populations (p. 28)

prevailing winds dominant wind patterns covering large portions of Earth (p. 440)

prey an animal consumed for food by a predator (p. 28)

primary consumer see **herbivore**

primary productivity a measure of the available energy provided by the producers in an ecosystem (p. 64)

primary succession one of two types of ecological succession; the occupation by plant life of an area not previously covered by vegetation (p. 71)

primary wave (P–wave) the compression type of body wave that radiates through Earth from the focus of an earthquake (p. 526)

producer an organism that makes its own food, usually using energy from the Sun in a process called photosynthesis; also called an autotroph (p. 25)

product a chemical that is produced in a chemical reaction (p. 233)

proliferation [pruh-LIFF-uhr-AY-shun] increase in numbers of individuals with new adaptive traits resulting from natural selection; populations with the new adaptations will proliferate until further selective pressure leads to further adaptations (p. 68)

proton a positively charged subatomic particle contained within the nucleus of an atom; has an electric charge of +1; stable when outside of the nucleus (p. 153; 281)

pure substance a substance that has identical properties in every sample; also called a substance (p. 150)

pyramid of biomass an ecological pyramid that represents a snapshot of the total mass of the living things at each trophic level in a community; for most communities, the pyramid of biomass has the standard pyramid shape (p. 40)

pyramid of energy an ecological pyramid that represents how much energy is available in each trophic level; the size of each level represents the amount of energy present in that trophic level (p. 39)

pyramid of numbers an ecological pyramid that represents the actual number of organisms present in each trophic level; the shape of a pyramid of numbers varies widely depending on the physical size of the producers (p. 40)

R

radiation energy that is transmitted in the form of particles (alpha and beta particles) or electromagnetic waves (gamma rays); also refers to the transfer of thermal energy in the absence of matter (thermal radiation) (p. 412)

radioactive decay when an unstable nucleus emits radiation in the form of an alpha particle, a beta particle, or a gamma ray (p. 284)

radioactivity the spontaneous emission of radiation from the nucleus of an atom (p. 278)

reactant a chemical that reacts in a chemical reaction (p. 233)

reaction rate the amount of a reactant consumed per unit of time or the amount of a product formed per unit of time in a chemical reaction (p. 250)

resource partitioning a process that reduces or eliminates competition for similar resources by individuals of different species; species develop adaptations that allow them to occupy different non-overlapping ecological niches and partition available resources (p. 68)

ridge push a push originating from the mid-ocean ridge that serves as a mechanism for motion of the tectonic plates (driven by convection currents in the mantle) (p. 518)

rift valley a divergent boundary that cuts across land, where small volcanoes and shallow earthquakes occur (p. 506)

S

salt a substance that releases positive ions and negative ions, other than H^+ and $OH,^-$ in solution (p. 203)

sapwood the younger wood just inside the bark where most of the tree's nutrients are transported (p. 108)

savanna a tropical grassland biome; of all the biomes, savannas support the greatest number and variety of large herbivores (p. 57)

scalar quantity [SKAY-luhr] a quantity that has both a number and a unit; also called magnitude (p. 359)

scientific and technological literacy a combination of the science-related attitudes, skills, and knowledge needed to develop inquiry, problem-solving, and decision-making abilities (p. 17)

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*" (p. 548)

sea breeze wind that blows in from the sea to replace a rising (low-pressure) air mass heated by the land during the day. This occurs because the land heats up faster than water, creating a difference in air pressure (p. 438)

sea-floor spreading the process by which new sea floor is created at a divergent boundary and pushed toward an opposing convergent boundary where it is recycled into the mantle (p. 502)

secondary succession one of two types of succession; the occupation by plant life in an area that was previously covered by vegetation but where there has been a significant disturbance such as fire, flooding, landslides, or forest harvesting (p. 72)

secondary wave (S–wave) the sheer type of body wave that radiates through Earth from the focus of an earthquake (p. 526)

seismic wave [SYE-zmick] a large mechanical wave or vibration through Earth (p. 495; 526)

serendipity [SER-uhn-DIP-uh-tee] the act of discovering or inventing something useful by accident (p. 9)

shallow-focus earthquake an earthquake with a focus located at a relatively shallow point (0–70 km) beneath Earth's surface (p. 526)

SI a system of measurement where all physical quantities can be expressed as a combination of seven SI base units; stands for Système international d'unités (p. 546)

single replacement reaction a chemical reaction in which an element reacts with a compound (containing elements) and one of the elements in the compound is replaced (p. 242)

skeleton equation an incomplete chemical equation in which the chemical formulas are correct but the atoms are not conserved (p. 235)

slab pull the pull that results when the oceanic portion of a tectonic plate descends into the mantle, pulling the rest of the plate with it (p. 518)

slope the steepness of the line on a graph; represented by the change in the *x*-axis variable divided by the corresponding change in the *y*-axis variable (rise over run) (p. 344)

soil degradation results when fertile topsoil is lost to erosion and when soil nutrients are depleted (p. 127)

specific heat capacity a measure of the amount of energy (Joules) needed to raise the temperature of 1 kg of a substance by 1 °C (p. 414)

speed the rate at which an object is travelling; equal to the distance an object travels divided by the time interval taken; symbol is v (p. 346)

spreading ridge see **mid-ocean ridge**

state see **phase**

strike–slip fault a type of transform boundary at which the land on either side of a fault line is moving in opposite directions parallel to the fault (p. 507)

structural formula a simplified Lewis diagram that shows the number of atoms in each organic molecule plus the arrangement of those atoms (p. 216)

subatomic particle any of the parts that make up the atom; includes electrons, protons, and neutrons (p. 153)

subduction zone the region where tectonic plates overlap and one is pushed down beneath the other (p. 506)

surface wave the type of seismic wave that travels along the outside of Earth, created when a body wave reaches the surface (p. 527)

symbiosis [sim-bye-OH-sis] a specialized form of interaction between two different species; often, each species develops very specialized behaviours, life cycles, or structures; includes mutualism, commensalism, and parasitism (p. 30)

synthesis reaction a chemical reaction in which two elements combine to form a compound; also called a combination reaction (p. 239)

T

technology the process and the products by which humans develop ways to satisfy some of their needs and wants (p. 6)

tectonic plate [teck-TAWN-ick] one of 12 large and 20 smaller sections of Earth's lithosphere that drift on the denser asthenosphere (p. 497)

temperate deciduous [di-SID-yoo-uhs] **forest** the biome characterized by higher temperatures than the boreal forest and 75–220 cm of precipitation per year and that supports the growth of huge forests of broadleaf trees; covers regions in southeastern Canada, the eastern United States, and large areas of Europe and Asia (p. 56)

temperate rainforest one of the rarest of the world's biomes; characterized by abundant moisture, mild climate, thick and rich soil, and the growth of shrubs and small trees; currently found only in British Columbia, Alaska, and Chile (p. 57)

temperature an indicator of the average kinetic energy of a substance, measured in SI units of degrees Celsius (°C) or kelvin (K) (p. 405)

terminal velocity the point at which a falling object travels at a constant velocity (no acceleration) (p. 390)

theory of plate tectonics the theory that the lithosphere is divided into large tectonic plates that drift over the asthenosphere, so that some plates are splitting apart, others are coming together, and some are passing each other in opposite directions (p. 505)

thermal energy the total kinetic and potential energy of all particles in a substance (p. 409)

thermocline a region between the warm top and cold deep layers of the ocean (p. 465)

time interval the difference between two times, such as the difference between a start time and an end time; represented by the symbol Δt (p. 342)

tornado a rapidly rotating wind that forms within a thunderstorm (p. 438)

Traditional Ecological Knowledge and Wisdom (TEKW) the knowledge, experiences, and wisdom gained over many generations of close interaction with the living and non-living components of the environment (p. 3)

transform boundary the place where two tectonic plates move past each other in opposite directions (p. 507)

trend a relationship between data that shows a pattern (p. 553)

trophic level [TROH-fick] a category of living things that describes the position of an organism in relation to the order of nutrient and energy transfers in an ecosystem; the first trophic level contains autotrophs and each higher level contains heterotrophs (p. 33)

tropical rainforest the biome characterized by rainfall between 200–450 cm annually and temperatures between 20–25 °C throughout the year; believed to contain at least half of Earth's terrestrial organisms (p. 58)

troposphere [TROH-puh-sfeer] the lowest portion of Earth's atmosphere, where weather occurs. 9.8–20 km thick (p. 417)

tundra a massive biome that extends in a continuous belt across Canada, Alaska, Asia, and Europe;

characterized by very little precipitation (usually < 25 cm annually), permafrost, and small, slow-growing plants such as grasses and mosses; the growing season is limited to a brief period of about eight weeks during the summer, preventing any significant tree growth (p. 55)

U

understorey the flowers, ferns, shrubs, and small trees that grow below the canopy layer in a forest (p. 56)

uniform motion a situation where an object is travelling at a constant velocity; travelling at constant speed in a constant direction (p. 363)

unpaired electron a single electron in an electron shell (p. 154)

V

valence electron an electron in the outermost shell of an atom (p. 170)

valence shell the outermost shell or orbital of an atom (p. 170)

vector quantity a quantity that has both magnitude (number and unit) and direction (p. 359)

velocity the rate of change of displacement; a vector quantity with both a magnitude and direction; symbol is $\vec{v}$ (p. 361)

volcanic belt a string of volcanoes created on the overriding continent parallel to a convergent boundary (p. 524)

volcanic island arc a chain of volcanic islands that form on the oceanic portion of an overriding tectonic plate near an oceanic–oceanic boundary (p. 524)

volcano the place where magma reaches Earth's surface (p. 522)

Z

zooplankton a type of microscopic plankton that can be found in oceans, seas, and freshwater bodies; feed on phytoplankton (p. 26)

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Unit A

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Appendix

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Additional photography by Dave Starrett

B.C. Science Probe 10

Key

- **atomic number** → 26
- most common ion charge → 3+
- other ion charge → 2+
- **symbol of element** (solids in black, liquids in blue, gases in red) → Fe
- density at SATP: (solids in g/cm³) (liquids in g/mL) (gases in g/L) → 7.87
- name of element → iron
- atomic mass (u)—based on C-12; ( )—mass number of most stable isotope → 55.85

Period	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIIIB	9 VIIIB
1	1 0.0899 1+ 1– **H** hydrogen 1.01								
2	3 0.534 1+ **Li** lithium 6.94	4 1.85 2+ **Be** beryllium 9.01							
3	11 0.971 1+ **Na** sodium 22.99	12 1.74 2+ **Mg** magnesium 24.31							
4	19 0.862 1+ **K** potassium 39.10	20 1.54 2+ **Ca** calcium 40.08	21 2.99 3+ **Sc** scandium 44.96	22 4.54 4+ 3+ **Ti** titanium 47.87	23 5.96 5+ 4+ **V** vanadium 50.94	24 7.20 3+ 2+ **Cr** chromium 52.00	25 7.20 2+ 4+ **Mn** manganese 54.94	26 7.87 3+ 2+ **Fe** iron 55.85	27 8.9 2+ 3+ **Co** cobalt 58.93
5	37 1.53 1+ **Rb** rubidium 85.47	38 2.6 2+ **Sr** strontium 87.62	39 4.47 3+ **Y** yttrium 88.91	40 6.49 4+ **Zr** zirconium 91.22	41 8.57 5+ 3+ **Nb** niobium 92.91	42 10.2 6+ **Mo** molybdenum 95.94	43 11.5 7+ **Tc** technetium (98)	44 12.4 3+ 4+ **Ru** ruthenium 101.07	45 12.4 3+ **Rh** rhodium 102.91
6	55 1.88 1+ **Cs** cesium 132.91	56 3.5 2+ **Ba** barium 137.33	57 6.15 3+ 2+ **La** lanthanum 138.91	72 13.3 4+ **Hf** hafnium 178.49	73 16.6 5+ **Ta** tantalum 180.95	74 19.4 6+ **W** tungsten 183.84	75 21.0 7+ **Re** rhenium 186.21	76 22.5 4+ **Os** osmium 190.23	77 22.4 4+ **Ir** iridium 192.22
7	87 — 1+ **Fr** francium (223)	88 5 2+ **Ra** radium (226)	89 10.1 3+ 2+ **Ac** actinium (227)	104 **Rf** rutherfordium (261)	105 **Db** dubnium (262)	106 **Sg** seaborgium (266)	107 **Bh** bohrium (264)	108 **Hs** hassium (277)	109 **Mt** meitnerium (268)

Period					
6	58 6.69 3+ **Ce** cerium 140.12	59 6.64 3+ **Pr** praseodymium 140.91	60 7.01 3+ **Nd** neodymium 144.24	61 7.26 3+ **Pm** promethium (145)	62 7.52 3+ 2+ **Sm** samarium 150.36
7	90 11.7 4+ **Th** thorium 232.04	91 15.4 5+ 4+ **Pa** protactinium 231.04	92 19.1 6+ 4+ **U** uranium 238.03	93 20.5 5+ **Np** neptunium (237)	94 19.8 4+ 6+ **Pu** plutonium (244)

- Metals
- Metalloids
- Non-metals
- Noble Gases
- Hydrogen

Periodic Table of the Elements

Measured values are subject to change as experimental techniques improve. Atomic molar mass values in this table are based on IUPAC website values (2005).

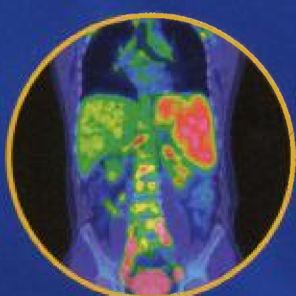
Period	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1									2 0.179 — **He** helium 4.00
2				5 2.34 — **B** boron 10.81	6 2.26 — **C** carbon 12.01	7 1.25 3– **N** nitrogen 14.01	8 1.43 2– **O** oxygen 16.00	9 1.70 1– **F** fluorine 19.00	10 0.900 — **Ne** neon 20.18
3				13 2.70 3+ **Al** aluminum 26.98	14 2.33 — **Si** silicon 28.09	15 1.82 3– **P** phosphorus 30.97	16 2.07 2– **S** sulfur 32.07	17 3.21 1– **Cl** chlorine 35.45	18 1.78 — **Ar** argon 39.95
4	28 8.90 2+ 3+ **Ni** nickel 58.69	29 8.92 2+ 1+ **Cu** copper 63.55	30 7.14 2+ **Zn** zinc 65.41	31 5.90 3+ **Ga** gallium 69.72	32 5.35 4+ **Ge** germanium 72.64	33 5.73 3– **As** arsenic 74.92	34 4.81 2– **Se** selenium 78.96	35 3.12 1– **Br** bromine 79.90	36 3.74 — **Kr** krypton 83.80
5	46 12.0 2+ 4+ **Pd** palladium 106.42	47 10.5 1+ **Ag** silver 107.87	48 8.64 2+ **Cd** cadmium 112.41	49 7.30 3+ **In** indium 114.82	50 7.31 4+ 2+ **Sn** tin 118.71	51 6.68 3+ 5+ **Sb** antimony 121.76	52 6.2 2– **Te** tellurium 127.60	53 4.93 1– **I** iodine 126.90	54 5.89 — **Xe** xenon 131.29
6	78 21.5 4+ 2+ **Pt** platinum 195.08	79 19.3 3+ 1+ **Au** gold 196.97	80 13.5 2+ 1+ **Hg** mercury 200.59	81 11.85 1+ 3+ **Tl** thallium 204.38	82 11.3 2+ 4+ **Pb** lead 207.2	83 9.80 3+ 5+ **Bi** bismuth 208.98	84 9.40 2+ 4+ **Po** polonium (209)	85 — 1– **At** astatine (210)	86 9.73 — **Rn** radon (222)
7	110 **Ds** darmstadtium (281)	111 **Rg** roentgenium (272)	112 **Uub** ununbium	113 **Uut** ununtrium	114 **Uuq** ununquadium	115 **Uup** ununpentium	116 **Uuh** ununhexium	117 **Uus** ununseptium	118 **Uuo** ununoctium

63 5.24 3+ 2+ **Eu** europium 151.96	64 7.90 3+ **Gd** gadolinium 157.25	65 8.23 3+ **Tb** terbium 158.93	66 8.55 3+ **Dy** dysprosium 162.50	67 8.80 3+ **Ho** holmium 164.93	68 9.07 3+ **Er** erbium 167.26	69 9.32 3+ **Tm** thulium 168.93	70 6.97 3+ 2+ **Yb** ytterbium 173.04	71 9.84 2+ **Lu** lutetium 174.97	6
95 13.7 3+ 4+ **Am** americium (243)	96 13.5 3+ **Cm** curium (247)	97 14 3+ 4+ **Bk** berkelium (247)	98 — 3+ **Cf** californium (251)	99 — 3+ **Es** einsteinium (252)	100 — 3+ **Fm** fermium (257)	101 — 2+ 3+ **Md** mendelevium (258)	102 — 2+ 3+ **No** nobelium (259)	103 — 3+ **Lr** lawrencium (262)	7

B.C. Science
PROBE 10

UNIT A
SUSTAINABILITY OF ECOSYSTEMS

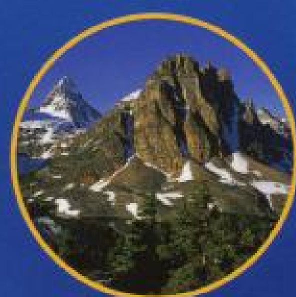
UNIT B
CHEMICAL REACTIONS



UNIT C
RADIOACTIVITY

UNIT D
MOTION

UNIT E
ENERGY TRANSFER IN NATURAL SYSTEMS



UNIT F
PLATE TECTONICS

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