unit

20 D Human Systems

The human body is organized into a number of different organ systems. Each of these organ systems has a critical role in maintaining your health. For example, your cardiovascular system transports nutrients and oxygen to your cells, and wastes and carbon dioxide from your cells. Elite athletes, such as the Olympic gold-medal winner Chandra Crawford, must have a healthy cardiovascular system. Unfortunately, cardiovascular disease is the leading cause of death in North America. About 44 000 Canadians, 40 % of them younger than 65, die each year from cardiovascular disease. Over 4000 patients in Canada and the United States are on the waiting list for a new heart.

Dr. Michael Sefton, director of the Institute of Biomaterials and Biomedical Engineering at the University of Toronto, is developing a possible way to provide an almost unlimited number of hearts for transplant. Sefton's "heart in a box" is a transplantable heart that can be grown in the laboratory. First, researchers create scaffolding—a supporting framework—of biodegradable plastic around which the cells will grow. Next, they seed the scaffolding with living cells and place it in an incubator that maintains constant temperature and provides nutrients and oxygen. Although researchers have not yet been able to grow a complete living heart, they have successfully grown components of the heart.

As you progress through the unit, think about these focusing questions:

- How do specialized structures function in the overall biochemical balance of the living system?
- What conditions result if these structures do not function normally?

UNIT 20 D PERFORMANCE TASK

Determining Fitness Level

Despite the increase in performance of elite athletes, the fitness level of the general public has been decreasing. The ability to perform physical activity depends on your body's ability to deliver oxygen to your cells. How can you design a fitness test to determine the amount of oxygen being delivered to your tissues? At the end of this unit, you may apply your skills and knowledge to complete this Performance Task.

www.science.nelson.com GO

GENERAL OUTCOMES

In this unit, you will

- explain how the human digestive and respiratory systems exchange energy and matter with the environment
- explain the role of the circulatory and defence systems in maintaining an internal equilibrium
- explain the role of the excretory system in maintaining an internal equilibrium in humans through the exchange of energy and matter with the environment
- explain the role of the motor system in the function of other body systems

Unit 20 D Human Systems

ARE YOU READY?

These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

Prerequisites

Concepts

- cells, organs, tissues, systems
- structure and function
- response to stimuli
- active and passive transport

Skills

- state a prediction and a hypothesis
- identify major variables
- organize data in appropriate formats
- interpret patterns and trends in data
- state a conclusion based on experimental data

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

www.science.nelson.com GO

Knowledge

1. Examine **Figure 1** and explain the function of each of the labelled tissues.

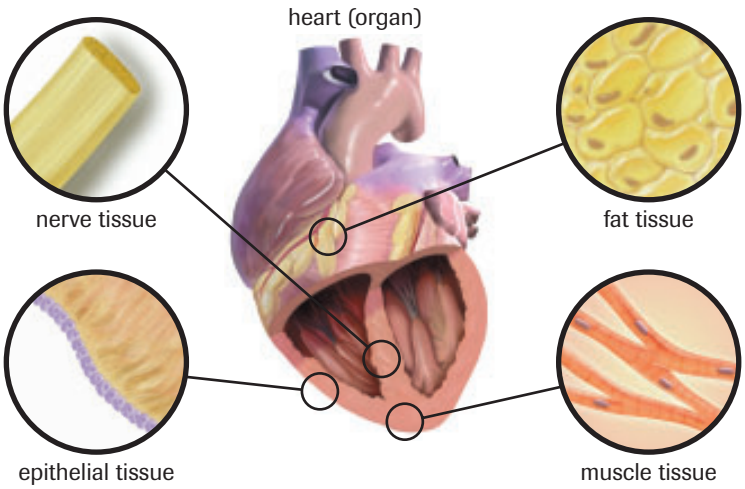


Figure 1
Tissues of the human heart

2. Explain what happens to an animal cell placed in
   (a) a hypertonic solution;
   (b) a hypotonic solution.

3. Copy **Table 1** into your notebook and fill in the blank spaces.

Table 1 Cellular Organization of Some Organ Systems

Level of cellular organization		Excretory system	
organ	ovary		
tissue		epithelial, blood, nerve, fat (adipose), and connective	
cell	egg		white blood cell (leukocyte)

4. In **Table 2**, match the organ(s) with the corresponding regulatory function. (*Note:* An organ can have more than one function, and a function can be linked to more than one organ.)

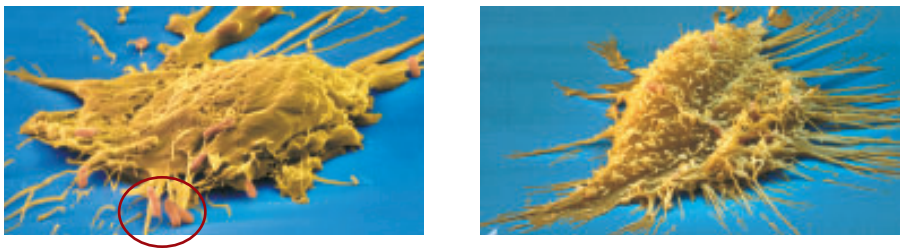
Table 2 Regulatory Functions of Some Organs

Organ(s)	Regulatory function
(a) skin	(i) disease prevention
(b) lymph vessels and lymph nodes	(ii) thermoregulation (regulation of body temperature)
(c) pancreas	(iii) maintaining blood sugar
(d) heart	(iv) maintaining blood pressure
(e) kidneys	(v) maintaining blood pH

Skills and STS Connections

5. A group of students conducts an experiment to determine how the body responds to stress. An ice cube is placed on the back of a subject's neck while another group member monitors changes in the subject's pulse.
   (a) Why is pulse used to monitor stress?
   (b) Create a hypothesis for the experiment.
   (c) Identify the manipulated and responding variables in the experiment.
   (d) What variables must be controlled to obtain reliable data?
   (e) Design a data table for the experiment.
   (f) Would you expect identical data from different subjects? Explain your answer.
   (g) Through the course of the experiment, when would you take the pulse? Give your reasons.
   (h) What practical information might the experiment provide?

6. **Figure 2** shows a white blood cell at two consecutive times.



(a) **(b)**

Figure 2
(a) At the first time point, bacteria cells (shown in the circle) are on the surface of the white blood cell.
(b) At the second time point, the bacteria cells are no longer visible.

   (a) Describe what is happening in **Figure 2**. Draw a conclusion from the photos.
   (b) Explain how this process helps to maintain a balanced internal environment.

7. Scientists monitored six types of ions in the cells of *Sargassum* (a brown alga often called seaweed) when maintained in brackish water (a mixture of salt and fresh water) and in marine water (seawater). The scientists noted that the concentration of ions did not change. The results are shown in **Table 3**.

Table 3 Ion Concentrations of *Sargassum* Cells

Ion	Ion concentration*		
	Cell	Marine water	Brackish water
calcium	1.7	12	1.7
magnesium	0.005	57	6.5
sulfate	0.01	36	2.8
sodium	90	500	60
potassium	490	12	1.4
chloride	520	520	74

*All concentrations are measured in mmol/L.

   Assume that the cell membrane is permeable to all of the ions.
   (a) Which ion must be actively transported inside the cell in both brackish water and marine water? Explain your answer.
   (b) Which ion enters the cell by diffusion from marine water, but must be actively transported inside the cell from brackish water? Explain.
   (c) Explain how a cell could maintain its sodium ion concentration despite living in marine or brackish water environments.

chapter

8 Nutrients, Enzymes, and the Digestive System

In this chapter

Canada has a multicultural society, which includes a wide variety of foods and styles of cooking. The foods of various cultures differ not only in flavour, but also in the types of ingredients used (**Figure 1**, next page).

Different diets may result in unique health problems. The high rate of heart disease in North America is due in part to the large amounts of fat consumed. Some people have decided that a vegetarian diet is healthier. Recently, high-protein, low-carbohydrate diets have become popular. However, diets high in animal protein also have higher amounts of cholesterol and saturated fats, which have been linked with cardiovascular disease.

The digestive system is responsible for converting the components of our diets into the molecules that are taken up and used by the cells of the body. Once inside the cells, these molecules supply the body with energy and the raw materials for the synthesis of essential chemical compounds used for growth, maintenance, and tissue repair.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Make a list of the essential nutrients that must be included in every diet.
2. Copy and complete the chart below in your notebook.

Nutrient	Undergoes digestion? yes	Undergoes digestion? no	Components after digested	Use by the body
protein				build structure
vitamins				coenzymes: assist enzymes, bind to substrate molecules
fats			fatty acid + glycerol	
polysaccharides				
water				

3. Make a list of the digestive system organs that you already know.

Career Connections:
Registered Dietician; X-ray Technician; Health Service Administrator

Figure 1
Typical cuisine from **(a)** North America, **(b)** Japan, **(c)** China, **(d)** South America

Exploration — Canada's Food Guide to Healthy Eating

- Go to the Nelson Web site and find the link to Health Canada's Food Guide to Healthy Eating.

www.science.nelson.com GO

(a) What recommendations does the food guide give? Why do you think it is recommended to eat large amounts of some foods and smaller amounts of others?

(b) According to the guide, which foods should be eaten in larger quantities? Which foods should be eaten in smaller quantities?

(c) Write down everything you might eat on a typical day. Score yourself using the Healthy Eating Scorecard.

(d) Research the typical daily diet of a person from a different culture in a country outside of North America. Compare your diet to it.

8.1 Essential Nutrients

Living things are composed of nonliving chemicals (**Figure 1**). Proteins, carbohydrates, lipids (fats), vitamins and minerals, and nucleic acids are often categorized as the chemicals of living things despite the fact that none of them are capable of life by themselves.

Scientific investigations have shown that the same principles of chemistry apply in both the physical world and the living world. An understanding of life comes from an understanding of how chemical reactions are regulated within cells.

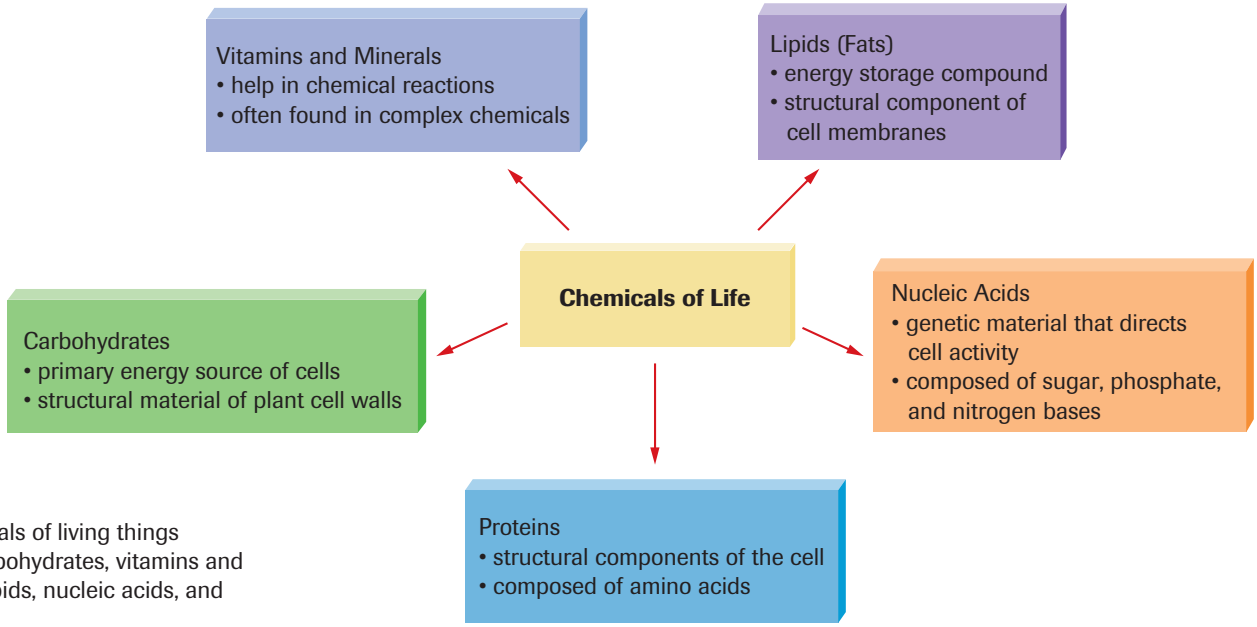


Figure 1
The chemicals of living things include carbohydrates, vitamins and minerals, lipids, nucleic acids, and proteins.

The foods you eat can be classified into three major groups of nutrients: carbohydrates, proteins, and lipids. These nutrients make up the bulk of what you eat. Vitamins and minerals are also required, but in much smaller amounts. Water is also essential for life, although it is not considered a nutrient. Most of the food you eat is a combination of nutrients. For example, the cereal you eat for breakfast or the bowl of vegetable soup you have for lunch is a combination of carbohydrates, proteins, and lipids, as well as some vitamins and minerals.

Carbohydrates

carbohydrate a molecule composed of sugar subunits that contain carbon, hydrogen, and oxygen in a 1:2:1 ratio

Carbohydrates are often described as energy nutrients. They provide a fast source of energy and make up the largest component in most diets. Potatoes, bread, corn, rice, and fruit contain large amounts of carbohydrates. Marathon runners often consume large quantities of carbohydrates a few days before a race to make sure that they have maximum energy reserves. However, under normal circumstances, it is not a good idea to eat excess quantities of carbohydrates because they will be stored as fat.

The human body is not able to make carbohydrates. You rely on plants as your source of carbohydrates. Using energy from the Sun, plants combine carbon dioxide and water to synthesize carbohydrates through the process of photosynthesis.

Carbohydrate Chemistry

Carbohydrates are either single sugar units or **polymers** of many sugar units. Single sugar units usually contain carbon, hydrogen, and oxygen in a 1:2:1 ratio. For example, triose sugars have the molecular formula $C_3H_6O_3$, and hexose sugars have the molecular formula $C_6H_{12}O_6$. The word *triose* refers to the fact that the sugars have a three-carbon chain (the prefix *tri-* means three). Hexose sugars contain six-carbon chain sugars (the prefix *hex-* means six). Many of the most important sugars contain either three-, five-, or six-chain sugars. Those that contain more than five carbons are often in a ring form.

polymer a molecule composed of three or more subunits

Common sugars like glucose, found in human blood; fructose, a plant sugar commonly found in fruits; and deoxyribose, a sugar component of the DNA molecule, can be identified as sugars by the *-ose* suffix. Even the large molecule cellulose, which makes up plant cell walls, is a carbohydrate.

Carbohydrates can also be classified according to the number of sugar units they contain. **Monosaccharides** are the simplest sugars, containing a single sugar unit. Glucose, galactose, and fructose are three common monosaccharides. **Figure 2** shows that they are **isomers**—that is, all three molecules have the same molecular formula, $C_6H_{12}O_6$, but different structural arrangements. The different chemical properties of these monosaccharides can be explained by their different structural arrangements. For example, fructose is much sweeter than glucose and is often used by food manufacturers to sweeten their products. The three sugars rotate between the straight-chain form and the ring structure, shown in **Figure 2**.

monosaccharide a single sugar unit

isomer one of a group of chemicals that have the same chemical formula but different arrangements of the atoms

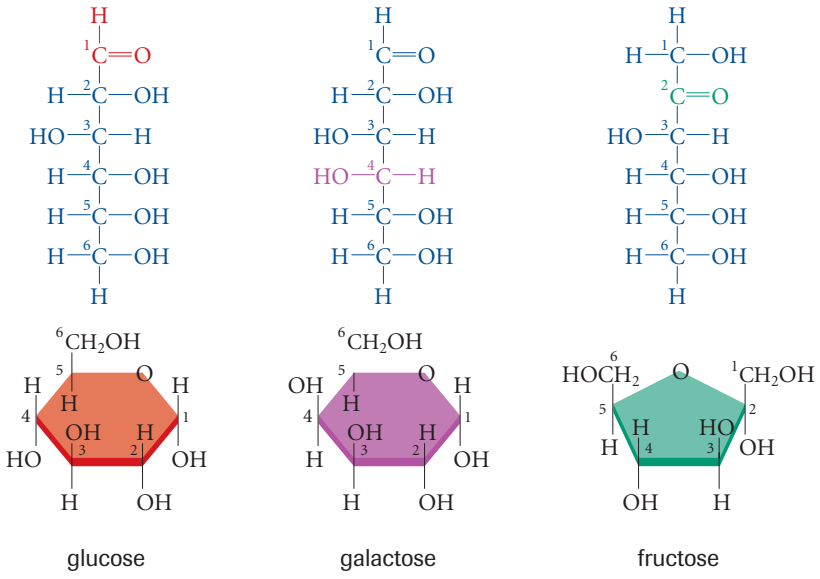


Figure 2
Glucose, galactose, and fructose are isomers.

disaccharide a sugar formed by the joining of two monosaccharide subunits

dehydration synthesis the process by which larger molecules are formed by the removal of water from two smaller molecules

hydrolysis the process by which larger molecules are split into smaller molecules by the addition of water

The combination of two monosaccharides forms a **disaccharide**. Sucrose (white table sugar) is a disaccharide formed from glucose and fructose. Sucrose is extracted from plants such as sugar cane and sugar beet. Maltose (malt sugar) is a disaccharide formed from two glucose units. Maltose is commonly found in the seeds of germinating plants. Lactose (milk sugar) is composed of glucose and galactose units. All disaccharides are formed by a process called **dehydration synthesis** (or dehydrolysis), in which a water molecule is formed from the two monosaccharide molecules (**Figure 3**, next page). The opposite reaction is **hydrolysis**, in which a water molecule is used to break the bond of the disaccharide.

EXTENSION

Condensation and Hydrolysis

View this animation of condensation (dehydration synthesis) and hydrolysis.

www.science.nelson.com GO

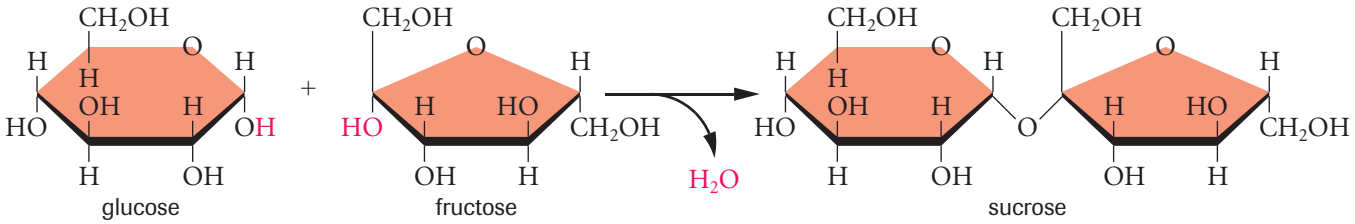


Figure 3
The formation of a disaccharide by dehydration synthesis. Note: Sucrose can only exist in the ring form.

polysaccharide a carbohydrate composed of many single sugar subunits

starch a plant carbohydrate used to store energy

Polysaccharides are carbohydrates formed by the union of many monosaccharide subunits. **Starch**, for example, is a plant polysaccharide that is composed of multiple subunits of glucose. Plants store energy in the chemical bonds of the starch molecule. Starches can exist in two different forms: amylose and amylopectin. Both molecules tend to bend in the shape of a helix, or coil (**Figure 4**). The amylose molecules contain up to 1000 or more glucose units with the first carbon of a glucose molecule linked to the fourth carbon in the next molecule (**Figure 4 (a)**). The amylopectins contain between 1000 and 6000 glucose subunits and have short branching chains of between 24 and 36 glucose units extending from the main branch (**Figure 4 (b)**).

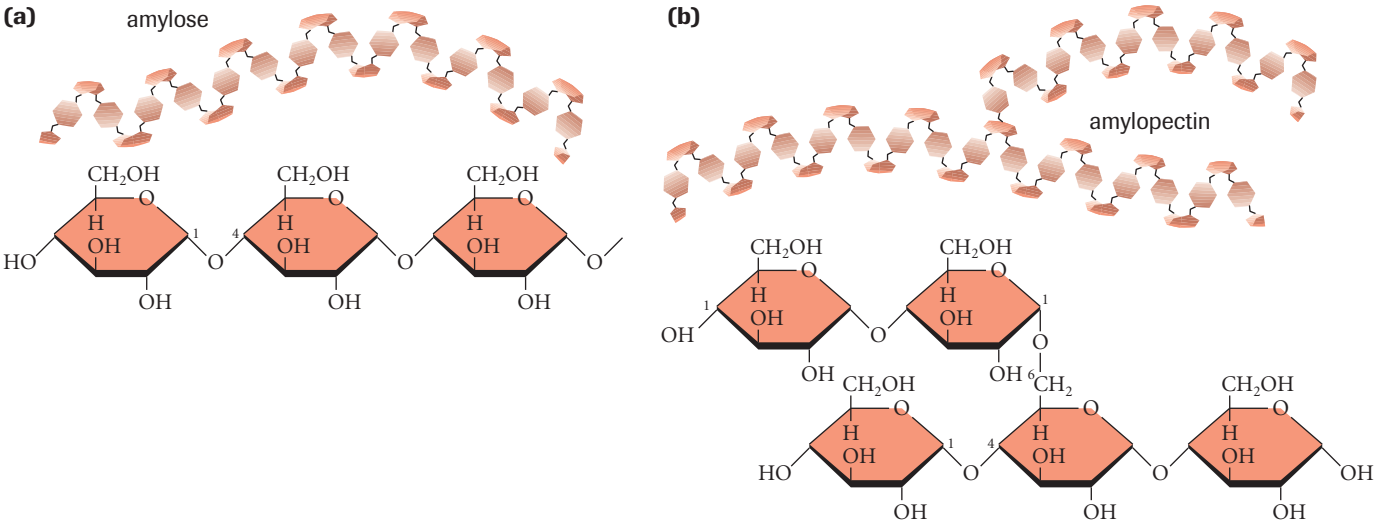


Figure 4
(a) Amylose is an unbranched polymer of glucose.
(b) Amylopectin is a branched polymer of glucose.

glycogen the form of carbohydrate storage in animals

cellulose a plant polysaccharide that makes up plant cell walls

Animals store carbohydrates in the form of a polysaccharide called **glycogen**. The structure of glycogen resembles that of the amylopectin starch molecule, except that its branching structures contain only 16 to 24 glucose units.

Plant cell walls are made up of the polysaccharide **cellulose**. Over 50 % of all organic carbon in the biosphere is tied up as cellulose. Cellulose molecules, like starch and glycogen, are composed of many glucose subunits. However, the bonding of the linking oxygen atoms differs between starch and cellulose; cellulose tends not to form coiled structures. The many layers of cellulose are attracted to one another by hydrogen bonds between the −OH groups (**Figure 5**, next page).

DID YOU KNOW ?

Carbohydrates for Energy

Athletes often eat starches. Since these complex carbohydrates are broken down slowly, they provide a prolonged source of energy without dramatically changing blood sugar levels.

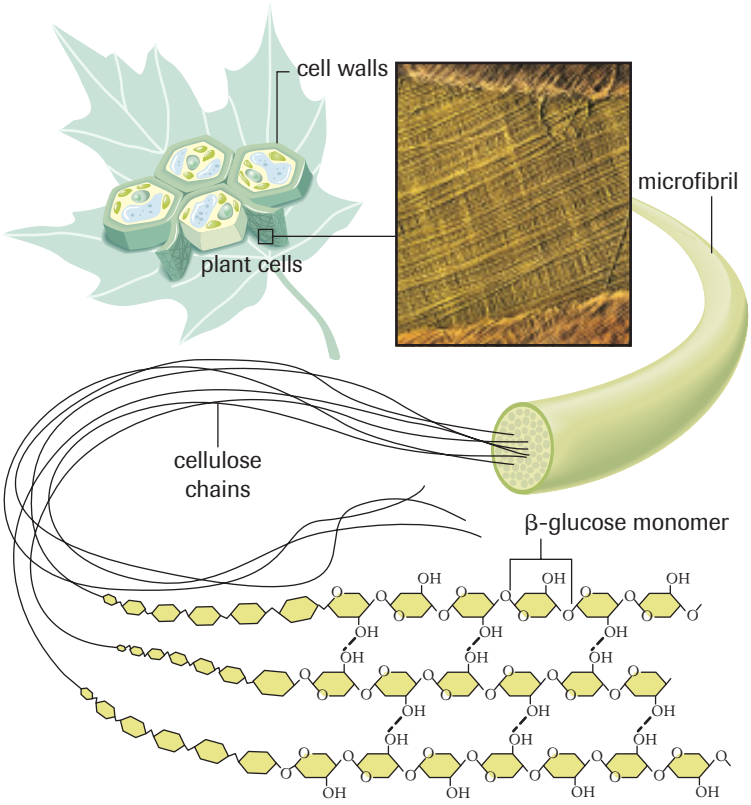


Figure 5
Cellulose fibres are composed of microfibrils, which are composed of many cellulose molecules held together by hydrogen bonds.

CHEMISTRY CONNECTION

Polymers

Glycogen, starch, and cellulose are three examples of naturally occurring polymers. Synthetic polymers, such as nylon, polyvinyl chloride, or polyesters, are commonly used in many consumer products. You can find out more information about polymers in your chemistry course.

www.science.nelson.com GO

Practice

1. What is the primary function of carbohydrates?
2. Name three single sugars and indicate where you would expect to find these sugars.
3. Copy and complete the following table.

Table 1 Common Sugars

Sugar	Composed of	Source
maltose		
sucrose		
lactose		

4. What happens to carbohydrates that are not immediately used by your body? Why might you want to limit your carbohydrate intake?
5. How can you recognize ingredients on food labels that are sugars?
6. How are starch and cellulose alike? How do they differ?

EXTENSION

Hydrolysis and Dehydrolysis

Listen to this Audio Clip for an analysis of the important elements associated with the synthesis and digestion of organic molecules in living organisms.

www.science.nelson.com GO

INVESTIGATION 8.1 *Introduction*

Identifying Carbohydrates

Different classes of carbohydrates react differently to the chemical reagent Benedict's solution. In this investigation, you will use Benedict's solution to determine which of three unknowns is a specific type of carbohydrate.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 271.

Lipids

You may have noticed while doing dishes how fat floats on the surface of water. This is because lipids are nonpolar. They are insoluble in polar solvents such as water. Many lipids are composed of two structural units: glycerol and fatty acids. Like complex carbohydrates, glycerol and fatty acids can be combined by dehydration synthesis (**Figure 6**).

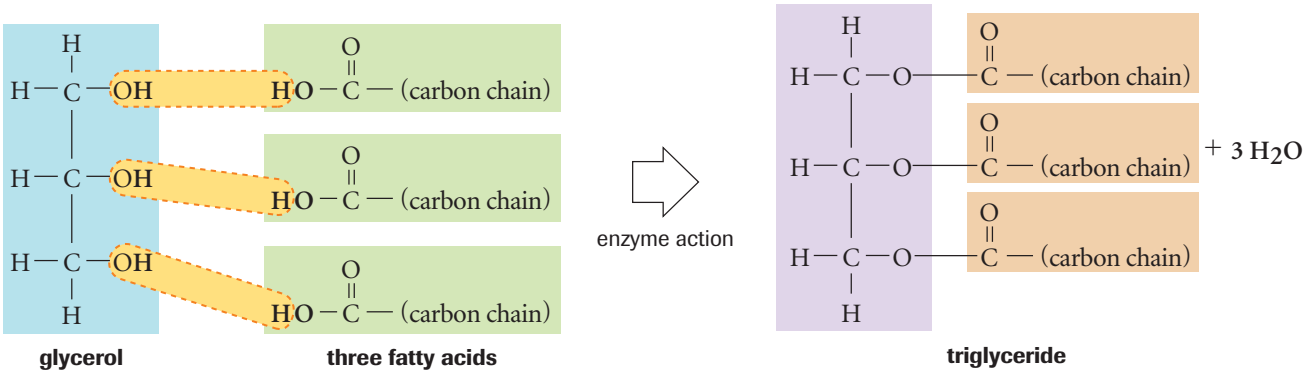


Figure 6
Triglycerides are formed by the union of glycerol and three fatty acids. Note the removal of water in the synthesis. The terms monoglyceride and diglyceride are used to describe the joining of glycerol with one or two fatty acids, respectively.

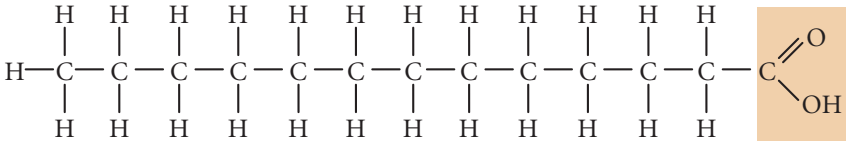
An important function of lipids is the storage of energy. Glycogen supplies are limited in most animals. Once glycogen stores have been built up, excess carbohydrates are converted into fat. This helps explain why eating carbohydrates can cause an increase in fat storage. Other lipids serve as key components in cell membranes, act as cushions for delicate organs of the body, serve as carriers for vitamins A, D, E, and K, and are the raw materials for the synthesis of hormones and other important chemicals. A layer of lipids at the base of the skin insulates you against the cold. The thicker the layer of fat, the better the insulation. Taking their cue from marine mammals, marathon swimmers often coat their bodies with a layer of fat before entering cold water.

triglyceride a lipid composed of glycerol and three fatty acids

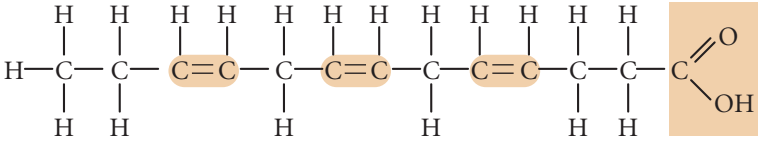
fat a lipid composed of glycerol and saturated fatty acids; solid at room temperature

oil a lipid composed of glycerol and unsaturated fatty acids; liquid at room temperature

Triglycerides are formed by the union of glycerol and three fatty acids (**Figure 6**). Triglycerides that are solid at room temperature are called **fats**. Most of the fatty acids in animal fats are *saturated* (**Figure 7**). This means that only single bonds exist between the carbon atoms. Because the single covalent bonds tend to be stable, animal fats are difficult to break down. Triglycerides that are liquid at room temperature are called **oils**. The fatty acids of most plants are unsaturated. This means that they contain double bonds



saturated fatty acid



unsaturated fatty acid

Figure 7
Saturated fats do not have double bonds between carbon atoms; unsaturated fats do.

between the carbon atoms. If the fatty acid contains only one double bond, it is monounsaturated; if it contains two or more double bonds, it is polyunsaturated. The unsaturated double bonds are somewhat reactive, and, therefore, plant oils are more easily broken down than animal fats.

A second group of lipids, called **phospholipids**, have a phosphate group bonded to the glycerol backbone of the molecule (**Figure 8**). The negatively charged phosphate replaces one of the fatty acids, providing a polar end to the lipid. The polar end of phospholipids is soluble in water, while the nonpolar end is insoluble. These special properties make phospholipids well suited for cell membranes.

phospholipid a lipid with a phosphate molecule attached to the glycerol backbone, making the molecule polar; the major components of cell membranes

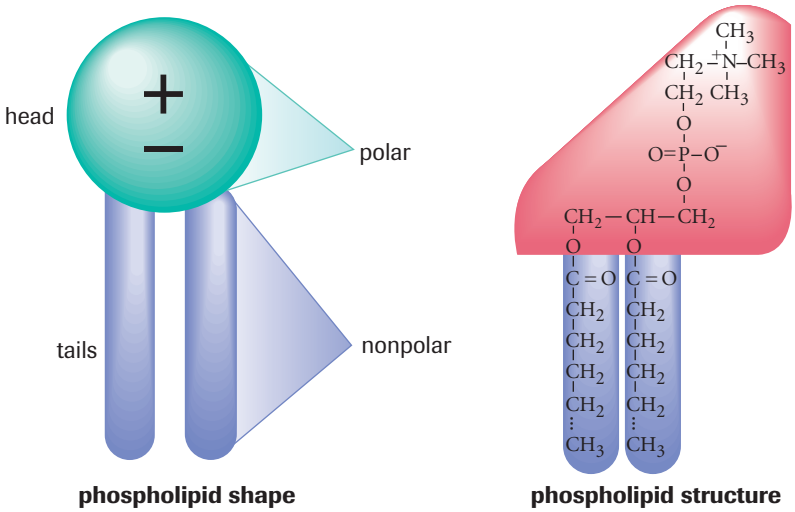


Figure 8
Phospholipid shape and structure. The phosphate group makes these lipids soluble in water as well as in lipids.

Waxes make up a third group of lipids. In waxes, long-chain fatty acids are joined to long-chain alcohols or to carbon rings. These long, stable molecules are insoluble in water, making them well suited as a waterproof coating for plant leaves or animal feathers and fur.

wax a long-chain lipid that is insoluble in water

Practice

7. What are fats?
8. What are the two structural components of fats?
9. How do saturated fats differ from unsaturated fats?
10. Are fats essential to your diet? Explain your answer.

Liposome Technology for Drug Delivery

Lipids can assemble themselves into double-layered spheres approximately the size of a cell. The spheres are known as liposomes. They function like cell membranes because they can fuse with a cell and deliver their contents to the cell's interior. Liposomes are used with cancer-fighting drugs to help the drugs target tumours. This helps to reduce unwanted side effects from drug interactions with healthy tissues and also enables patients to accept higher doses of anti-cancer drugs. One of these liposomal drugs was discovered by Dr. Theresa Allen and her research group at the University of Alberta.

Liposomes are also showing promise as a means of increasing the efficiency of gene therapy. Gene therapy is the process of introducing new genes into the DNA of a person's cells to correct a genetic disease. In a process similar to endocytosis, researchers have successfully inserted DNA into liposomes that have fused with target cells.

Fats and Health

Although fats are a required part of your diet, problems arise when you consume too much. Doctors recommend that no more than 30 % of total energy intake be in the form of fats. Fats are concentrated energy sources containing more than twice as much energy as an equivalent mass of carbohydrate or protein. By eating 100 g of fat, you take in about 3780 kJ of energy. (The kilojoule, kJ, is a unit used to measure food energy.) By comparison, 100 g of carbohydrates or protein yield 1680 kJ of energy. When energy input or consumption exceeds energy output, the result is weight gain.

Heart disease has been associated with diets high in saturated fats. Recall that the single bonds between the carbon molecules make the fats stable. The stable fats tend to remain intact inside the cells of the body much longer than more reactive macromolecules. High-fat diets and obesity have also been linked to certain types of cancer, such as breast, colon, and prostate. Obesity has also been linked to high blood pressure and adult-onset diabetes. According to one report, over 80 % of people with adult-onset diabetes are overweight.

The Cholesterol Controversy

Heart disease, the number-one killer of North Americans, can be caused by the accumulation of cholesterol in the blood vessels. Scientific research on cholesterol has changed direction in recent years. Lipid-rich foods, such as fish and olive oil, were once thought to raise blood cholesterol levels. Currently, most scientists believe that these foods may actually reduce blood cholesterol levels. Similarly, alcohol in moderate consumption may contribute to a decrease in blood cholesterol levels. Added to this confusion is the fact that genes play a major role in determining cholesterol levels. Research indicates that people with a certain genetic makeup are predisposed to atherosclerosis, which is a buildup of cholesterol in the walls of blood vessels that causes narrowing of the vessels (**Figure 9**).

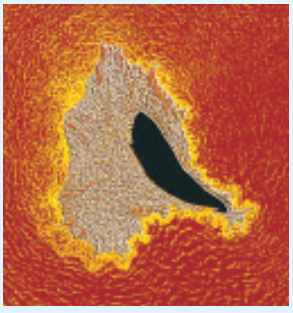


Figure 9
Atherosclerosis (tan area) causes restricted blood flow in blood vessels and can lead to a blockage, possibly causing a heart attack or stroke.

Not all cholesterol is bad. Cholesterol is found naturally in cell membranes and acts as the raw material for the synthesis of certain hormones—sex hormones are made from it.

The cells of the body package cholesterol in water-soluble protein in order to transport it in the blood. Two important types are low-density lipoprotein and high-density lipoprotein.

Low-Density Lipoprotein (LDL)

LDL is considered to be "bad" cholesterol. About 70 % of cholesterol intake is in the form of LDL. High levels of LDL have been associated with the clogging of arteries. LDL particles bind to receptor sites on cell membranes and are removed from the blood (principally by the liver). However, as the level of LDL increases and exceeds the number of receptor sites, excess LDL-cholesterol begins to form deposits in the walls of arteries. The accumulation of cholesterol and other substances in the artery walls is known as plaque. Unfortunately, plaque restricts blood flow and can lead to a heart attack or stroke.

High-Density Lipoprotein (HDL)

HDL is often called "good" cholesterol. HDL carries bad cholesterol back to the liver, which begins breaking it down. HDL lowers blood cholesterol. Most researchers now believe that the balance between LDL and HDL is critical in assessing the risks of cardiovascular disease. Some researchers believe that exercise increases the level of HDL. Strong evidence also supports the theory that fibre, or cellulose, in the diet helps reduce cholesterol. It is believed that fibre binds to cholesterol in the gastrointestinal tract. However, it should be pointed out that fibre does not affect everyone the same way.

Trans Fats

By adding hydrogen molecules to unsaturated fats, such as vegetable oils, manufacturers are able to convert them into more stable saturated fats. This process, known as hydrogenation, is used to convert vegetable oil into margarine or shortening. The word *trans* comes from the transformation of unsaturated fats, with reactive double bonds between carbon atoms, into the more stable, less reactive saturated fats. The process increases the shelf-life of foods.

By increasing the shelf-life of trans fats, manufacturers also make them more difficult for you to break down. Rather than becoming a source of energy, these fats are stored in the body. Trans fats lead to obesity. Scientific evidence shows that the consumption of trans fats and dietary cholesterol raises LDL levels while lowering HDL levels, which increases the risk of heart disease. Many physicians indicate that trans fats are far worse than naturally occurring saturated fats. On November 23, 2004, the House of Commons passed a motion calling for a task force to create a regulation that would limit the trans fat content in all food products. Although no maximum daily intake has been established in Canada, most experts advocate between 1 g and 2 g of trans fats at most. Many North Americans consume as much as 20 g of trans fats per day. It's easy to see how when you look at the following examples:

- Five small chicken nuggets from a fast-food outlet contained nearly 4 g of trans fats.
- An apple danish from a donut shop contained about 2.7 g of trans fats.
- One large serving of French fries contained as much as 6 g of trans fats.

Case Study Questions

1. Doctors recommend that no more than 30 % of your dietary intake be fat. Why should fat consumption be limited?
2. Differentiate between "good" and "bad" cholesterol.
3. The level of LDL in your blood does not solely determine your risk for heart attack.
   (a) What influence do genes have?
   (b) What influence do HDL levels have?
4. What are trans fats? Why are they a reason for concern?
5. Should legislation be introduced to limit trans fats in foods?

Proteins

Unlike carbohydrates and fats, proteins are not primarily energy compounds. **Proteins** are used to form the structural parts of a cell. Whenever cells are damaged and require repair, proteins are manufactured. Your cells also make proteins to build structures for new cells. Proteins are composed of building blocks called **amino acids**. **Figure 10** shows the general structure of an amino acid. The NH_2 group is the amino group, and the COOH group is the carboxyl group. The R group can represent a number of different structures and differentiates one amino acid from another.

Cytoplasmic organelles like the mitochondria and ribosomes are composed largely of protein. The predominant part of muscles, nerves, skin, and hair is protein. Antibodies are specialized proteins that help the body defend itself against disease; enzymes are proteins that speed chemical reactions. Like lipids and carbohydrates, proteins are composed of carbon, hydrogen, and oxygen. However, proteins contain nitrogen and, often, sulfur atoms as well. Like sugars and lipids, proteins can supply energy for the tissues, although energy production is not their main function.

The diversity among people and among different species can, in part, be explained by proteins. A limited number of carbohydrates and lipids are found in all living things, but the array of proteins is almost infinite. Proteins are composed of 20 different amino acids. With a change in position of a single amino acid, the structure of a protein can be altered. The structure of six amino acids is shown in **Figure 11**. A small protein may contain only a few amino acids, while a large one may have more than 250 000 amino acids.

protein a chain of amino acids that form the structural parts of cells or act as antibodies or enzymes

amino acid a chemical that contains nitrogen; can be linked together to form proteins

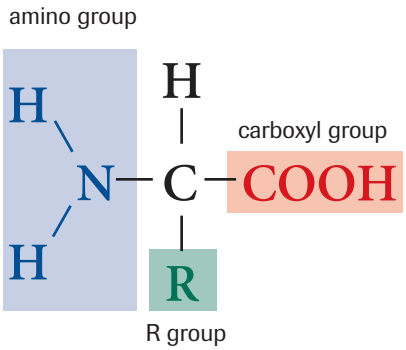


Figure 10
Amino acid structure

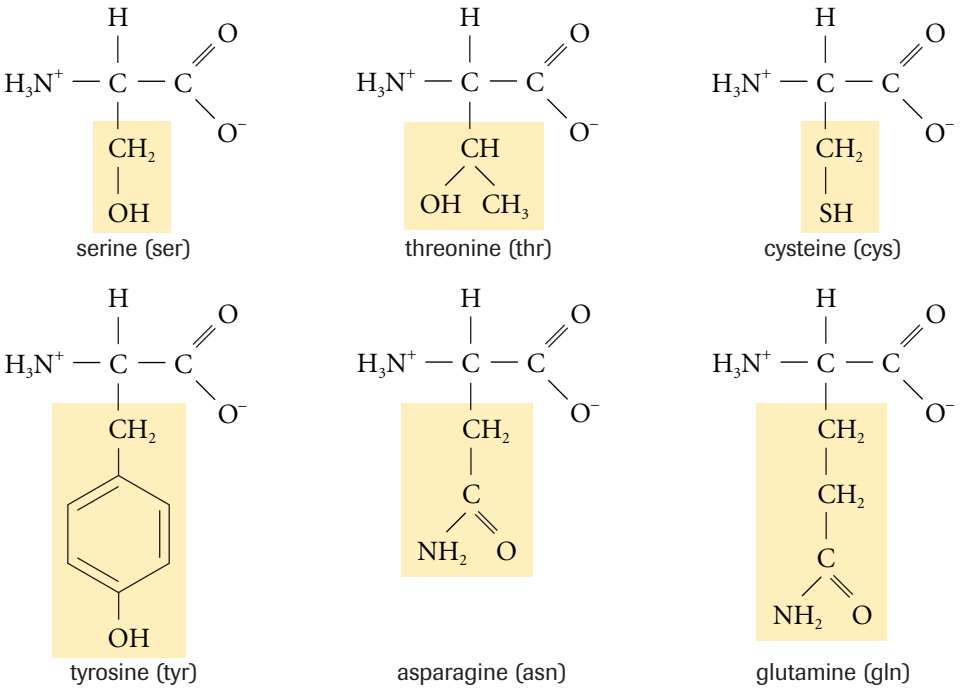


Figure 11
Each amino acid contains an amino and a carboxyl group, which are shown in their ionized form as they would be inside a cell.

The order and number of amino acids determine the type of protein. Fish protein is distinctively different from cow protein and human protein. The protein you eat is digested and absorbed, and the individual amino acids are carried in the blood to the cells of your body. Your cells reassemble the amino acids in sequences that are determined by your genes. **Figure 12** shows how amino acids are joined. As in carbohydrate and lipid synthesis, a water molecule is removed during the synthesis of protein. The covalent bond that forms between the carboxyl group of one amino acid and the amino group of the adjoining amino acid is called a **peptide bond**. For this reason, chains of amino acids are referred to as **polypeptides**.

peptide bond the bond that joins amino acids

polypeptide a chain of three or more amino acids

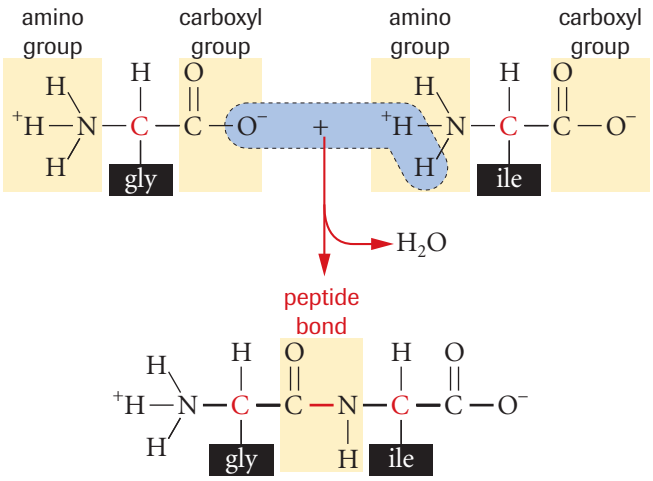


Figure 12
Dehydration synthesis of amino acids to form a polypeptide

The importance of proteins in the diet cannot be overestimated. Although the body is capable of making many of the amino acids, there are eight amino acids that the body cannot synthesize. These are called **essential amino acids** and must be obtained from your food. The lack of any one of the essential amino acids will lead to specific protein deficiencies and disease.

essential amino acid an amino acid that must be obtained from the diet

Structure of Proteins

Proteins are polypeptides that are folded into specific three-dimensional shapes. Some proteins contain more than one polypeptide. A protein's shape, or structure, determines its function. The structure of a protein is determined by its sequence of amino acids. Changing just a single amino acid can alter the structure of a protein. There are four levels of protein structure: primary, secondary, tertiary, and quaternary.

The primary structure of a protein is the unique sequence of amino acids in the chain (**Figure 13 (a)**, next page). British chemist Frederick Sanger was the first to determine the primary structure of a protein. He identified the amino acid sequence of cow insulin. The primary structure of a protein determines its secondary structure. Depending on the amino acids in the polypeptide chain, folds and coils can occur along the length of the chain. These make up the secondary structure. Hydrogen bonding between amino acids pulls the chain into helical coils and pleated sheets (**Figure 13 (b)**, next page).

Additional folding of the polypeptide chain forms the tertiary structure (**Figure 13 (c)**, next page). The tertiary structure occurs because of interactions between the R groups of different amino acids. An example of an R-group interaction is a disulfide bridge. When the sulfur-containing R groups of two cysteine amino acids are close together, they form a bond called a disulfide bridge. A single polypeptide chain of hemoglobin, the iron-containing pigment found in red blood cells, is a tertiary protein structure.

Quaternary proteins are large globular proteins formed from two or more polypeptides (**Figure 13 (d)**, next page). Hemoglobin is a quaternary protein. It contains four individual polypeptide chains that combine to form the functional hemoglobin molecule.

CAREER CONNECTION

Registered Dietician

As many Canadians rely more on fast food, concern has been raised about how diet affects health. Dieticians provide information on how many calories should be consumed and the types of foods needed to maintain health. Investigate career possibilities for registered dieticians.

www.science.nelson.com GO

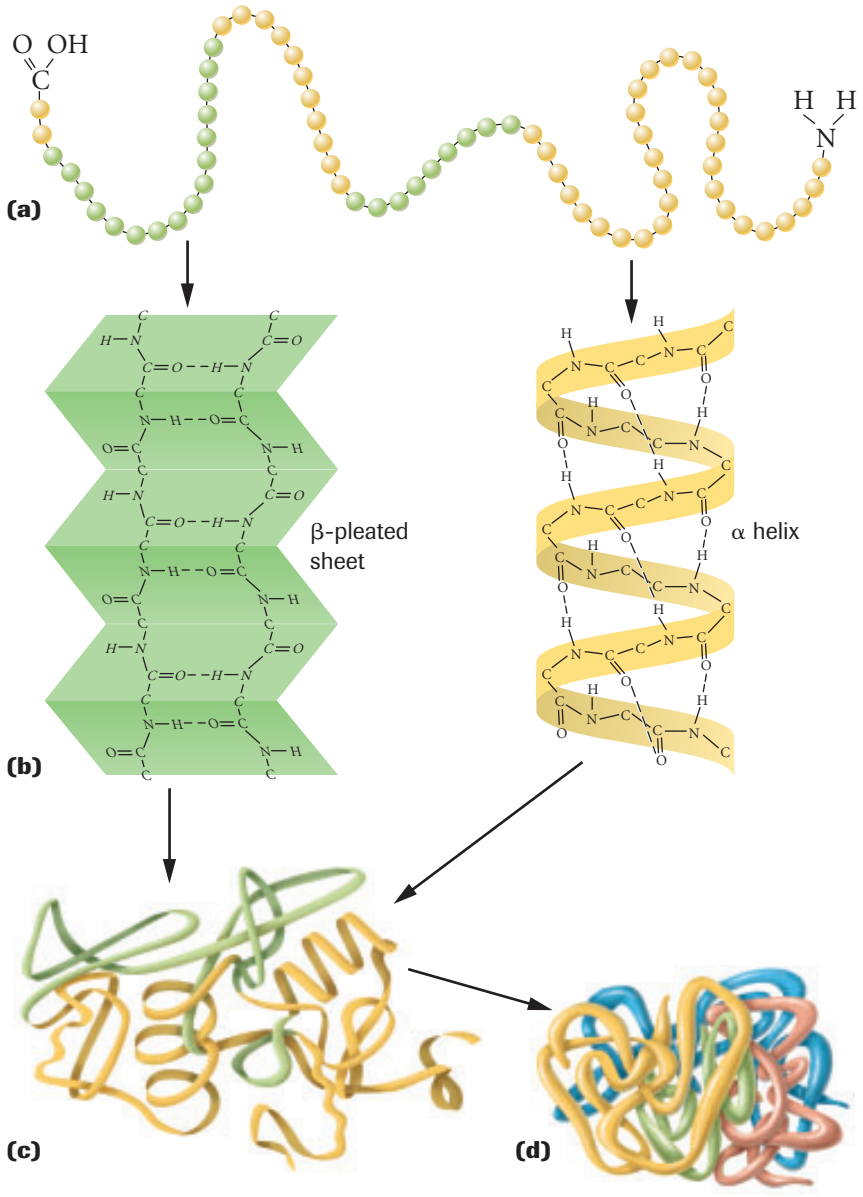


Figure 13

(a) The primary structure of a protein is the sequence of amino acids in the polypeptide strand.

(b) Hydrogen bonds that form with nearby amino acids coil and fold the polypeptide into α helices and β-pleated sheets; these constitute the polypeptide's secondary structure.

(c) The polypeptide folds further to form its tertiary structure. These fold are stabilized by R group interactions.

(d) The clustering of two or more polypeptides in tertiary structure generates the quaternary structure of a protein.

Denaturation and Coagulation

Exposing a protein to excess heat, radiation, or a change in pH will alter its shape. Physical or chemical factors that disrupt bonds cause changes in the configuration of the protein, a process called **denaturation**. The protein may uncoil or assume a new shape. The result is a change in the protein's physical properties as well as its biological activity. Once the physical or chemical factor is removed, the protein may assume its original shape.

A permanent change in protein shape is referred to as **coagulation**. The boiling of an egg, for example, causes the shape of proteins to be altered. The proteins in the egg are said to have coagulated because no matter how much cooling takes place, they will never assume their original shape.

denaturation the process that occurs when the bonds of a protein molecule are disrupted, causing a temporary change in shape

coagulation the process that occurs when the bonds of a protein molecule are disrupted, causing a permanent change in shape

INVESTIGATION 8.2 *Introduction*

Identifying Lipids and Proteins

Lipids and proteins have different chemical compositions, and therefore can be distinguished based on their reaction with certain chemicals. In this investigation, you will use chemical reagents to conduct tests on some common foods and on unknown samples to determine if they contain lipids or proteins.

To perform this investigation, turn to page 272.

Report Checklist

● Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
○ Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

EXPLORE an issue

Irradiation Technology

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

Food irradiation is a process in which foods are exposed to high levels of radiation to disrupt the DNA of bacteria and other harmful agents growing on the food (**Figure 14**) that could otherwise cause food-borne diseases. This technology is so effective that the food eaten by astronauts is sterilized by irradiation so they do not ingest any microbes that could make them sick while in space.

Irradiation extends the shelf-life of food since food spoilage is caused by bacteria and other microbes. With an extended shelf-life, foods can be transported over greater distances and, consequently, a greater variety of foods are available to consumers at a lower price.

The food does not become radioactive, and the nutritional value that is lost is approximately the same as that lost in cooking. However, it should be noted that the radiation can alter the molecular chemistry of the food, creating radiolytic products. In some studies, benzene and formaldehyde have been identified.

The ionizing energy does create a large number of short-lived free radicals that would be potentially harmful if they persisted, but many experts say they do not. These short-lived free radicals kill microorganisms such as *Salmonella* and inhibit sprouting and ripening in fruits and vegetables. The irradiation of cereal grains kills invading insects that also lead to food contamination and spoilage.

Opponents of radiation technology indicate that some of the new chemical bonds formed in irradiated foods can be harmful, and it is for this reason that they claim the technology should be severely restricted or eliminated completely. In addition, beneficial chemicals, such as vitamins, are often destroyed by the process. Opponents also point out that animals fed irradiated foods have demonstrated various health problems, including premature births, mutations, organ damage, and immune system dysfunction.

Proponents of irradiation technology say that this technology, like traditional methods of preservation, such as salting, canning, and freezing, changes the food only slightly while significantly reducing the spoilage by bacteria.

Despite the many benefits, irradiation is not for all foods. Foods high in fats, such as dairy products and fatty fish, can develop bad odours and tastes because of the breakdown of fat to fatty acids. The technology is much more accepted in North America and Asia, and European governments are more reluctant to use it. At this time, there are no standards for labelling irradiated food.

Figure 14
A technician moves a container of fruit above a pool that is used to study food irradiation. The pool contains an accelerator that produces X-rays.

Statement
Irradiated foods should be allowed.

1. Form a group and research the issue.

www.science.nelson.com GO

2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statement.
5. Defend your position in the debate.
6. What responsibilities do governments have in regulating irradiation technology?

SUMMARY Essential Nutrients

- Carbohydrates are molecules that contain hydrogen, carbon, and oxygen. Carbohydrates are the preferred source of energy for cells.
- Lipids are compounds formed from glycerol and fatty acids. Lipids are energy-storage compounds.
- Proteins are molecules constructed of amino acids. Proteins are the structural components of cells.

Table 2 Nutrients: An Overview

Nutrient	Sources	Function in humans
carbohydrates	• plants	• energy source
lipids	• plant oils (unsaturated fats) • animal fats (saturated fats)	• energy storage • insulation of skin and cushioning of organs • synthesis of hormones (steroids)
proteins	• plants and animals	• structural components of the cell • enzymes • antibodies

Section 8.1 Questions

1. Provide an example of dehydration synthesis by showing how two monosaccharides form a disaccharide. Show the reactants and end products of the reaction.
2. Explain why marathon runners consume large quantities of carbohydrates a few days prior to a big race.
3. Why is cellulose, or fibre, considered to be an important part of the diet?
4. The following information was gathered by analyzing amino acid sequences of a protein. **Table 3** shows the number of amino acids that are different between two organisms.

Table 3 Amino Acid Differences between Some Organisms

Organism	dog	horse	donkey	pig	duck
dog	-	10	8	4	12
horse		-	1	5	16
donkey			-	4	15
pig				-	13
duck					-

a) From the information in the table, which two organisms do you think are most closely related? Why?
b) How similar do you think the amino acids would be between a dog and a fish? Would you expect the amino acids to be more or less similar than those of a dog and a duck? Give your reasons.

5. Using **Figure 15**, identify advantages or disadvantages associated with each of the foods listed.

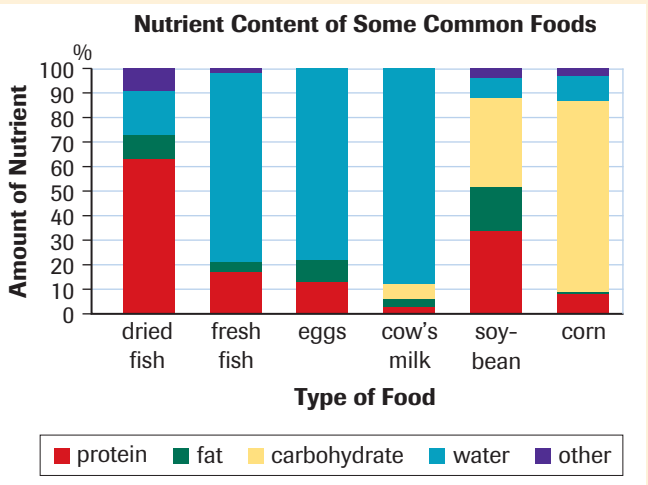


Figure 15

6. A student believes that the sugar inside a diet chocolate bar is sucrose because a test with Benedict's solution yields negative results. How would you go about testing whether or not the sugar present is a nonreducing sugar?

8.2 Enzymes

catalyst a chemical that increases the rate of chemical reactions without altering the products or being altered itself

enzyme a protein catalyst that permits chemical reactions to proceed at low temperatures

substrate a molecule on which an enzyme works

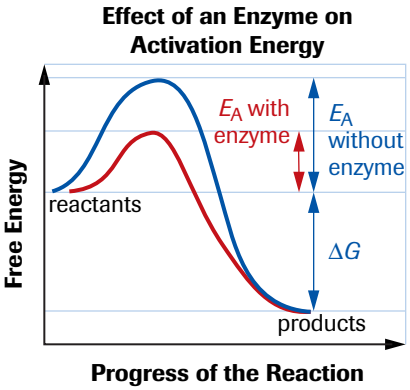


Figure 1
An enzyme decreases the activation energy needed for a reaction to occur.

active site the area of an enzyme that combines with the substrate

cofactor an inorganic ion that helps an enzyme combine with a substrate molecule

coenzyme an organic molecule synthesized from a vitamin that helps an enzyme to combine with a substrate molecule

Molecules are in constant motion. Even molecules in solids vibrate in fixed positions. Although chemical reactions sometimes occur when molecules collide, most reactions do not occur spontaneously. Adding thermal energy to a system increases the system's kinetic energy. This means that the molecules move faster, increasing the number of collisions and the probability of a reaction taking place. However, heating cells is dangerous—too much thermal energy could destroy the cell.

Chemical reactions must proceed at relatively low temperatures within cells. **Catalysts** are chemicals that speed up chemical reactions at low temperatures without altering the products formed by the reaction. The catalyst remains unchanged after the chemical reaction, and so can be used again and again. Reactions that occur within living organisms are regulated by protein catalysts called **enzymes**. Enzymes permit low-temperature reactions by reducing the reaction's activation energy. **Figure 1** compares two energy-releasing reactions—one with an enzyme, and one without.

The molecules on which the enzyme works are called the **substrates**. Each substrate molecule combines with a specific enzyme. The substrate molecules are changed during the reaction, and a product is formed. It has been estimated that about 200 000 different chemical reactions occur within the cells of your body. Each reaction uses a specific enzyme to catalyze it.

Enzymes are identified by the suffix *-ase*, which is added to the name of the substrate that the enzyme combines with. Carbohydrases break down carbohydrates; for example, the enzyme that controls the hydrolysis of sucrose into its two component parts—glucose and fructose—is called sucrase. Proteases break down proteins, while lipases act on lipids.

Enzymes increase the probability of reactions occurring by bringing substrate molecules together. Enzymes have folded surfaces that trap particular substrate molecules, aligning them to cause the chemical reaction. Having large molecules collide is not enough—the molecules must collide at the appropriate binding sites if the reaction is to proceed.

The **active site** of the enzyme is the area that joins with the substrate molecules. Each enzyme has a specially shaped active site that provides a "dock" for specific substrate molecules. This long-standing model, called the "lock-and-key model," was first proposed by Emil Fischer in 1890. The temporary joining of the enzyme with the substrate forms the enzyme-substrate complex (**Figure 2**).

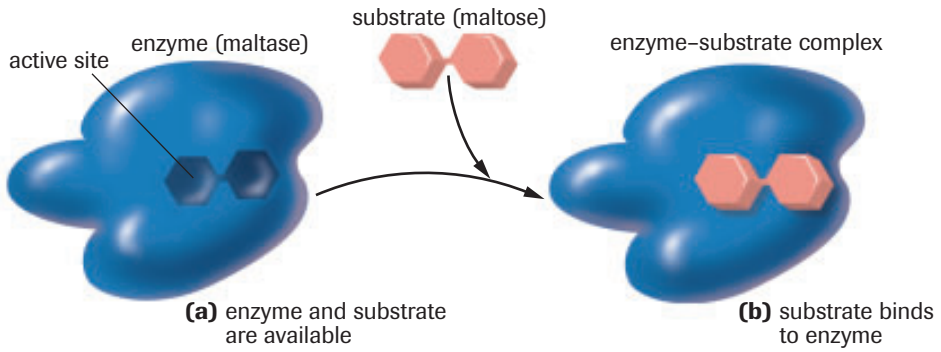


Figure 2
The enzyme maltase binds to maltose, its substrate.

A modified theory, called the "induced-fit model," replaced the lock-and-key model in 1973. The induced-fit model suggests that the actual shape of the active site is altered slightly when the substrate molecules are trapped, making the fit between enzyme and substrate even tighter during the formation of the enzyme-substrate complex (**Figure 2** , previous page).

Some enzymes require **cofactors** or **coenzymes** to help them bind to substrate molecules. Cofactors are inorganic ions such as iron, zinc, and potassium, as well as copper-containing compounds. Coenzymes are organic molecules that are synthesized from vitamins. Coenzymes and some cofactors may work with more than one enzyme.

Factors Affecting Enzyme Reactions

It has been estimated that a single enzyme can catalyze between 100 reactions and 30 million reactions every minute. Why do some reactions occur much faster than others? To compare reaction rates, you must examine the different factors that affect enzymes.

pH

The graph in **Figure 3** indicates that enzymes function best within certain pH ranges. The enzyme pepsin, shown in green, operates best in an acidic condition. Not surprisingly, this enzyme is found in the stomach, an area of low pH. The second enzyme, trypsin, shown in blue, is most effective in a basic medium. Not surprisingly, trypsin is found in the small intestine, an area that is generally about pH 9.

To understand why pH affects enzyme activity, you must look at the molecular structure of the protein molecule. Remember that the folds in the protein molecule are created by hydrogen bonds between negatively charged acid groups and positively charged amino groups. The addition of positively charged H^+ ions, characteristic of an acidic solution, or the introduction of negatively charged OH^- ions, characteristic of a basic solution, will affect the hydrogen bonds. Thus, the three-dimensional shape of an enzyme is altered by a change in pH. When the folds in the protein are changed, the active site of the enzyme is transformed, altering the reaction.

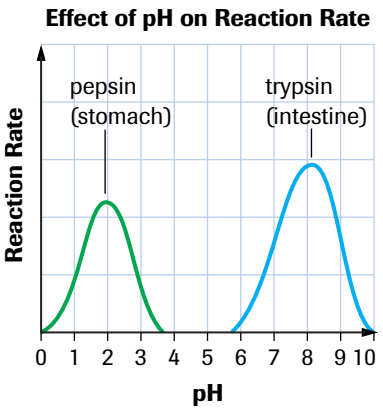


Figure 3
Different enzymes function within different pH ranges.

Substrate Molecule Concentration

Enzyme activity can also be affected by the concentration of substrate molecules. For chemical reactions, the greater the number of substrate molecules, the greater the number of collisions, and the greater the rate of the reaction. Up to a point, enzyme-catalyzed reactions behave in the same manner. The reaction rate shown in **Figure 4** begins to level off at point X because there is a limit to the amount of enzyme available. Substrate molecules cannot join with the active site of an enzyme until it is free. Once the number of substrate molecules exceeds the number of enzyme molecules, the excess substrate molecules will not gain access to the active site of an enzyme. Therefore, the reaction rate begins to level off.

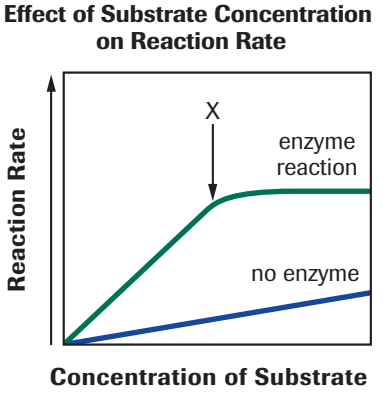


Figure 4
A higher concentration of substrate molecules increases the reaction rate.

Temperature

The graph in **Figure 5** indicates how temperature affects enzyme-catalyzed reactions. The fact that reaction rates increase as the temperature increases should not be surprising. As energy is added, the molecules begin to move faster. The faster the molecules move, the greater the number of collisions. Subsequently, more collisions cause a greater number of products to be formed. But why do reaction rates in our cells peak at about 37 °C and then drop, even though the molecules are moving faster and colliding more often?

To answer this question, recall some important facts about enzymes. The fact that enzymes are proteins is particularly significant because at high temperatures, proteins change shape or are denatured. Any change in enzyme shape will have an effect on the formation of the

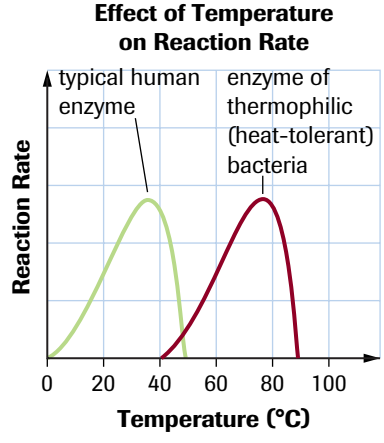


Figure 5
Different enzymes function within different temperature ranges.

enzyme-substrate complex. The greater the change to the active site of the enzyme, the less effective the enzyme. Once the enzyme is denatured, the active site is so severely altered that the substrate can no longer bind with the enzyme. The reaction is no longer catalyzed by the enzyme and, therefore, proceeds at a much slower rate.

The effect of temperature on enzymes helps explain why high fevers can be so dangerous. The relationship between temperature and enzyme-catalyzed reactions also indicates some of the advantages of being a homeotherm, an animal that maintains a constant body temperature. Mammals, birds, and other homeotherms keep their bodies at optimal temperatures for reactions.

Competitive Inhibition

competitive inhibitor a molecule with a shape complementary to a specific enzyme that competes with the substrate for access to the active site of the enzyme and blocks chemical reactions

Inhibitor molecules can affect enzyme reactions. Often referred to as **competitive inhibitors**, these molecules have shapes very similar to that of the substrate. The inhibitors actually compete with the substrate molecules for the active sites of the enzymes (**Figure 6**). As long as the inhibitors remain joined to the enzyme, the substrate cannot bind, and the enzyme cannot function properly.

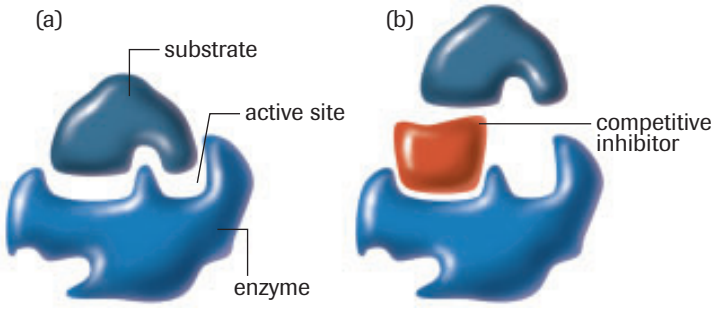


Figure 6
(a) The substrate normally binds to the active site.
(b) A competitive inhibitor competes with the substrate for the active site.

INVESTIGATION 8.3 ***Introduction***

Factors That Affect the Catalase Enzyme Reaction

Catalase is an enzyme found in many species that live in oxygen-rich environments. Catalase breaks down hydrogen peroxide (H_2O_2), a toxin. What factors affect the rate of catalase activity?

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 274.

Regulation of Enzyme Activity

Metabolic pathways are orderly sequences of chemical reactions, with enzymes regulating each step of the reaction. Consider the following example of a metabolic pathway. Testosterone is a male sex hormone synthesized from cholesterol or other steroids. The hormone, which is produced in larger quantities from puberty onward, is responsible for the development of secondary male sex characteristics.

Can you imagine what would happen if all of the steroids in the body were converted into testosterone? The regulation of chemicals produced by metabolic pathways is essential. The production of chemicals within a cell is regulated by the need for those chemicals. As the product from a series of chemical reactions begins to accumulate within a cell, the product interferes with one of the enzymes in a process known as **feedback inhibition**. The interference slows the reaction rate, preventing the accumulation of final products. The final product of the metabolic pathway interferes with the enzyme by combining with its regulatory site. The binding

feedback inhibition the inhibition of an enzyme in a metabolic pathway by the final product of that pathway

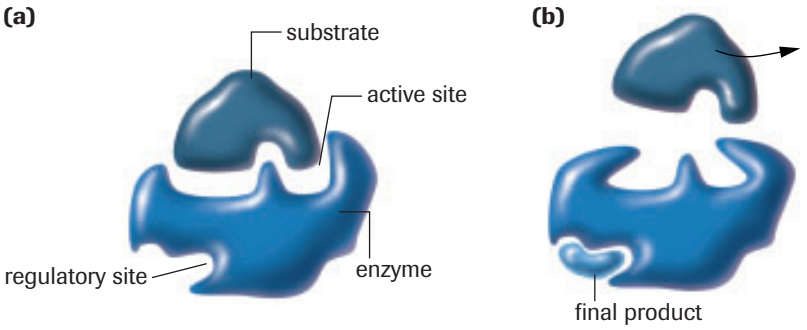


Figure 7
(a) The substrate can bind to the active site.
(b) The final product attaches to the regulatory site and changes the shape of the enzyme so that the substrate can no longer bind.

of the final product with the regulatory site of the enzyme alters the active site, and thus prevents the union of the enzyme and substrate (**Figure 7**).

Regulatory sites are not just used to turn off metabolic pathways. A buildup of the initial substrate can turn on enzyme activity. If the substrate molecule combines at the regulatory site of one of the enzymes, **precursor activity** occurs. During precursor activity, the combination of the substrate and enzyme actually improves the fit of the enzyme-substrate complex. This speeds up the formation of final products. Both feedback inhibition and precursor activity involve the binding of a molecule with the regulatory site of the enzyme. Both processes are called **allosteric activity**. The binding of the final product with the regulatory site of the enzyme will change the enzyme's active site, thereby inhibiting subsequent reactions. The binding of one of the initial reactants with the regulatory site will help mould the active site of the enzyme, improving the fit between substrate and enzyme. **Figure 8** summarizes these processes.

precursor activity the activation of the last enzyme in a metabolic pathway by the initial substrate

allosteric activity a change in an enzyme caused by the binding of a molecule

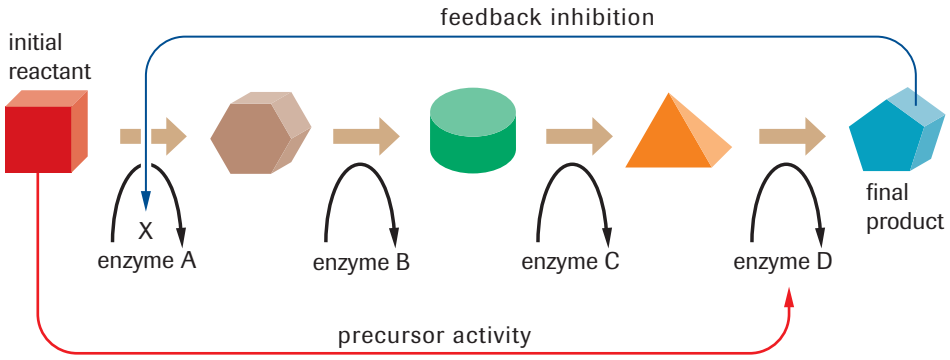


Figure 8
Allosteric activity involves both precursor activity and feedback inhibition. Precursor activities turn metabolic pathways "on," while feedback inhibition activities turn metabolic pathways "off."

SUMMARY Enzymes

- Chemical reactions within cells are regulated by enzymes. Enzymes are protein catalysts that lower activation energy and permit chemical reactions to proceed at body temperature.
- Cofactors are inorganic ions that help enzymes combine with substrate molecules. Coenzymes are organic molecules that help enzymes combine with substrate molecules.
- A competitive inhibitor has a shape complementary to a specific enzyme, thereby permitting it access to the active site of the enzyme. Inhibitors block chemical reactions.

- Feedback inhibition is the inhibition of the first enzyme in a metabolic pathway by the final product of that pathway.
- Precursor activity is the activation of the last enzyme in a metabolic pathway by the initial substrate.

Section 8.2 Questions

1. Explain the importance of enzymes in metabolic reactions.
2. How do enzymes increase the rate of reactions?
3. List and explain four factors that affect the rate of chemical reactions.
4. How do cofactors and coenzymes work?
5. What are competitive inhibitors?
6. What is allosteric activity?
7. How are metabolic pathways regulated by the accumulation of the final products of the reaction?
8. Explain how enzymes work in the lock-and-key model. How has the induced-fit model changed the way in which biochemists describe enzyme activities?
9. Use the metabolic pathway in **Figure 9** to explain feedback inhibition.
10. Use **Figure 10** to answer the following questions.
    (a) Match labels A, B, and C in the diagram to the following: reactants, products, and activation energy.
    (b) How will decreasing the number of substrate molecules affect the rate of reaction? Explain your answer.
    (c) If an enzyme is introduced into this chemical reaction, explain how the reaction curve would change.
11. The reaction shown in **Figure 11** is catalyzed by an enzyme.
    (a) Complete the graph by showing what would happen if a competitive inhibitor was added at "T."
    (b) Explain why the inhibitor would affect the rate of the chemical reaction.
12. Using the information that you have gained about enzymes, explain why high fevers can be dangerous.

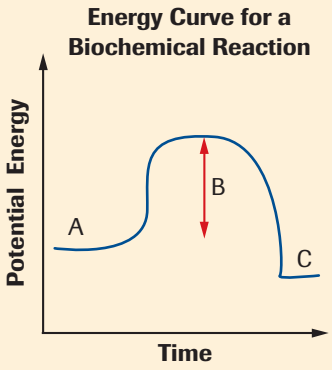


Figure 10

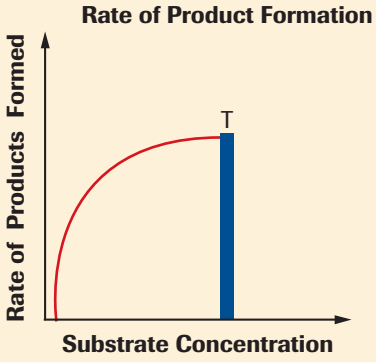


Figure 11

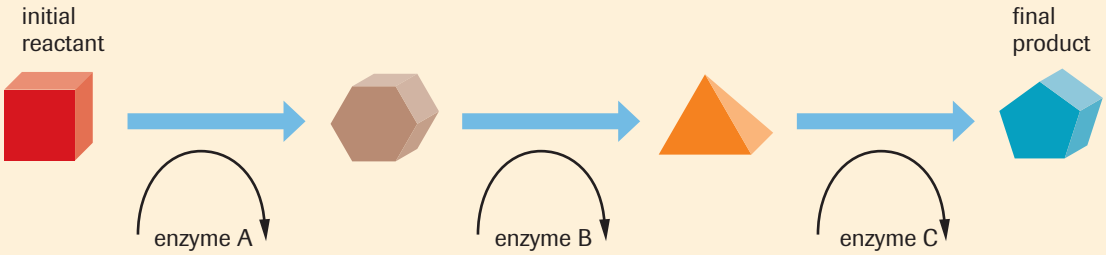


Figure 9

Ingestion 8.3

There are four components of the digestive process:

1. ingestion—the taking in of nutrients
2. digestion—the breakdown of complex organic molecules into smaller components by enzymes
3. absorption—the transport of digested nutrients to the cells of the body
4. egestion—the removal of food waste from the body

The digestive tract of adult humans, normally 6.5 m to 9 m long, stores and breaks down organic molecules into simpler components. **Figure 1** shows the entire digestive system. Physical (mechanical) digestion begins in the mouth, where food is chewed and formed into a bolus (the Greek word for ball) by the tongue. Physical digestion breaks food into smaller pieces, increasing the surface area for chemical digestion.

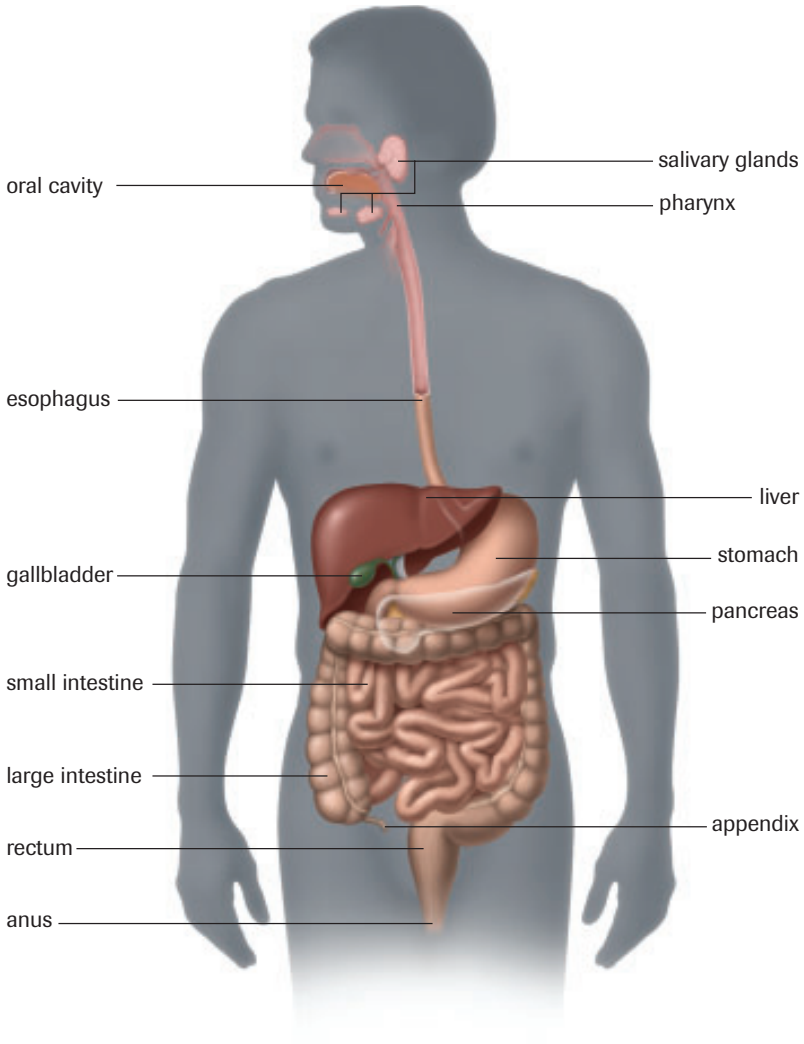


Figure 1
The human digestive system and accessory organs

CAREER CONNECTION

X-ray Technician

X-ray technicians perform various functions, such as advising patients how to prepare for X rays and ensuring that the X ray is taken safely. X-ray technicians need to know the fundamentals of anatomy, disease, and how trauma affects various organ systems. Research the programs available for certification as an X-ray technician.

www.science.nelson.com GO

Salivary Glands

amylase an enzyme that breaks down complex carbohydrates

Saliva, the watery fluid produced by the salivary glands, contains **amylase** enzymes, which break down starches (complex carbohydrates) to simpler carbohydrates. Saliva dissolves food particles and makes it possible to taste what is being eaten. It also lubricates the food so that it can be swallowed.

We detect the flavour when food particles dissolved in saliva penetrate the cells of the taste buds located on the tongue and cheeks. (Our sense of smell is also involved in tasting food.) Different types of receptors respond to specific flavours. For example, the taste buds are equipped with receptors (**Figure 2**) that have a specific geometry that permits the identification of sweet tastes from carbohydrates. Nerve cells for taste are stimulated when receptor sites are bound by chemical compounds with a complementary shape. Try dissolving foods in saliva by drying your tongue and then placing a few grains of salt on it. You will not detect any flavour until the crystals dissolve in your saliva.

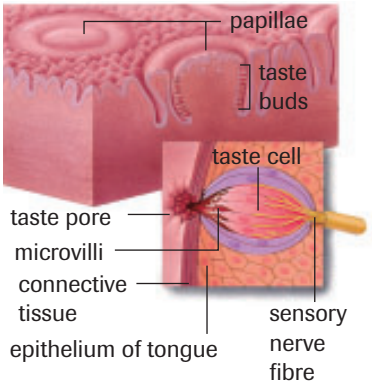


Figure 2
Taste buds are located along the tongue.

Teeth

The teeth are important structures for physical digestion (**Figure 3**). Eight chisel-shaped teeth at the front of your mouth, called incisors, are specialized for cutting. The incisors are bordered by sharp, dagger-shaped canine teeth that are specialized for tearing. Next to the canine teeth are the premolars. These broad, flattened teeth are specialized for grinding. The molars are next. These teeth tend to be even broader and have cusps that are even more flattened. They are designed for crushing food. The last set of molars are the wisdom teeth, so called because they usually do not emerge until we reach about 16 to 20 years of age. Each tooth is covered with enamel, which is the hardest substance in the human body.

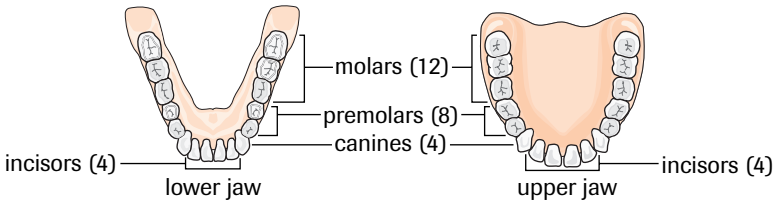


Figure 3
Human adult teeth

Esophagus

peristalsis rhythmic, wavelike contractions of muscle that move food along the gastrointestinal tract

Once swallowed, food travels from the mouth to the stomach by way of the esophagus. The bolus of food stretches the walls of the esophagus, activating muscles that set up waves of rhythmic contractions called **peristalsis**. Peristaltic contractions, which are involuntary, move food along the gastrointestinal tract (**Figure 4**). The only points at which food is moved voluntarily along the tract is during swallowing and during the last phase, egestion. Peristaltic action will move food or fluid from the esophagus to the stomach even if you stand on your head.

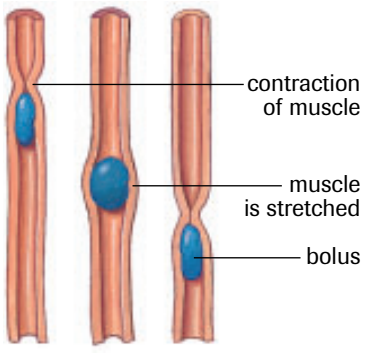


Figure 4
Rhythmic contractions of muscle move food along the digestive tract.

Practice

1. What are the functions of saliva?
2. How does chewing assist in the digestion of food?
3. What are amylase enzymes and why are they necessary?
4. How is food moved along the esophagus?

Stomach

The stomach is the site of food storage and initial protein digestion. The stomach contains three layers of muscle, which run in different directions so that the muscle contractions can churn the food (**Figure 5 (a)**).The movement of food to and from the stomach is regulated by circular muscles called **sphincters**. Sphincters act like the drawstrings on a bag. Contraction of the lower esophageal sphincter (LES) closes the opening to the stomach, while its relaxation allows food to enter. The LES prevents food and acid from being regurgitated up into the esophagus. A second sphincter, the pyloric sphincter, regulates the movement of food and stomach acids into the small intestine (**Figure 5 (b)**).

sphincter a constrictor muscle that regulates the opening and closing of a tubelike structure

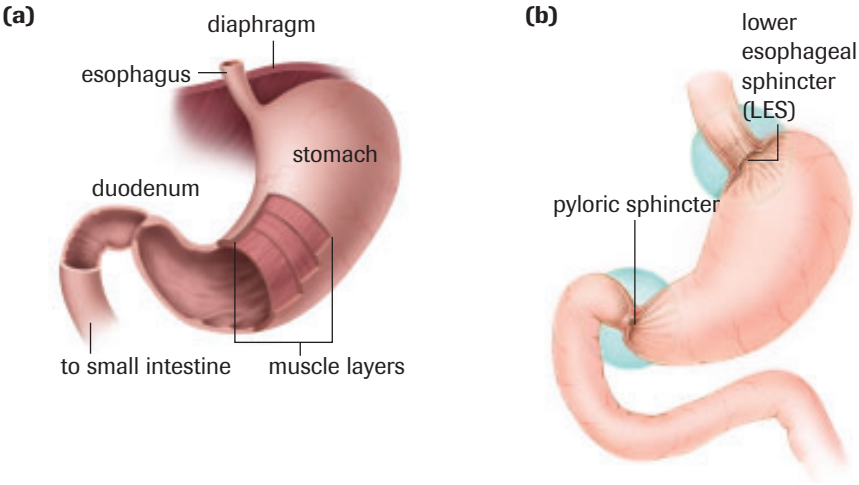


Figure 5
(a) Muscle is responsible for the contractions of the stomach.
(b) Sphincters regulate the movement of food.

The J-shaped stomach has numerous ridges that allow it to expand so that it can store about 1.5 L of food. Millions of cells line the inner wall of the stomach. These cells secrete the various stomach fluids, called gastric fluids or gastric juice, that aid digestion. Contractions of the stomach mix the food with the gastric fluids. Therefore, the stomach is involved in both physical and chemical digestion. Approximately 500 mL of these fluids are produced following a large meal. Gastric fluid includes **mucus**, hydrochloric acid (HCl), pepsinogens, and other substances. Hydrochloric acid kills many harmful substances that are ingested with food. It also converts pepsinogen into its active form, **pepsin**, which is a protein-digesting enzyme. Pepsin breaks the long amino acid chains in proteins into shorter chains, called polypeptides.

mucus a protective lubricating substance composed mostly of protein

pepsin a protein-digesting enzyme produced in the stomach

The pH inside the stomach normally ranges between 2.0 and 3.0, but may approach pH 1.0. Acids with a pH of 2.0 can dissolve fibres in a rug! It is the high acidity of hydrochloric acid that makes it effective at killing pathogens and allows pepsin to do its work. How does the stomach safely store these strong chemicals, both of which dissolve the proteins that make up cells? A layer of alkaline mucus protects the stomach lining from being digested. Pepsinogen moves through the cell membrane and mucous lining, is activated by HCl, and becomes pepsin. The pepsin breaks down the proteins in the food, but not the proteins of the stomach's cells because these proteins are protected by the mucous layer. The esophagus does not have a protective mucous layer, so if the LES is weak, stomach acid may enter the esophagus and damage its lining. This causes the pain known as heartburn.

EXTENSION

Activation of Digestive Zymogens

What are digestive zymogens? This Audio Clip will give you information on a number of protein-digesting enzymes that are secreted into the stomach and duodenum, and unravel the mechanism of how they are activated from a zymogen state.

www.science.nelson.com GO

DID YOU KNOW

How Big Is Your Stomach?

The stomach capacity of a newborn human baby can be as little as 60 mL. An adult stomach has a maximum capacity of about 1.5 L, while the stomach of a cow is divided into four compartments and may hold up to 300 L.

ulcer a lesion on the surface of an organ

Peptic Ulcers

When the protective mucous lining of the stomach breaks down, the cell membrane is exposed to the HCl and pepsin. The destruction of the cell membrane leads to a peptic **ulcer**. Beneath the thin layer of cells is a rich network of blood vessels. As the acids irritate the cells of the stomach lining, there is an increase in blood flow and acid secretions. With this increased blood flow and acid secretion, more tissue is burned, and the cycle continues. Eventually the blood vessels begin to break down.

Most ulcers are the result of an infection by a bacterium called *Helicobacter pylori (H. pylori)*. Dr. Barry Marshall, an Australian physician, first made this connection in the early 1980s. Scientists were initially skeptical of Dr. Marshall's findings, since it was believed that bacteria would be unable to survive the highly acidic conditions of the stomach. In 2005, Dr. Marshall received a Nobel Prize in Physiology or Medicine for his work with *H. pylori* and ulcers. A simple breath test for the presence of *H. pylori* is now widely available. Dr. Marshall is currently working in the United States, where he is investigating a possible link between the microbe and some forms of stomach cancer.

If an *H. pylori* infection is found early enough, treatment with an antibiotic can cure the ulcer. In some cases, the amount of damage is severe enough to also require surgery. A device called an endoscope can be fitted with a light-emitting glass fibre and then positioned inside a patient's body (**Figure 6**). Physicians then use the endoscope to view the damage. Tiny forceps fitted in the endoscope may be used to extract small pieces of tissue for a biopsy. Special lasers designed for surgical applications may be used to remove any damaged tissue. The laser beam is thinner than most scalpels and provides the added advantage of sealing small blood vessels.

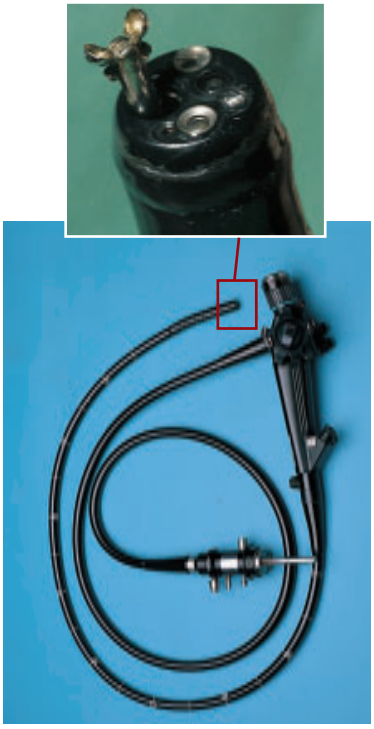


Figure 6
The endoscope can be used to look inside the body.

EXPLORE an issue

Fad Diets

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

Dieting is big business. An array of low-calorie food products and specialized diet plans are competing in an ever-expanding market. Diet plans like the Atkins Diet are high in protein and low in carbohydrates, while the Beverly Hills Diet recommends low protein and high carbohydrate consumption. Some weight-loss plans include appetite suppressants such as amphetamines, as well as laxatives.

People who are overweight are more prone to certain diseases such as atherosclerosis and diabetes; however, being underweight can also cause problems, such as fatigue and increased risk of illness and injury.

Statement
Specialized diet plans may actually contribute to malnutrition in people who use them consistently.

Point
Some diets emphasize high-calorie fatty foods such as steaks, cheese, and milk, which can increase cholesterol levels. Liquid protein diets provide only about 400 calories per day, whereas most people need about 1200 calories per day.

Counterpoint
Low-calorie, nonfattening foods are carefully monitored by nutritionists. Prepared products are not the only answer to good eating. People must take responsibility for maintaining a healthy balance in their food intake. Dieting alone cannot be expected to perform miracles.

1. Research the issue.

www.science.nelson.com GO

2. Reflect on your findings. Discuss the various viewpoints with others.
3. Prepare for the class debate.

WEB Activity

Web Quest—What Are You Eating?

Have you ever explored the intake and output of energy in your own body? This Web Quest guides you through collecting data on your own food intake and physical activity. Using this information, you can then analyze the data and find out exactly what is happening with calories coming in and going out of your own body!

www.science.nelson.com GO

SUMMARY *Ingestion*

- Saliva contains amylase enzymes that initiate carbohydrate breakdown, and it dissolves food particles, activates the taste buds, and lubricates the food.
- Teeth bite, tear, grind, and crush food into smaller particles.
- After food is swallowed, movement through the esophagus is regulated by peristalsis, contractions of muscle.
- Sphincter muscles regulate the movement of food into and out of the stomach.
- Digestive fluids in the stomach include hydrochloric acid (HCl), pepsinogens, and mucus. HCl kills pathogens and helps convert pepsinogen into pepsin. Pepsin digests proteins. Mucus protects the stomach from the above two fluids.

EXTENSION

Dying To Be Thin

For some young people, the conflict between real and fashionable images of the body can lead to an eating disorder. In severe cases, eating disorders such as anorexia can cause low blood pressure, bone loss, damage to the kidneys, liver and heart, and even death. This is a *NOVA* video.

www.science.nelson.com GO

Section 8.3 Questions

1. How are the digestive system and other organ systems interdependent?
2. Differentiate between physical and chemical digestion. Provide examples of each.
3. Is the movement of food through your digestive system voluntary or involuntary? What mechanisms are responsible for moving food along the gastrointestinal tract?
4. The type of teeth that a mammal has is matched to diet. Keeping in mind the function of different types of teeth, name an animal that would have well-developed (a) canines, and (b) molars and premolars.
5. How is movement of food into and out of the stomach regulated?
6. What substances make up gastric fluid?
7. What is the function of the mucous layer that lines the stomach?
8. What is an endoscope and why is it useful?
9. List and discuss two factors that affect enzyme activity. Provide two examples.
10. State the functions of the enzymes amylase and pepsin.
11. What are two factors that contribute to stomach ulcers?
12. In stomach cells, protein-digesting enzymes are stored in the inactive form. Once the enzymes leave the stomach, an acid in the stomach changes the shape of the inactive enzyme, making it active. The active enzyme begins to digest proteins. Why must protein-digesting enzymes be stored in the inactive form?
13. Where would you expect to find digestive enzymes that function best at a pH of 2.0? at a pH of about 7.0?
14. Why does the low pH of the stomach stop the starch digestion that begins in the mouth? What is the advantage to the body of this delay?
15. Would a mouth with a pH of 5.0 have more or less tooth decay than a mouth with a pH of 7.0? Why?
16. Find out about the different kinds of ulcers. Learn about the risk factors, symptoms, and treatments.

    www.science.nelson.com GO
17. Heartburn, or acid indigestion, occurs when stomach acids back up into the esophagus, burning its lining. Antacids can be taken to reduce the burning sensation. How might using antacids to mask the pain of heartburn inadvertently lead to more serious problems?

8.4 Digestion

CAREER CONNECTION

Health Service Administrator

These health professionals direct and evaluate health programs and plans. Health service administrators have opportunities to work in a wide range of fields, including medicine, pharmacy, accounting, and management. If you are interested in medical service and administration, explore this career further.

www.science.nelson.com GO

Most chemical digestion takes place in the small intestine, so named because of its narrow diameter. In humans, the small intestine is up to 7 m in length, but only 2.5 cm in diameter (**Figure 1**). The large intestine, by comparison, is only 1.5 m in length, but 7.6 cm in diameter. In mammals, the length of the small intestine is related to diet. Meats are relatively easy to digest, while plant materials are more difficult to digest. Accordingly, carnivores, such as wolves and lions, have short small intestines while herbivores, such as rabbits, have long small intestines. Omnivores, such as raccoons, pigs, bears, and humans, have small intestines that are of intermediate length, allowing them to digest both types of food.

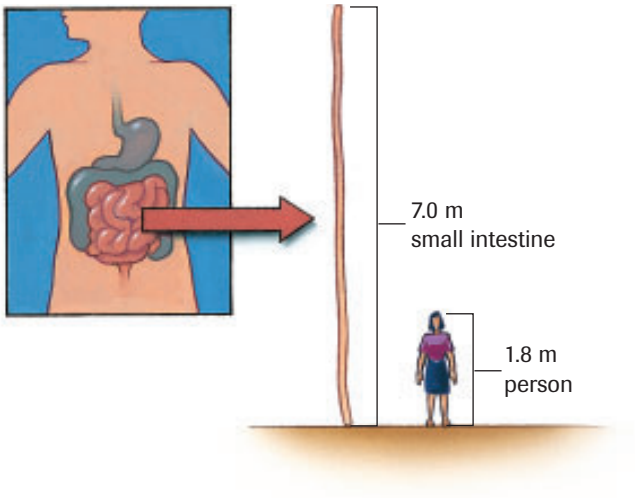


Figure 1
A comparison of the length of the small intestine to the height of a person

Small Intestine

The majority of digestion occurs in the first 25 cm to 30 cm of the small intestine, an area known as the **duodenum**. The second and third components of the small intestine are called the jejunum and the ileum. The small intestine secretes digestive enzymes and moves its contents along by peristalsis.

duodenum the first segment of the small intestine

The stomach absorbs some water, specific vitamins, some medicines, and alcohol, but most absorption takes place within the small intestine. Long fingerlike projections called **villi** (singular: villus) greatly increase the surface area of the small intestine (**Figure 2 (a)**). One estimate suggests that villi account for a tenfold increase in surface area for absorption. The cells that make up the lining of each villus have **microvilli**, which are fine, threadlike extensions of the membrane that further increase the surface for absorption (**Figure 2 (b)**).

villi small, fingerlike projections that extend into the small intestine to increase surface area for absorption

microvilli microscopic, fingerlike projections of the cell membrane

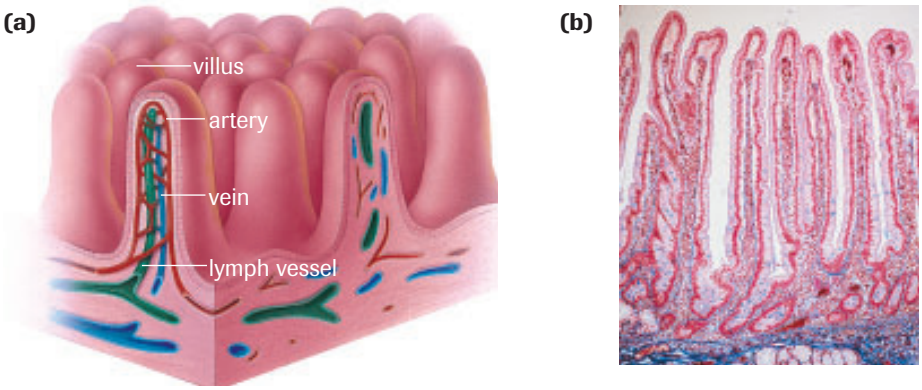


Figure 2
(a) Blood and lymph vessels of a villus
(b) Microvilli

Each villus is supplied with a **capillary** network that intertwines with lymph vessels called **lacteals** that transport materials. Some nutrients are absorbed by diffusion, but some nutrients are actively transported from the digestive tract. Monosaccharides and amino acids are absorbed into the capillary networks; fats are absorbed into the lacteals.

capillary a blood vessel that connects arteries and veins; the site of fluid and gas exchange

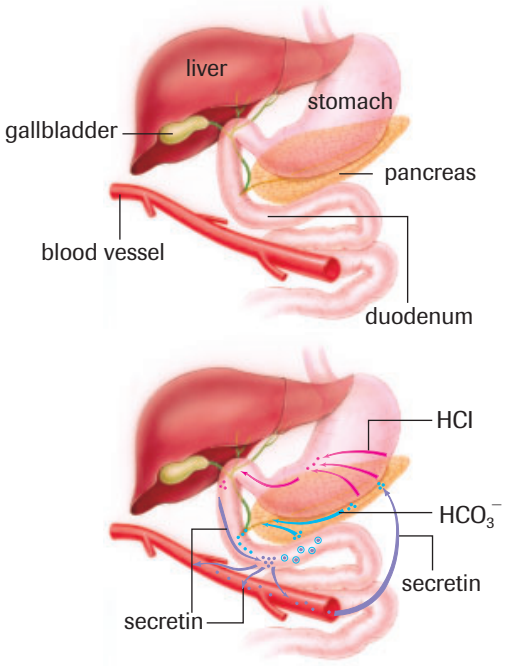
lacteal a small vessel that transports the products of fat digestion to the circulatory system

Pancreas

As you already know, food moves from the stomach to the small intestine. Partially digested food reaches the small intestine already soaked in HCl and pepsin. How are the cells of the small intestine protected? To answer this question, you must look beyond the small intestine to the pancreas.

When acids enter the small intestine, a chemical called prosecretin is converted into **secretin**. Secretin is absorbed into the bloodstream and carried to the pancreas, where it signals the release of a solution containing bicarbonate ions. Bicarbonate ions (HCO_3^-) are released from the pancreas and carried to the small intestine, where they buffer the HCl in gastric fluid and raise the pH from about 2.5 to 9.0. The basic pH inactivates pepsin. Thus, the small intestine is protected from stomach acids by the release of secretin. These steps are summarized in **Figure 3**.

secretin a hormone released from the duodenum that stimulates pancreatic and bile secretions



- HCl enters the duodenum from the stomach.
- HCl stimulates the conversion of prosecretin into secretin.

prosecretin (inactive form) —HCl→ **secretin (active form)**

- Secretin is aborbed into the blood vessels.
- Secretin is carried by the circulatory system to the pancreas.
- Here secretin acts as a chemical messenger, stimulating the release of pancreatic fluids.
- The HCO_3^- ions, released by the pancreas, neutralize the HCl from the stomach. The neutralization of acid protects the lining of the duodenum.

Figure 3
The function of secretin

The pancreatic secretions also contain enzymes that promote the breakdown of the three major components of food: proteins, carbohydrates, and lipids. A protein-digesting enzyme, called trypsinogen, is released from the pancreas. Once trypsinogen reaches the small intestine, an enzyme called **enterokinase** converts the inactive trypsinogen into **trypsin**, which acts on the partially digested proteins. Trypsin breaks down long-chain polypeptides into shorter-chain peptides.

A second group of enzymes, the **erepsins**, are released from the pancreas and small intestine. They complete protein digestion by breaking the bonds between short-chain peptides, releasing individual amino acids (**Figure 4**, next page).

The pancreas also releases amylase enzymes, which continue the digestion of carbohydrates begun in the mouth by salivary amylase. The intermediate-size chains are broken down into disaccharides. The small intestine releases disaccharide enzymes, called disaccharidases, which complete the digestion of carbohydrates.

enterokinase an enzyme of the small intestine that converts trypsinogen to trypsin

trypsin a protein-digesting enzyme

erepsin an enzyme that completes protein digestion by converting short-chain peptides to amino acids

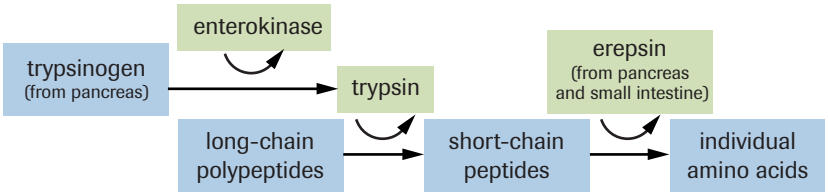


Figure 4
Breakdown of proteins in the small intestine

lipase a lipid-digesting enzyme

Lipases are enzymes released from the pancreas that break down lipids (fats). There are two different types of lipid-digesting enzymes. Pancreatic lipase, the most common, breaks down fats into fatty acids and glycerol. Phospholipase acts on phospholipids.

For a summary of the enzymes found in the small intestine, where they are produced, and the reactions that take place, see **Table 1**.

Table 1 Digestion in the Small Intestine

Enzyme	Produced by	Reaction
lipase	pancreas	fat droplets + H_2O → glycerol + fatty acids
trypsin	pancreas	protein + H_2O → peptides
erepsin	pancreas, small intestine	peptides + H_2O → amino acids
pancreatic amylases	pancreas	starch + H_2O → maltose
maltase	small intestine	maltose + H_2O → glucose

INVESTIGATION 8.4 *Introduction*

Effect of pH and Temperature on Starch Digestion

The digestion of many components of food is not accomplished in the stomach, but in the small intestine. For example, starch digestion occurs mainly in the small intestine. What happens to these components when they are in the stomach?

To perform this investigation, turn to page 275.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ○ Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

DID YOU KNOW?

Are You Lactose Intolerant?

Many people are unable to digest lactose (milk sugar) because their bodies do not produce sufficient quantities of the enzyme lactase. Normally, the disaccharide lactose is broken down into two monosaccharides, which are then absorbed into the blood. Lactose-intolerant people are unable to break down lactose in the small intestine, so when it moves to the large intestine, water is drawn in by osmosis, causing diarrhea.

Practice

1. How are the cells of the small intestine protected from stomach acid? Explain the mechanism and the chemicals involved.
2. What enzymes secreted by the pancreas promote digestion?
3. Explain the chemicals and processes involved in protein digestion and carbohydrate digestion. Why are carbohydrates not digested in the stomach?
4. List the lipid-digesting enzymes secreted from the pancreas. Do these enzymes allow for complete breakdown of lipids?
5. How is the duodenum protected against stomach acid? Why does pepsin not remain active in the duodenum?
6. In cases of extreme obesity, a section of the small intestine may be removed. What effect do you think this procedure has on the patient?
7. Describe what the inside of the small intestine looks like and how this organ increases the efficiency of its operation.

Liver and Gallbladder

The liver continually produces a fluid called bile. Bile contains **bile salts**, which aid fat digestion. When the stomach is empty, bile is stored and concentrated in the gallbladder.

bile salt a component of bile that breaks down large fat globules

When there are fats in the small intestine, the hormone **cholecystokinin** (CCK) is released. CCK is carried in the blood to the gallbladder (**Figure 5**) and triggers the gallbladder to release bile salts. Once inside the small intestine, the bile salts emulsify, or break down, large fat globules. The breakdown of fat globules into smaller droplets is physical digestion, not chemical digestion, since chemical bonds are not broken. The physical digestion prepares the fat for chemical digestion by increasing the exposed surface area on which fat-digesting enzymes, such as pancreatic lipase, can work.

cholecystokinin a hormone secreted by the small intestine that stimulates the release of bile salts

- Fats enter the duodenum and stimulate the release of the hormone CCK.
- CCK is carried by the bloodstream to the gallbladder.
- CCK stimulates the release of bile salts from the gallbladder.
- Bile emulsifies fats.

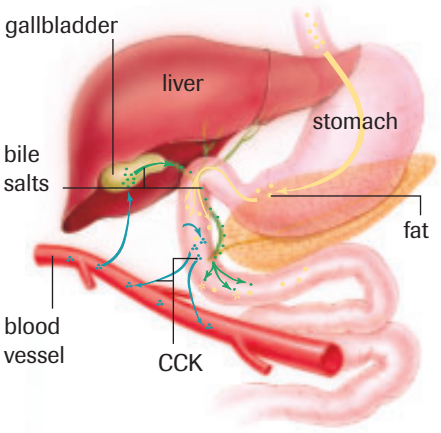


Figure 5
The function of cholecystokinin

Bile also contains pigments. The liver breaks down hemoglobin from red blood cells and stores the products in the gallbladder for removal. The characteristic brown colour of feces results from hemoglobin breakdown.

The liver also stores glycogen and vitamins A, B_{12}, and D. In addition, the liver is able to **detoxify** many substances in the body. Harmful chemicals are made soluble and can be dissolved in the blood and eliminated in the urine. One of the more common poisons is alcohol.

detoxify to remove the effects of a poison

Table 2 outlines the various functions of the liver.

Table 2 Liver Functions

Function	Examples
synthesis	• produces bile salts, which are stored in the gallbladder and which emulsify fats • manufactures blood proteins
breakdown/conversion	• removes the highly toxic nitrogen group from amino acids, forming urea (the main component of urine) • converts the toxic component of hemoglobin, allowing it to be excreted with bile salts • converts glucose into glycogen and glycogen into glucose to maintain a constant blood sugar level
storage	• stores glycogen • stores vitamins A, B_{12}, and D
detoxification	• converts harmful compounds, such as alcohol, to less harmful products

DID YOU KNOW ?

Lily-Livered

The liver was once considered to be the centre of emotions. The term lily-livered, meaning cowardly, implies inadequate blood flow to the liver.

Liver and Gallbladder Problems

gallstone crystals of bile salts that form in the gallbladder

jaundice the yellowish discoloration of the skin and other tissues brought about by the collection of bile pigments in the blood

cirrhosis chronic inflammation of the liver tissue characterized by the growth of nonfunctioning fibrous tissue

The production and concentration of bile can result in certain problems. Cholesterol, an insoluble component of bile, acts as a binding agent for the salt crystals found in bile. The crystals precipitate and form larger crystals called **gallstones**. Gallstones can block the bile duct, impairing fat digestion and causing considerable pain. Any obstruction of the bile duct or accelerated destruction of red blood cells can cause **jaundice**, turning skin and other tissues yellow.

Alcohol, like many other harmful agents, can destroy liver tissue if consumed in large quantities. Damaged liver cells are replaced by fibrous connective tissue and nodules, which are not able to carry out normal liver functions. This condition, which can also result from nutritional deprivation or infection, is referred to as **cirrhosis** of the liver.

mini Investigation — Emulsification of Fats

Materials: eyedropper, test tube, vegetable oil, bile salts or liquid soap, hand lens (magnifying glass), test tube stopper

- Fill a test tube one-quarter full of water.
- Add 10 drops of vegetable oil. Record the location and appearance of the oil in the test tube.
- Shake the test tube (with stopper) and immediately examine its contents with the hand lens. Record your observations.
- Let the test tube stand for 2 min to 3 min. Observe any changes.
- Add about 5 drops of liquid soap or a pinch of bile salts to the test tube.
- Shake the test tube (with stopper). Immediately examine the contents with the hand lens and record your observations.

(a) What effect did the liquid soap or bile salts have on the oil?

Large Intestine

colon the largest segment of the large intestine, where water reabsorption occurs

Chemical digestion is complete by the time food reaches the large intestine. The **colon**, the largest part of the large intestine, must store waste long enough to reabsorb water from it. Some inorganic salts, minerals, and vitamins are also absorbed with the water.

The large intestine houses bacteria, such as *Escherichia coli (E. coli)*, which are essential to life and use waste materials to synthesize vitamins B and K. Cellulose, the long-chain carbohydrate characteristic of plant cell walls, reaches the large intestine undigested. Although cellulose cannot be broken down by humans, it serves an important function: cellulose provides bulk. As wastes build up in the large intestine, receptors in the wall of the intestine provide information to the central nervous system, which, in turn, prompts a bowel movement. The bowel movement ensures the removal of potentially toxic wastes from the body. Individuals who do not eat sufficient amounts of cellulose (roughage or fibre) have fewer bowel movements. This means that wastes and toxins remain in their bodies for longer periods of time. Scientists have determined that cancer of the colon can be related to diet. Individuals who eat mostly processed, highly refined foods are more likely to develop cancer of the colon.

EXTENSION

The Negative Impacts of Gallstones

Listen to this Audio Clip to identify the components of bile and investigate the negative effects associated with gallstones and gallbladder dysfunction.

www.science.nelson.com GO

Practice

8. What are the components of bile? Where is bile produced and where is it stored?
9. Explain the importance of bile salts in digestion.
10. Why doesn't fat dissolve in water?
11. Why is the liver important in processing toxins in the body? What happens if the level of toxins is very high?
12. What is the function of the colon in the digestive system?
13. Why is cellulose considered to be an important part of your diet?

Control of Digestion

The control of digestion is exerted by the nervous and hormonal systems. Seeing, smelling, or tasting food will produce gastric secretions even before there is any food in the stomach. Swallowing motions also stimulate production of gastric juices, regardless of whether food is actually swallowed.

Hormones play a large role in the control mechanism. For example, secretin is released when acid from the stomach moves into the small intestine along with food. Secretin is absorbed into the blood and travels to the pancreas where it initiates the release of substances that raise the pH of the small intestine. Another hormone, called **gastrin**, is produced when the walls of the stomach are distended by the presence of food. Partially digested protein in the stomach also stimulates the release of gastrin. Gastrin travels in the blood to the parietal cells of the stomach and signals them to release HCl (**Figure 6 (a)**).

gastrin a hormone secreted by the stomach that stimulates the release of HCl

The speed at which the digestive system processes food can also be controllled. When food enters the stomach, nerves in the stomach wall cause the muscles to contract and gastric fluids to be secreted. A large meal will activate more receptors, causing more forceful stomach contractions and faster emptying. If the meal is fatty, the small intestine secretes **enterogastrone**, which slows peristaltic movements, allowing time for fat digestion and absorption (**Figure 6 (b)**).

enterogastrone a hormone secreted by the small intestine that decreases gastric secretions and motility

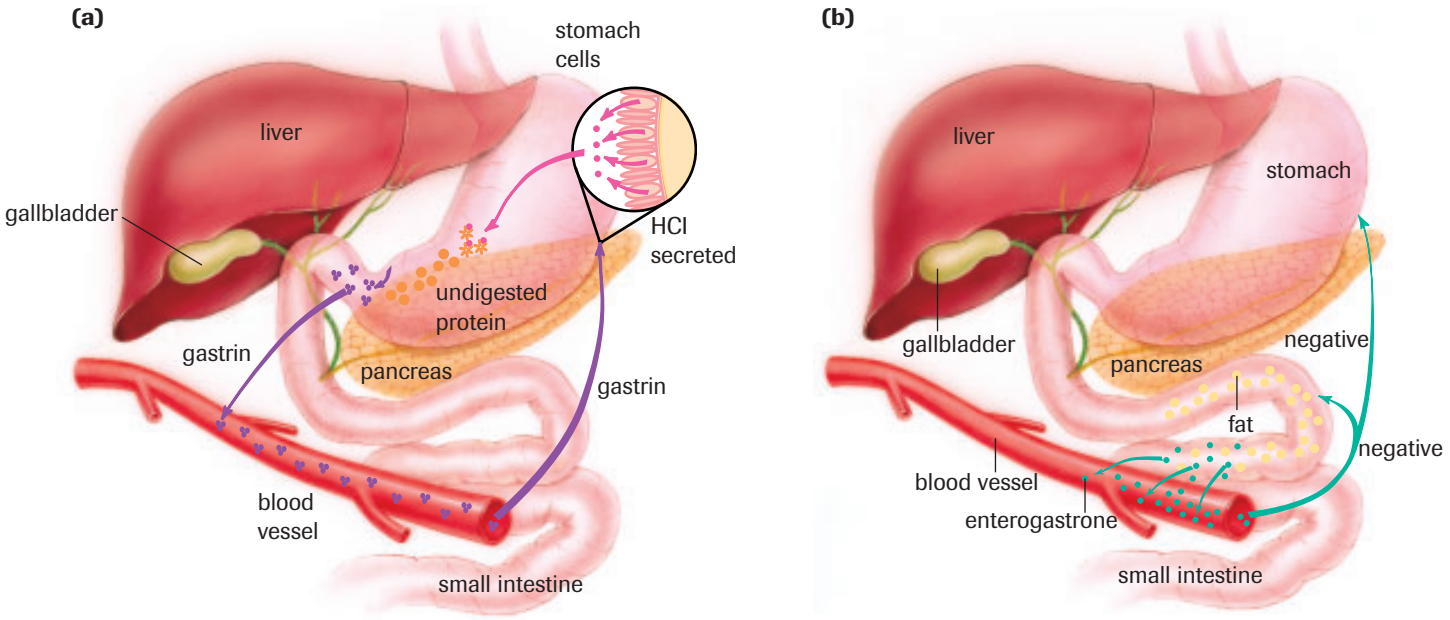


Figure 6
The function of **(a)** gastrin and **(b)** enterogastrone

SUMMARY Digestion

Table 3 Digestive Organs and Their Functions

Organ	Function
mouth	chewing of food and digestion of starch
stomach	storage of food and initial digestion of proteins
small intestine	digestion of carbohydrates, proteins, lipids; the absorption of nutrients
pancreas	production of digestive enzymes that act on food in the small intestine; storage of bicarbonate ions that neutralize stomach acid in the small intestine
large intestine	absorption of water and storage of undigested food

Table 4 Organs and Substances Involved in Digestion

Organ of secretion	Secretion	Function
salivary glands	salivary amylase	initiates the breakdown of polysaccharides to simpler carbohydrates
stomach	hydrochloric acid	converts pepsinogen to pepsin; kills microbes
	pepsinogen	when converted to pepsin, initiates the digestion of proteins
	mucus	protects the stomach from pepsin and HCl
pancreas	pancreatic amylase	continues the breakdown of carbohydrates into disaccharides
	bicarbonate ions	neutalize HCl from the stomach
	trypsinogen	when activated to trypsin, converts long-chain peptides into short-chain peptides
	lipase	breaks down fats to glycerol and fatty acids
small intestine	erepsin	completes the breakdown of proteins
	disaccharidases (e.g., maltase)	break down disaccharides (e.g., maltose) into monosaccharides
liver	bile	emulsifies fat
gallbladder	bile	stores and secretes concentrated bile from the liver
large intestine	mucus	helps movement of food waste

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

Tummy Bugs

Dr. Lora Hooper (Washington University in St. Louis, Missouri) is part of a team that recently discovered some stomach bugs responsible for turning on our genes to aid in digestion. These bacteria also produce a chemical that strengthens the stomach lining.

www.science.nelson.com GO

Section 8.4 Questions

1. What important physical change must fats undergo before chemical change can take place? Where and how does this physical change occur?
2. Explain the mechanism that triggers the release of bile salts.
3. Are nutrients absorbed passively or actively in the digestive tract? Where are carbohydrates, amino acids, and fats absorbed?
4. Sketch the two ways in which absorbed nutrients leave the intestine and get to body cells.
5. What are some signals that trigger the secretion of digestive fluids even in the absence of food in the stomach?
6. How do hormones help regulate digestion?
7. What are gallstones and what causes them?
8. What is jaundice? Why does this condition produce a yellowing of the skin?
9. What kind of dietary changes would a person without a gallbladder need to make? Why?
10. Research the latest techniques used in the removal of gallstones.

www.science.nelson.com GO

INVESTIGATION 8.1

Identifying Carbohydrates

Benedict's solution identifies reducing sugars, and iodine solution identifies starches. Iodine turns blue-black in the presence of starches. The Cu^{2+} ions in the Benedict's solution are converted to Cu^{+} ions in the presence of a reducing sugar. Not all sugars are reducing sugars. All monosaccharides are reducing sugars, but some disaccharides will not react with Benedict's solution.

Table 1 summarizes the quantitative results obtained when a reducing sugar reacts with Benedict's solution.

Table 1 Reducing Sugar and Benedict's Solution Reactions

Colour of Benedict's solution	Approximate % of sugar
blue	negative
light green	0.5–1.0
green to yellow	1.0–1.5
orange	1.5–2.0
red to red brown	> 2.0

Purpose

To identify reducing sugars qualitatively and quantitatively

Materials

safety goggles
lab apron
test-tube brushes
detergent
400 mL beaker
hot plate
thermometer or temperature probe
10 mL graduated cylinder
distilled H_2O
5 % fructose solution
5 % glucose (dextrose) solution
5 % sucrose solution
5 % maltose solution
5 % starch solution
9 test tubes
test-tube rack
Benedict's solution
wax pencil
test-tube clamp
5 medicine droppers
depression plates
iodine solution
solutions X, Y, and Z

Caution: The chemicals used are toxic and are irritants. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Procedure

Before you begin:

- Make sure that all the glassware is clean and well rinsed.
- Note the location of the eyewash station.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Part 1 : Reducing Sugars

Caution: Handle hot objects and their contents carefully to avoid burns.

1. Prepare a water bath by heating 300 mL of tap water in a 400 mL beaker until it reaches approximately 80 °C (**Figure 1**).

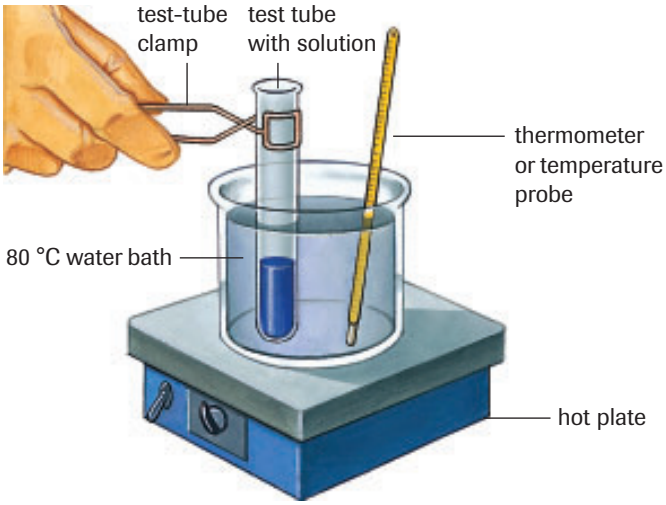


Figure 1
Heating a test tube in a hot water bath

2. Label the test tubes 1 to 6. Using a 10 mL graduated cylinder, measure 3 mL each of distilled water, fructose, glucose, maltose, sucrose, and starch solutions. Record which tube contains each solution. Pour each solution into a separate test tube. Clean and rinse the graduated cylinder after each solution. Add 1 mL of Benedict's solution to each of the test tubes.
3. Using a test-tube clamp, place each of the test tubes in the hot water bath (**Figure 1**). Observe for 6 min.

(a) Record any colour changes.

Part 2: Iodine Test

4. Using a medicine dropper, place a drop of water on a depression plate and add a drop of iodine.

(b) Record the colour of the solution.

5. Repeat the procedure, this time using drops of starch, glucose, maltose, and sucrose instead of water.

(c) Record the colour of the solutions. Which solutions indicated a positive test?

INVESTIGATION 8.1 *continued*

Part 3: Checking Unknown Solutions

6. Test the three unknown solutions for reducing sugars and starches. Design your own table, showing both qualitative and quantitative data.

(d) Record your data.

Analysis and Evaluation

(e) Why should the graduated cylinder be cleaned and rinsed after the measurement of each solution?

(f) Which test tube served as a control in the test for reducing sugars and starches?

(g) What laboratory data suggest that not all sugars are reducing sugars?

(h) A student decides to sabotage the laboratory results of his classmates and places a sugar cube into solution Z. Explain the effect of dissolving a sugar cube in the solution.

(i) A drop of iodine accidently falls on a piece of paper. Predict the colour change, if any, and provide an explanation for your prediction.

INVESTIGATION 8.2

Report Checklist

○ Purpose	○ Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Identifying Lipids and Proteins

In this investigation, you will use laboratory tests to identify lipids and proteins. You will then use these tests to establish which of these nutrients are present in an unknown sample. Read the investigation, then predict whether lipid, protein, or neither will be present in the unknown sample. Record your evidence, then complete the analysis and evaluation of the evidence.

Problem

Does the unknown sample contain lipids or proteins?

Materials

goggles
lab apron
5–10 test tubes
test-tube rack
test-tube brush
10 mL graduated cylinder
distilled water
waterproof marker
medicine droppers
rubber stoppers
detergent solution

For lipid tests:
Sudan IV indicator
unglazed brown paper (2 letter-sized sheets)
unknown solution
vegetable oil
skim milk
whipping cream

For protein test:
Biuret reagent
gelatin
egg albumin
skim milk
unknown solution

Sudan IV indicator is flammable, and both Sudan IV and Biuret reagent are toxic and can cause an itchy rash. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Procedure

Before you begin
- make sure that all the glassware is clean and well rinsed;
- note the location of the eyewash station; and
- put on your apron and goggles.

Part 1: Sudan IV Lipid Test

Sudan IV solution is an indicator of lipids, which are soluble in certain solvents. Lipids turn from a pink to a red colour. Polar compounds will not assume the pink colour of the Sudan IV indicator.

1. Using a 10 mL graduated cylinder, measure 3 mL each of distilled water, vegetable oil, skim milk, whipping cream, and the unknown solution.
2. Pour each solution into a separate labelled test tube. Clean and rinse the graduated cylinder after each solution.
3. Add 6 drops of Sudan IV indicator to each test tube.
4. Place stoppers on the test tubes and shake them vigorously for 2 min. Record the colour of the mixtures in a chart.

Part 2: Translucence Lipid Test

Lipids can be detected using unglazed brown paper. Because lipids allow the transmission of light through the brown paper, the test is often called the translucence test.

5. Draw one circle (10 cm diameter) on a piece of unglazed brown paper.
6. Place 1 drop of water in the circle and label the circle accordingly.
7. Using more sheets, draw a total of 7 more circles (10 cm diameter).
8. Place 1 drop of vegetable oil, skim milk, whipping cream, and unknown solution, each inside its own circle, labelling the circles as you do.
9. When the water has evaporated, hold both papers to the light and observe. In a chart, record whether or not the papers appear translucent.

Part 3: Protein Test

Proteins can be detected by means of the Biuret reagent test. Biuret reagent reacts with the peptide bonds that join amino acids together, producing colour changes from blue, indicating no protein, to pink (+), violet (++), and purple (+++). The + sign indicates the relative amounts of peptide bonds.

10. Measure 2 mL of water, gelatin, albumin, skim milk, and the unknown solution into separate labelled test tubes.
11. Add 2 mL of Biuret reagent to each of the test tubes, then tap the test tubes with your fingers to mix the contents. Record any colour changes in a chart.

Analysis

(a) Explain the advantage of using two separate tests for lipids.

(b) Which test tube served as a control in the test for lipids, and proteins?

(c) Summarize your group's findings about the nutrients present in your unknown solution. Be sure to include the identifying code.

Evaluation

(d) Why should the graduated cylinder be cleaned and rinsed after measuring out each solution?

(e) List possible sources of error, and indicate how you could improve your method.

Synthesis

(f) A student heats a test tube containing a large amount of protein and Biuret reagent. She notices a colour change from violet to blue. Explain why.

(g) Predict the results of a lipid test on samples of butter and margarine.

INVESTIGATION 8.3

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Factors That Affect the Catalase Enzyme Reaction

Organisms that live in oxygen-rich environments need the catalase enzyme. The catalase enzyme breaks down hydrogen peroxide (H_2O_2), a toxin that forms readily from H_2O and O_2. The reaction below describes the effect of the catalase enzyme.

The formation of hydrogen peroxide:

$$2\ H_2O + O_2 \rightarrow 2\ H_2O_2 \text{ (hydrogen peroxide)}$$

The effect of catalase:

$$2\ H_2O_2 \xrightarrow{\text{catalase}} 2\ H_2O + O_2$$

Purpose

To identify factors that affect the rate of enzyme-catalyzed reactions

Materials

safety goggles
lab apron
6 test tubes
waterproof marker
3 % hydrogen peroxide
tweezers or forceps
10 mL graduated cylinder
fine sand
scalpel
potato
chicken liver (fresh)
stirring rod
mortar and pestle

Caution: Hydrogen peroxide is a strong irritant. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Procedure

Part 1: Identifying the Enzyme

1. Label three clean test tubes 1, 2, and 3.
2. Using a 10 mL graduated cylinder, measure 2 mL of hydrogen peroxide and add it to test tube 1. Add a sprinkle of sand to the test tube and observe.
3. Add 2 mL of H_2O_2 to test tubes 2 and 3. Using the scalpel, remove a piece of potato approximately the size of a raisin and add it to test tube 2. Observe the reaction. Repeat the procedure once again, but this time add a piece of liver the size of a raisin to test tube 3. Observe the reaction.
4. Compare the reaction rates of the three test tubes. Use 0 to indicate little or no reaction, 1 to indicate slow, 2 to indicate moderate, 3 for fast, and 4 for very fast.

(a) Record your results.

Part 2: Factors That Affect Reaction Rates

5. Divide the hydrogen peroxide used in test tube 3 into two clean test tubes. Label one of the test tubes 4 and the other 5. Using tweezers or forceps, remove the liver from test tube 3 and divide it equally into test tubes 4 and 5. Add a second piece of liver to test tube 4 and observe. Add 1 mL of fresh hydrogen peroxide to test tube 5 and observe.

(b) Record your results.

6. Using a scalpel, cut another section of liver the size of a raisin. Add sand to a mortar and grind the liver into smaller pieces with the pestle. Remove the liver and place it in a clean test tube labelled 6. Add 2 mL of H_2O_2 and compare the reaction rate of the liver in test tube 6 with that of the uncrushed liver in test tube 3.

(c) Record your results.

Analysis and Evaluation

(d) In Part 1, which test tube served as the control?

(e) Account for the different reaction rates between the liver and potato.

(f) Explain the different reaction rates in test tubes 4 and 5.

(g) Why did the crushed liver in test tube 6 react differently from the uncrushed liver in test tube 3?

(h) Predict what would happen if the liver in test tube 3 were boiled before adding the H_2O_2. Give reasons for your prediction.

EXTENSION

Catalase and the Breakdown of Hydrogen Peroxide

Catalase plays an essential role in preventing hydrogen peroxide from reaching toxic levels. This Audio Clip explores hydrogen peroxide production in living organisms and how catalase is involved.

www.science.nelson.com GO

INVESTIGATION 8.4

Effect of pH and Temperature on Starch Digestion

Very little starch is broken down in the mouth. The low pH of the digestive fluids in the stomach halts digestion of carbohydrates such as starch until the carbohydrates leave the stomach and enter the small intestine.

Report Checklist

○ Purpose	○ Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

Purpose

To determine the pH and temperature at which amylase digests starch most quickly

Design

A cornstarch suspension will be mixed with an enzyme solution at different pH levels and at different temperatures to see which acidity level and which temperature result in the most complete breakdown of starch. The efficiency can be measured by how much sugar is produced. Benedict's reagent is used to indicate the presence of maltose, a disaccharide.

Benedict's reagent is toxic and can cause a rash. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eyes, rinse for at least 15 min and inform your teacher.

Materials

apron
goggles
10 test tubes
1 % cornstarch suspension
Benedict's reagent
ice cubes
two 250 mL beakers
ring clamp
25 mL graduated cylinder
eyedropper
rubber stoppers for test tubes
test-tube rack
5 % amylase solutions at pH 2.0, 7.0, and 12.0
hot plate
thermometers
utility stand
tap water
labelling materials
timer or watch
glass stirring rod

Procedure

Part 1: The Effect of pH on Starch Digestion

1. Create a table in your notebook or a spreadsheet and complete it as you perform each step in the activity.
2. Put on your apron and goggles.
3. Label 4 test tubes from 1 to 4. Set up a water bath as shown in **Figure 1**.

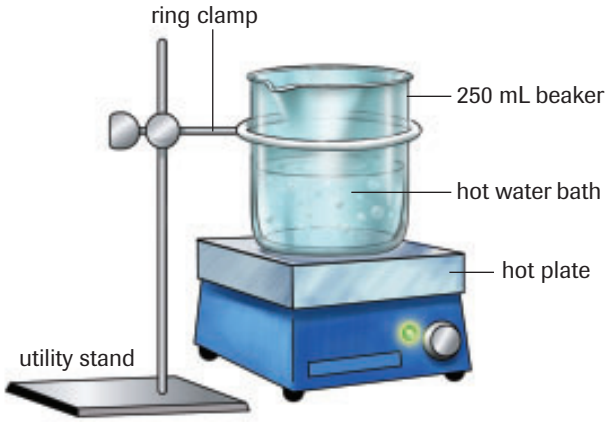


Figure 1
Water bath setup

4. Place 15 mL of the 1 % cornstarch suspension into each of the 4 test tubes.
5. Add 5 drops of the pH 2.0 amylase solution to test tube 2. Add 5 drops of the pH 7.0 amylase solution to test tube 3. Add 5 drops of the pH 12.0 amylase solution to test tube 4. Put a rubber stopper in each test tube and shake (**Figure 2**).

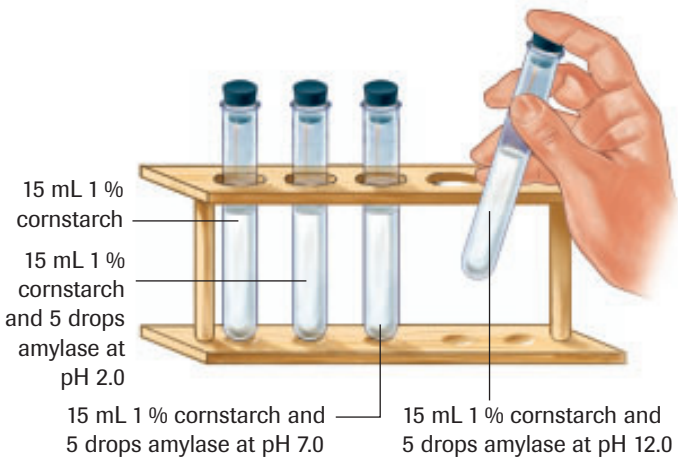


Figure 2
Test-tube setup

6. Let the test tubes sit for 20 min. Record your observations of each test tube. A colour change from blue to yellow to orange indicates maltose.

INVESTIGATION 8.4 *continued*

7. Add 5 mL of Benedict's reagent to each of the 4 test tubes and place them in the hot water bath at 100 °C. If you use the same cylinder as in Step 4, make sure to rinse and dry it first. Record your observations after 5 min. Do not let the test tubes sit in the hot water bath for more than 5 min.

Analysis

(a) In which test tube did starch digestion occur? How could you tell?

(b) What is the function of test tube 1?

(c) At what pH does amylase work best to digest starch?

Part 2: The Effect of Temperature on Starch Digestion

8. Create a table to record your data as you perform each step in the activity.
9. Label 6 test tubes from 1 to 6.
10. Place 15 mL of cornstarch suspension in each test tube.
11. Add 5 drops of amylase solution at pH 7.0 to test tubes 1, 3, and 5.
12. Place test tubes 1 and 2 in the hot water bath and heat until the cornstarch suspension reaches 50 °C. Do not heat the contents of the test tubes above 50 °C (**Figure 3**).

Figure 3
Heating the test tubes

13. Place test tubes 3 and 4 in a beaker of ice water. Let the cornstarch suspensions chill to a temperature between 0 °C and 5 °C. Stirring the water with a stirring rod may speed the cooling process.
14. Keep test tubes 5 and 6 at room temperature. Record the temperature of the cornstarch suspension.
15. Let all test tubes stand for 20 min. Maintain temperature conditions for the test tubes. Record your observations of each test tube.
16. Add 5 mL of Benedict's reagent to each test tube and place them in a hot water bath at 100 °C for 5 min. Record your observations in the table.

Analysis

(d) What would overheating have done to the contents of test tubes 1 and 2? What happens to the ability of the enzyme to convert starch to sugar at the tested temperatures?

(e) What was the function of test tubes 2, 4, and 6?

(f) At what temperature did amylase work best to convert starch to sugar?

Evaluation

(g) Identify possible sources of error, and indicate how you could improve the procedure.

Synthesis

(h) How are the conditions in the experiment similar to the conditions in the digestive system? How are they different?

Chapter 8 SUMMARY

Outcomes

Knowledge

- describe the chemical nature of carbohydrates, fats, and proteins and their enzymes, i.e., carbohydrases, proteases, and lipases (8.1)
- explain enzyme action and factors influencing that action, i.e., temperature, pH, substrate concentration, feedback inhibition, competitive inhibition (8.2)
- identify the principal structures of the digestive system, i.e., mouth, esophagus, stomach, sphincters, small and large intestines, liver, pancreas, gallbladder (8.3)
- describe the chemical and physical processing of matter through the digestive system into the bloodstream (8.4)

STS

- explain that the goal of technology is to provide solutions to practical problems by discussing and evaluating the role of food treatment to solve problems of food spoilage (8.1)
- explain that the products of technology are devices, systems, and processes that meet given needs; however, these products cannot solve all problems (8.1)

Skills

- ask questions and plan investigations (8.1, 8.2, 8.4)
- conduct investigations and gather and record data and information: by performing experiments to detect the presence of carbohydrates, proteins, and lipids (8.1) and; performing an experiment to investigate the influence of enzyme concentration, temperature, or pH on activity of enzymes (8.2, 8.4)
- analyze data and apply mathematical and conceptual models (8.2, 8.4)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

8.1

carbohydrate
polymer
monosaccharide
isomer
disaccharide
dehydration synthesis
hydrolysis
polysaccharide
starch
glycogen
cellulose
triglyceride
fat
oil
phospholipid
wax
protein
amino acid
peptide bond
polypeptide
essential amino acid
denaturation
coagulation

8.2

catalyst
enzyme
substrate
active site
cofactor
coenzyme
competitive inhibitor
feedback inhibition
precursor activity
allosteric activity

8.3

amylase
peristalsis
sphincter
mucus
pepsin
ulcer

8.4

duodenum
villi
microvilli
capillary
lacteal
secretin
enterokinase
trypsin
erepsin
lipase
bile salt
cholecystokinin
detoxify
gallstone
jaundice
cirrhosis
colon
gastrin
enterogastrone

MAKE a summary

1. In this chapter, you studied the importance of digestion in providing substances needed for energy and growth. Create a concept map that shows how the digestive system exchanges matter and energy with the environment. Check other concept maps to help you make your sketch clear.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 8
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Chapter 8 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

Use the following information to answer questions 1 and 2.

Figure 1 shows the substrates and product of an enzyme-catalyzed reaction.

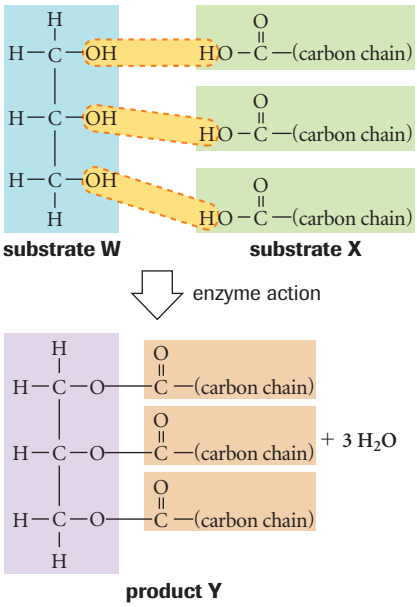


Figure 1

1. Identify the process and final product shown in the reaction.
   A. process is dehydration synthesis; final product (Y) is a triglyceride
   B. process is dehydration synthesis; final product (Y) is a polypeptide
   C. process is hydrolysis; final product (Y) is a triglyceride
   D. process is hydrolysis; final product (Y) is a polypeptide

2. Identify the initial substrates shown in the reaction.
   A. substrate W is glycerol; substrate X is a fatty acid
   B. substrate W is an amino acid; substrate X is a monosaccharide
   C. substrate W is a disaccharide; substrate X is a triglyceride
   D. substrate W is an amino acid; substrate X is glycerol

3. In chemical reactions, enzymes
   A. prevent energy loss
   B. lower the amount of energy required to initiate a chemical reaction
   C. increase the energy of the reactants
   D. decrease the energy of the final products

Use the following information to answer questions 4 and 5.

A student tested the activity of three enzymes in solutions at different pH values. The results are shown in **Figure 2**.

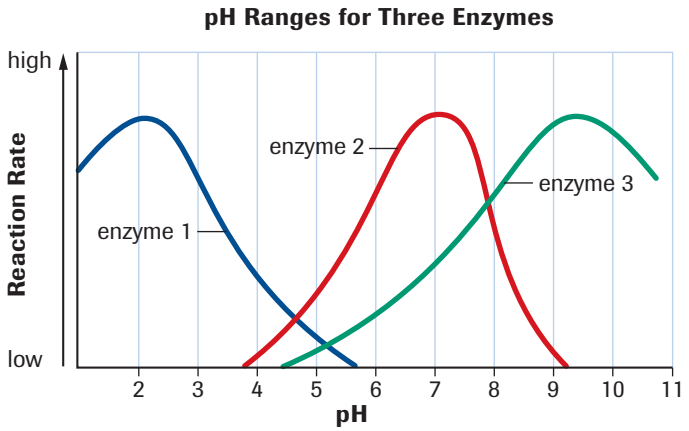


Figure 2

4. According to the data provided in the graph,
   A. enzyme 1 works best in an alkaline environment
   B. enzyme 2 works best in an acidic environment
   C. enzyme 3 works best in an alkaline environment
   D. enzymes 1 and 3 work equally well in acidic and alkaline environments

5. Select the optimal pH levels for enzymes 1, 2, and 3.
   A. 5; 7; 8
   B. 5.5; 4; 4.5
   C. 2; 7; 9.5
   D. 1; 9; 12

6. Identify why enzymes in the stomach do not digest the stomach itself.
   A. A protective mucous layer coats the stomach. Protein-digesting enzymes are stored in the inactive form.
   B. HCl is buffered to maintain a neutral pH. Fat-digesting enzymes are stored in the inactive form.
   C. A protective mucous layer coats the stomach. HCl is buffered to maintain a neutral pH.
   D. Fat-digesting enzymes are stored in the inactive form. Protein-digesting enzymes are stored in the inactive form.

Use the following information to answer questions 7 and 8.

Figure 3 shows organs of the digestive system.

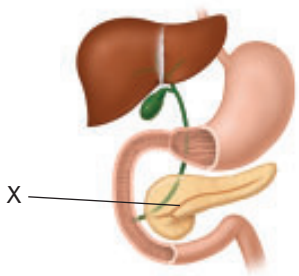


Figure 3

7. If the duct labelled X becomes blocked, the blockage would
- A. prevent pancreatic enzymes from entering the small intestine, and prevent bile salts from the liver from entering the small intestine
- B. prevent enzymes and food from the stomach from entering the small intestine, and prevent pancreatic enzymes from entering the large intestine
- C. prevent bile salts from the stomach from entering the small intestine, and prevent pancreatic enzymes from entering the small intestine
- D. prevent pancreatic enzymes from entering the large intestine, and prevent enzymes and food from the stomach from entering the small intestine

8. Identify the three food nutrients whose digestion would be impaired by the blockage of the duct.
- A. vitamins, cofactors, monosaccharides
- B. proteins, lipids, amino acids
- C. lipids, proteins, polysaccharides
- D. vitamins, amino acids, lipids

9. NR The following structures are found in the digestive system:
1. duodenum
2. pyloric sphincter
3. pharynx
4. rectum

List these structure in the order that food passes through them. (Record all four digits of your answer.)

Part 2

10. **Why** are phospholipids well suited for cell membranes?

11. DE Three different digestive fluids are placed in test tubes. The fluid placed in test tube 1 was extracted from the mouth. The fluids in test tubes 2 and 3 were extracted from what was believed to be the stomach. Five millilitres of olive oil are placed in each of the test tubes, along with a pH indicator. The initial colour of each of the solutions is red, indicating the presence of a slightly basic solution. The solution in test tube 3 turns clear after 10 min, but all of the other test tubes remain red. Write a unified response addressing the following aspects of this experiment.
- **Describe** the conclusions you would draw from the experiment.
- **Justify** each of the conclusions with the data provided. (*Hint:* Consider which substance is digested. What are the structural components?)

Use the following information to answer questions 12 to 14.

Data were collected from two different chemical reactions and are displayed in **Figure 4**.

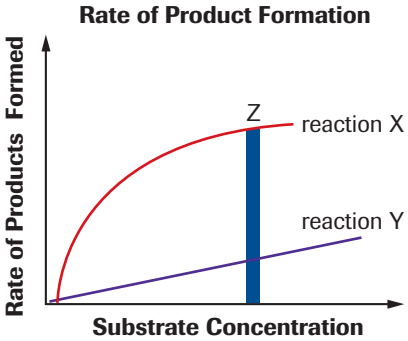


Figure 4

12. DE Identify the reaction that would most likely represent an enzyme-catalyzed reaction. **Explain** why.

13. DE **Why** does reaction X begin to level off at point Z?

14. DE **Predict** how the reaction curve would change if additional enzymes were added to both reaction X and reaction Y. **Explain** your prediction.

15. If a molecule similar to substrate "R" attaches itself to enzyme "r," **how** might the reaction in **Figure 5** be affected?

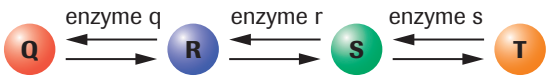


Figure 5

16. **Why** are pepsin and trypsin stored in inactive forms? Why can erepsins be stored in active forms?

17. Under certain abnormal conditions, the stomach does not secrete hydrochloric acid. **Identify** two functions that hydrochloric acid has in the digestive process and **describe** how the failure to secrete hydrochloric acid will affect these processes.

18. **Why** do individuals with gallstones experience problems digesting certain foods?

19. **Why** might individuals with an obstructed bile duct develop jaundice?

chapter

9 Respiratory System and Motor System

In this chapter

Top water polo players are superb athletes. The sport requires the strength of a rower, the endurance of a cross-country skier, and the scoring touch of a soccer player.

What separates athletes, like Waneek Horn-Miller, an Aboriginal athlete (**Figure 1**), from the majority of us? The exceptional physical fitness of an athlete depends largely on the superior ability to deliver oxygen and chemical fuels to the cells of the body. To sustain life-giving processes, all cells require nutrients and oxygen. Within the mitochondria inside the cells, oxygen is used during cellular respiration to convert organic chemicals to energy-rich ATP molecules that fuel cellular activities. In muscle cells, this energy is used for movement. Athletes also often have a superior respiratory system that provides an excellent exchange of air, ensuring plentiful oxygen for the cells.

Training can increase your ability to take in oxygen (through the respiratory system) and deliver it (through the circulatory system) to cells of the body. Training can also change the amount of muscle tissue in your body, while inactivity can cause the amount of muscle tissue to shrink.

However, not everyone who trains will become an elite athlete. Your inherited physiology may not allow for sufficient ventilation for you to excel in one sport, but may make you better suited for a different sport or activity.

In this chapter, you will first look at the respiratory system and how it works to deliver oxygen to the cells. Then, you will look at the muscles in the human motor system. The motor system supports all the systems of the human body, including the respiratory system and digestive system you read about in the previous chapter.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. What everyday experiences indicate the importance of providing oxygen to living cells?
2. Fitness can be measured by the body's ability to provide oxygen for the tissues of the body. Make a list of sports that you believe require great fitness. Make another list of sports that you believe require less fitness. Be prepared to justify your answers.
3. Predict how changes in oxygen level might affect muscle activity.

Career Connections:
Physiologist; Commercial Diver; Prosthetist and Orthotist

Figure 1
Waneek Horn-Miller led Canada's women's national water polo team in the 2000 Olympics in Sydney.

Exploration — Making a Model of the Chest Cavity

You can make a model of the human chest cavity. The balloons represent the lungs, and the latex glove represents the diaphragm.

Materials: empty 2-L plastic bottle, two balloons, Y-tube, rubber stopper with hole, latex surgical glove, elastic band, scissors

- Cut the bottom off the plastic bottle.
- Place the rubber stopper into the neck of the bottle.
- Place a balloon over the two ends of the Y-tube.
- Insert the Y-tube and balloons into the bottle. Twist the free end of the Y-tube into the hole in the rubber stopper.
- Stretch the glove over the bottom of the bottle and secure with the elastic band (**Figure 2**).

(a) Predict what will happen when you pull down and then push up on the glove. Test your prediction.

(b) Relate your observations to air pressure in the model.

(c) How could you improve the model?

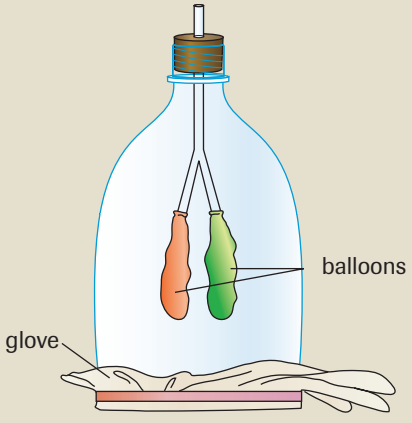


Figure 2
Model of chest cavity

9.1 The Importance of an Oxygen Delivery System

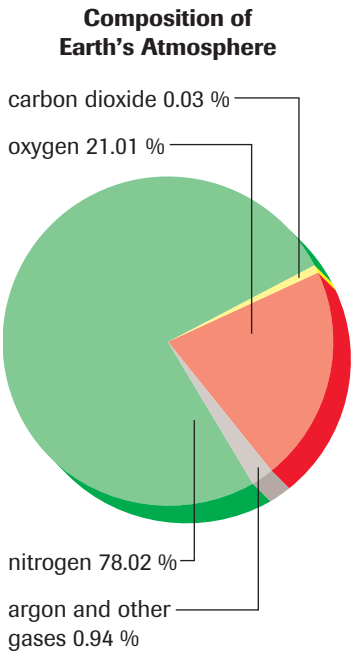


Figure 1
Nitrogen and oxygen are the two most abundant components in atmospheric air.

You live in a sea of air. Nitrogen, oxygen, carbon dioxide, and trace gases are taken into and expelled from your body with every breath. Earth's atmosphere is made up of approximately 78 % nitrogen and 21 % oxygen; the remaining gases, argon, carbon dioxide, and others, make up about 1 % (**Figure 1**). The second most abundant component, oxygen, is vital to life. Cells obtain energy through a chemical reaction called oxidation, in which organic compounds are broken down using oxygen. Although a small amount of energy can be obtained in anaerobic conditions (in the absence of oxygen), life processes in humans cannot be maintained without an adequate supply of oxygen.

Oxygen is so essential to the survival of humans that just a few minutes without it will result in death. By comparison, individuals can live for a number of days without water and several weeks without food. It has been estimated that an average adult utilizes 250 mL of oxygen every minute while resting. Oxygen consumption may increase up to 20 times with strenuous exercise.

Respiration and Breathing

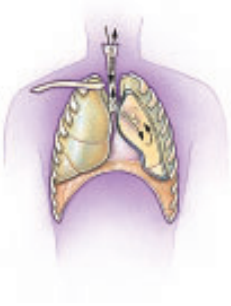
Breathing, or ventilation, involves the movement of air between the external environment and the body. The uptake of oxygen and the release of carbon dioxide by cells take place across a **respiratory membrane**.

The term **respiration** can be used to describe all processes that supply oxygen to the cells of the body for the breakdown of glucose and to describe the process by which carbon dioxide is transported to the lungs for exhalation. **Figure 2** shows the processes involved in respiration.

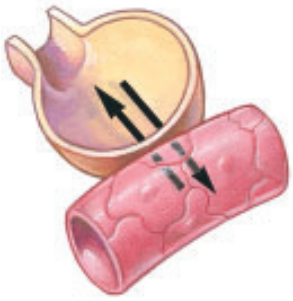
breathing the process of the exchange of air between the lungs and the environment, including inspiration and expiration

respiratory membrane the membrane where the diffusion of oxygen and other gases occurs between the living cells of the body and the external environment (the atmosphere or water)

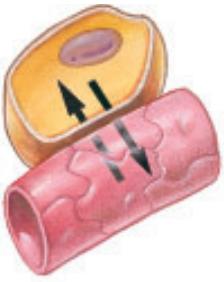
respiration all processes involved in the exchange of oxygen and carbon dioxide between cells and the environment, including breathing, gas exchange, and cellular respiration



Breathing is the process by which air enters and leaves the lungs.



External respiration takes place in the lungs and involves the exchange of O_2 and CO_2 molecules between the air and the blood.



Internal respiration takes place within the body and involves the exchange of O_2 and CO_2 molecules between the blood and tissue fluids.

Cellular respiration involves the production of ATP in body cells.

Figure 2
The processes of respiration

Oxygen is used for cellular respiration. Organelles called mitochondria are the centres of cellular respiration. During the process of cellular respiration, oxygen and sugar molecules react, resulting in the production of carbon dioxide and water. The energy released is used to maintain cell processes, such as growth, movement, and the creation of new molecules. The concentration of oxygen in cells is much lower than in their environment because cells continuously use oxygen for cellular respiration. Oxygen must be constantly replenished if a cell is to survive.

Practice

1. Why is oxygen so essential for survival?
2. Differentiate between breathing and cellular respiration.
3. What is the function of the respiratory membrane?

The Human Respiratory System

In humans, air enters the respiratory system either through the two nasal cavities or the mouth (**Figure 3**). Foreign particles are prevented from entering the lower respiratory tract by tiny hairs lining the nasal cavities that act as a filtering system. The nasal cavities warm and moisten incoming air and contain mucus, which traps foreign particles and keeps the cells lining the cavities moist.

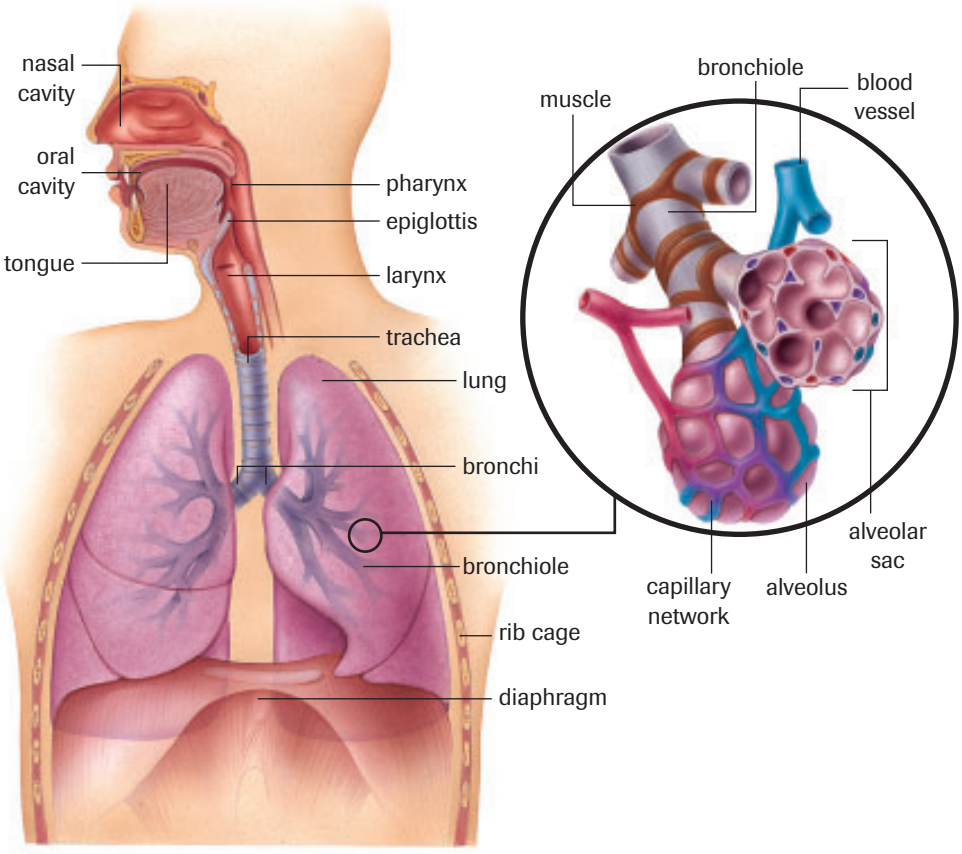


Figure 3
The human respiratory system

CAREER CONNECTION

Physiologist

Physiologists study the functions of cells, organs, tissues, and their interrelationships. There are many specializations in physiology, including exercise physiology, which studies how the body responds to exercise. Physiologists may work in a laboratory, or they may teach. What education is required to become a physiologist? Explore further to find examples of the type of work physiologists do.

www.science.nelson.com GO

EXTENSION

Structure of an Alveolus

This animation provides a cutaway view of an alveolus and takes a closer look at the respiratory membrane which separates the capillaries from the alveoli.

www.science.nelson.com GO

trachea the windpipe

cilia tiny hairlike structures found on some cells that sweep away foreign debris

epiglottis the structure that covers the glottis (opening of the trachea) during swallowing

The nasal cavities open into an air-filled channel at the back of the mouth called the pharynx. Two openings branch from the pharynx: the **trachea**, or windpipe, and the esophagus, which carries food to the stomach. Mucus-producing cells, some of which are ciliated, line the trachea. The mucus traps debris that may have escaped the filters in the nasal passage. This debris is swept by the **cilia** (singular: cilium) from the windpipe back into the pharynx. The wall of the trachea is supported by bands of cartilage, which keep the trachea open. An enlarged segment of cartilage (the larynx) supports the **epiglottis**, a flaplike structure that covers the glottis, or opening of the trachea, when food is being swallowed. When food is chewed, it is forced to the roof of the mouth and pushed backward. This motion initiates a reflex action, which closes the epiglottis, allowing food to enter the esophagus rather than the trachea. If you have ever taken in food or liquids too quickly, you will know how it feels to bypass this reflex. Food or liquid entering the trachea stimulates the cilia, and particles too large to be swept out of the respiratory tract are usually expelled by a second more powerful reflex: a violent cough.

larynx the voice box

Air from the pharynx enters the **larynx**, or voice box, located at the upper end of the trachea. The larynx contains two thin sheets of elastic ligaments that form the vocal cords (**Figure 4**). The vocal cords vibrate as air is forced past them. Different sounds are produced by a change in tension on the vocal cords. Your larynx is protected by thick cartilage commonly known as the Adam's apple. Following puberty, the cartilage and larynx increase in size and thickness, more so in males than females. In the same way as a larger drum creates a lower-pitched sound, the larger voice box in males produces a deeper sound. Rapid growth of the larynx creates problems for adolescent boys, who have difficulty controlling the pitch of their voices. Have you ever noticed how your voice lowers when you have a cold? Inflammation of the vocal cords causes swelling and produces lower-frequency vibrations. Should the infection become severe and result in a condition referred to as laryngitis, you may temporarily lose your voice.

DID YOU KNOW ?

What Are Hiccups?

All of us have had the hiccups at one time or another. An irritation of the diaphragm causes air to become trapped in the respiratory tract and the diaphragm experiences a muscular spasm. The hiccup sound is produced when air is taken in as the glottis closes.

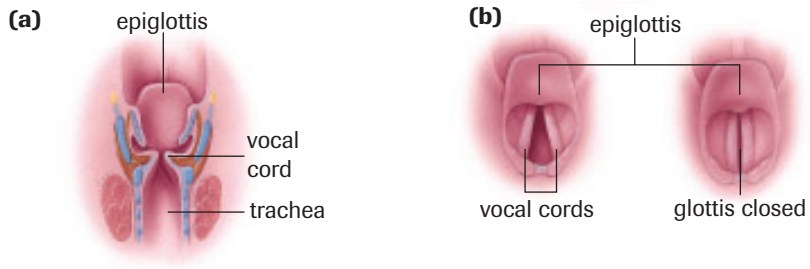


Figure 4
(a) Larynx, showing the vocal cords
(b) Position of the vocal cords when the glottis is open and closed during speech

bronchi the passages from the trachea to the left and right lung

bronchiole the smallest passageways of the respiratory tract

alveoli sacs of the lung in which gas exchange occurs

Inhaled air moves from the trachea into two **bronchi** (singular: bronchus), which, like the trachea, contain bands of cartilage. The bronchi carry air into the right and left lungs, where they branch into many smaller airways called **bronchioles**. Unlike the trachea and bronchi, the bronchioles do not contain cartilaginous bands. Muscles in the walls of the bronchioles can decrease their diameter. Any closing of the bronchioles increases the resistance of air movement and can produce a wheezing sound. Air moves from the bronchioles into tiny sacs called **alveoli** (singular: alveolus). Measuring between 0.1 and 0.2 µm (micrometres) in diameter, each alveolus is surrounded by capillaries. In the alveoli, gases diffuse between the air and blood according to concentration gradients. Oxygen and carbon dioxide both move from areas of higher concentration to areas of lower concentration. Therefore, oxygen moves from the air within alveoli into the capillaries, while carbon dioxide moves from the capillaries into the air in the alveoli. The

alveoli are composed of a single layer of cells, which permits rapid gas exchange. (However, the respiratory membrane is really three layers thick.) Each lung contains about 150 million alveoli. That provides enough surface area to cover half a tennis court, or about 40 times the surface area of the human body.

Have you ever tried to pull the cover slip from a microscope slide, only to discover that it seems to be fused to the slide? This phenomenon is caused by water molecules adhering to the glass. A similar problem faces the alveoli. During inhalation the alveoli appear bulb shaped, but during exhalation the tiny sacs collapse. The two membranes touch but are prevented from sticking together by a film of fat and protein called lipoprotein. This film lines the alveoli, allowing them to pop open during inhalation. Some newborn babies, especially premature babies, do not produce enough of the lipoprotein. Extreme force is required to overcome the surface tension created, and the baby experiences tremendous difficulty inhaling. This condition, referred to as respiratory distress syndrome, often results in death.

The outer surface of the lungs is surrounded by a thin membrane called the **pleural membrane**, which also lines the inner wall of the chest cavity. These two membranes adhere to each other. This adhesion is why the lungs expand and draw in air when the volume of the chest cavity is increased. The space between the pleural membranes is filled with a small amount of fluid that reduces the friction between the lungs and the chest cavity during inhalation. Pleurisy, the inflammation of the pleural membranes, is most often caused by a viral infection or pneumonia. The inflammation may result in friction of the membranes. Sometimes, fluid builds up between the pleural membranes. This buildup of fluid puts pressure on the lungs, making expiration (exhalation) easier, but inspiration (inhalation) much more difficult and painful.

EXTENSION

Maintaining the Alveolar Space

Why do the alveoli in your lungs stay expanded? This Audio Clip will explore the factors that prevent the alveoli from collapsing.

www.science.nelson.com GO

pleural membrane a thin membrane that surrounds the outer surface of the lungs and lines the inner wall of the chest cavity

Practice

4. Describe the function of cilia in the respiratory tract.
5. Explain how the functions of the trachea, esophagus, and epiglottis are related.

DID YOU KNOW?

Chest Wound First-Aid

If you are injured and have a hole in your chest, one first-aid technique is to place your hand over the wound to create a seal.

Breathing Movements

Pressure differences between the atmosphere and the chest, or thoracic, cavity determine the movement of air into and out of the lungs. Atmospheric pressure remains relatively constant, but the pressure in the chest cavity may vary. An understanding of breathing hinges on an understanding of gas pressures.

Gases move from an area of high pressure to an area of low pressure. Inspiration occurs when pressure inside the lungs is less than that of the atmosphere, and expiration occurs when pressure inside the lungs is greater than that of the atmosphere.

The **diaphragm**, a dome-shaped sheet of muscle that separates the thoracic, or chest, cavity from the abdominal cavity, can regulate the pressure in the chest cavity. During inspiration, the diaphragm muscle contracts, or shortens, pulling downward. The chest volume increases and pressure in the lungs decreases. The atmospheric pressure is now greater than the pressure in the chest cavity, and air moves into the lungs. During expiration, the diaphragm relaxes and returns to its dome shape due to the force exerted by the organs in the abdomen. The chest volume decreases and pressure increases. The pressure in the chest cavity is now greater than the atmospheric pressure, and air moves out of the lungs.

diaphragm a sheet of muscle that separates the organs of the thoracic cavity from those of the abdominal cavity

intercostal muscle a muscle that raises and lowers the rib cage

The diaphragm is assisted through the action of the intercostal muscles, which cause the ribs to move (**Figure 5**). Have you ever noticed how your ribs rise when you inhale? The ribs are hinged to the vertebral column, allowing them to move up and down. Bands of muscle, the **intercostal muscles**, are found between the ribs. A nerve stimulus causes the intercostal muscles to contract, pulling the ribs upward and outward. This increases the volume of the chest, lowers the pressure in the chest cavity, and air moves into the lungs. If the intercostals are not stimulated, the muscles relax and the rib cage falls. The chest wall pushes against the lungs with greater pressure, and air is forced out of the lungs.

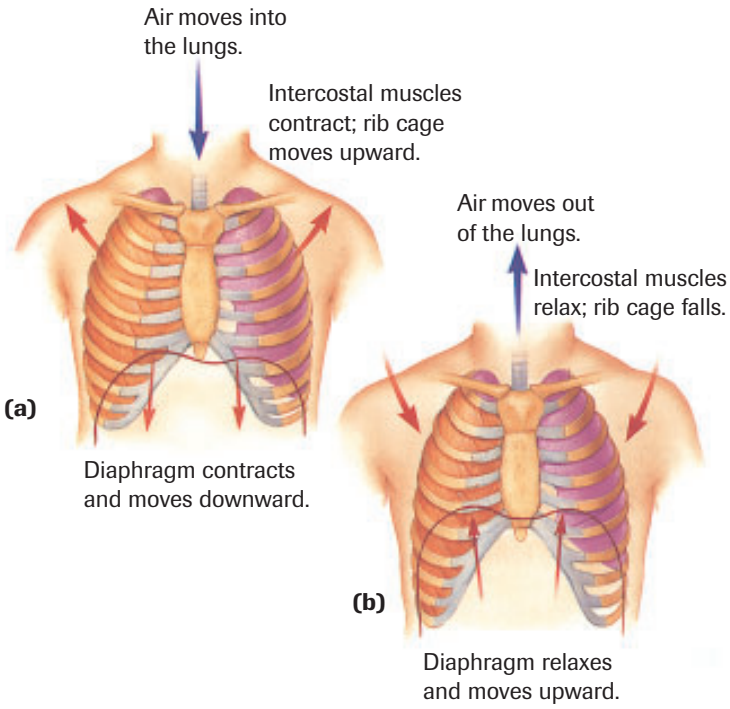


Figure 5
Changes in chest volume during inspiration and expiration
(a) The intercostal muscles contract and the rib cage pulls upward. Because pressure in the chest cavity is lower than the atmospheric pressure, air moves into the lungs.
(b) The intercostal muscles relax and the rib cage falls. Because pressure in the chest cavity is higher than the atmospheric pressure, air moves out of the lungs.

EXTENSION

Pressure-gradient Changes During Respiration

This animation discusses ventilation and examines the relationship between atmospheric and intra-alveolar pressure.

www.science.nelson.com GO

The importance of the pressure difference between the lungs and the atmosphere can be illustrated by a pneumothorax. A pneumothorax is an accumulation of air inside the chest in the space between the pleural membranes that line the lungs and the inner chest wall. The pressure of the air causes the lung to collapse. A traumatic pneumothorax results from a penetrating injury to the chest, such as a bullet hole or stab wound. When the diaphragm contracts and the rib cage rises, the pressure inside the chest cavity is reduced; however, air flows directly through the hole in the chest. To treat a pneumothorax, the air must be removed so that the lung can re-expand.

INVESTIGATION 9.1 *Introduction*

Determining Lung Capacity

The lungs of healthy, fit people tend to have a greater volume than the lungs of those who experience poor health or who are less fit. What is your lung capacity?

To perform this investigation, turn to page 305.

Report Checklist

● Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

SUMMARY The Importance of an Oxygen Delivery System

- The cells of the body obtain energy through oxidation. Thus, oxygen is essential to survival.
- Respiration includes all the processes involved in the exchange of oxygen and carbon dioxide between cells and the environment.
- Air enters the respiratory system through the nose or the mouth; then, it enters the pharynx, trachea, bronchi, and the bronchioles and alveoli in the lungs.
- In the alveoli, gases diffuse between air and blood according to concentration gradients. Oxygen moves into the alveoli and carbon dioxide moves out of the alveoli.
- The movement of gases into and out of the lungs is determined by the difference in pressure between the atmosphere and the thoracic cavity. Pressure in the thoracic cavity is regulated by the diaphragm. The diaphragm is assisted by the movement of the intercostal muscles.
  - During inspiration (inhalation), the intercostal muscles contract, the diaphragm flattens and pulls downward, the rib cage pulls up and outward, chest volume increases, pressure in the lungs decreases, and air moves into the lungs.
  - During expiration (exhalation), the intercostal muscles relax, the diaphragm becomes dome shaped, the rib cage falls, chest volume decreases, pressure in the lungs increases, and air moves out of the lungs.

Section 9.1 Questions

1. Describe the similarities and differences between the bronchi, bronchioles, and alveoli. How is each type of structure well suited for its purpose in the lungs?
2. Explain how and why oxygen and carbon dioxide diffuse between the alveoli and the air in the lungs.
3. Why does a throat infection cause your voice to produce lower-pitched sounds?
4. Trace the pathway of a breath of air from its point of entry to its diffusion in the lungs. Refer to the structures that the air passes by or through.
5. What is respiratory distress syndrome?
6. Why does the buildup of fluid in the chest cavity, as occurs with pleurisy, make exhalation easier but inhalation more difficult?
7. Describe the movements of the ribs and the diaphragm during inhalation and exhalation.
8. Bronchitis is an inflammation of the bronchi or bronchioles that causes them to swell. What problems would be caused as the airways swell and decrease in diameter?
9. Nicotine inhaled with cigarette smoke causes blood vessels to narrow. What problems would this cause for the cells of the body?

9.2 Gas Exchange and Transport

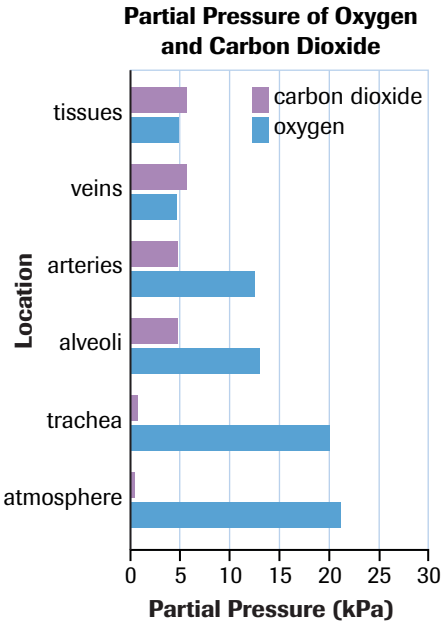


Figure 1
Partial pressures of oxygen and carbon dioxide

An understanding of gas exchange in the human body is tied to an understanding of the physical nature of gases. As mentioned in the previous section, gases diffuse from an area of higher pressure to an area of lower pressure.

Dalton's law of partial pressure states that each gas in a mixture exerts its own pressure, or partial pressure. The graph in **Figure 1** shows the partial pressures of oxygen and carbon dioxide in the body. Gases diffuse from an area of high partial pressure to an area of lower partial pressure. The highest partial pressure of oxygen is found in atmospheric air. Oxygen diffuses from the air (21.2 kPa) into the lungs (13.3 kPa for the alveoli).

The partial pressure of oxygen in the blood differs depending on location. Arteries carry blood away from the heart while veins carry it back to the heart. Arteries are connected to veins by capillaries, where gas exchange takes place and oxygen diffuses into the tissues. (Remember that energy is continuously released from nutrients by reactions within the cells that require oxygen. Oxygen will never accumulate in the cells.) Therefore, the largest change in the partial pressure of oxygen is observed as oxygen travels from the arteries (12.6 kPa) into the capillaries (5.3 kPa).

Carbon dioxide, the product of cellular respiration, follows an opposite pattern. Partial pressure of carbon dioxide is highest in the tissues and venous blood. The partial pressure of nitrogen, although not shown in the graph, remains relatively constant. Atmospheric nitrogen is not involved in cellular respiration.

Practice

1. (a) Where is the partial pressure of oxygen the highest? the lowest?
   (b) How is this related to the diffusion of oxygen into the tissues?
2. Where is the partial pressure of carbon dioxide the highest? the lowest?

Oxygen Transport

Oxygen (O_2) moves from the atmosphere, the area of highest partial pressure, to the alveoli. It then diffuses from the alveoli into the blood and dissolves in the plasma. Oxygen is not very soluble in blood—about 0.3 mL of oxygen per 100 mL of blood. However, even at rest, the body requires approximately 10 times that amount of oxygen. **Hemoglobin** greatly increases the oxygen-carrying capacity of the blood. The hemoglobin molecule consists of four polypeptides that are composed of heme, the iron-containing pigment, and globin, the protein component. Each heme group contains an iron atom, which binds with oxygen. When oxygen dissolves into the plasma, hemoglobin forms a weak bond with the oxygen molecule to form **oxyhemoglobin**. Once oxyhemoglobin is formed, other oxygen molecules can dissolve in the plasma. With hemoglobin, the blood can carry 20 mL of oxygen per 100 mL of blood, almost a 70-fold increase.

The amount of oxygen that combines with hemoglobin is dependent on partial pressure. The partial pressure in the lungs is approximately 13.3 kPa. Thus, blood leaving the lungs is still nearly saturated with oxygen. As blood enters the capillaries, the partial pressure drops to about 5.3 kPa. This drop in partial pressure causes the dissociation, or split, of oxygen from the hemoglobin, and oxygen diffuses into the tissues. **Figure 2** (on the next page) shows an oxygen–hemoglobin dissociation curve. You will notice that very little oxygen is released from the hemoglobin until the partial pressure of oxygen reaches 5.3 kPa. This ensures that most of the oxygen remains bound to the hemoglobin

hemoglobin the oxygen-carrying molecule in red blood cells

oxyhemoglobin hemoglobin that is bound to oxygen

EXTENSION

Partial Pressure Gradients
Oxygen and carbon dioxide exchange occurs across capillaries and is driven by partial pressure gradients. This animation reviews the partial pressures of CO_2 and O_2 in different regions of the body.

www.science.nelson.com GO

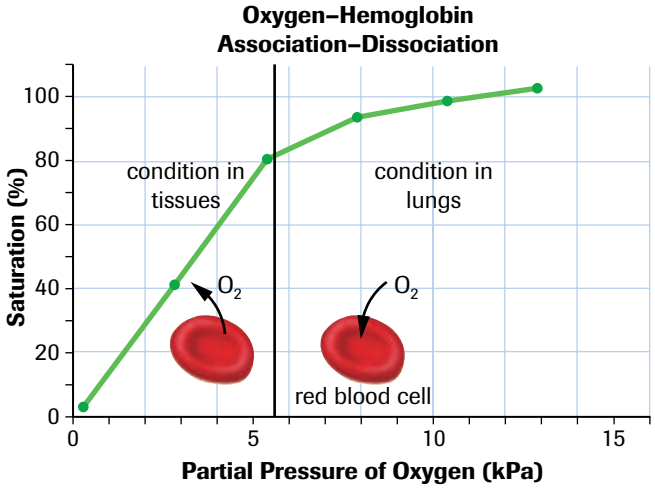


Figure 2
Oxygen–hemoglobin dissociation curve

until it gets to the tissue capillaries. Also note that venous blood still carries a rich supply of oxygen. Approximately 70 % of the hemoglobin is still saturated when blood returns to the heart.

EXTENSION

The Oxyhemoglobin Dissociation Curve

This Audio Clip analyzes the oxyhemoglobin dissociation curve and its correlation to hemoglobin's changing affinity for oxygen, as it gains and loses oxygen molecules.

www.science.nelson.com GO

Carbon Dioxide Transport

Carbon dioxide (CO_2) is about 20 times more soluble than oxygen. About 9 % of the carbon dioxide produced by the tissues of the body is carried in the plasma. Approximately 27 % of the body's carbon dioxide combines with hemoglobin to form carbaminohemoglobin. The remaining 64 % of the body's carbon dioxide combines with water from the plasma to form carbonic acid (H_2CO_3):

$$CO_2 + H_2O \rightarrow H_2CO_3$$

An enzyme called **carbonic anhydrase** increases the rate of this chemical reaction by about 250 times. The rapid conversion of free carbon dioxide into carbonic acid decreases the concentration of carbon dioxide in the plasma. This maintains a low partial pressure of carbon dioxide, ensuring that carbon dioxide continues to diffuse into the blood (**Figure 3**).

carbonic anhydrase an enzyme found in red blood cells that speeds the conversion of carbon dioxide and water to carbonic acid

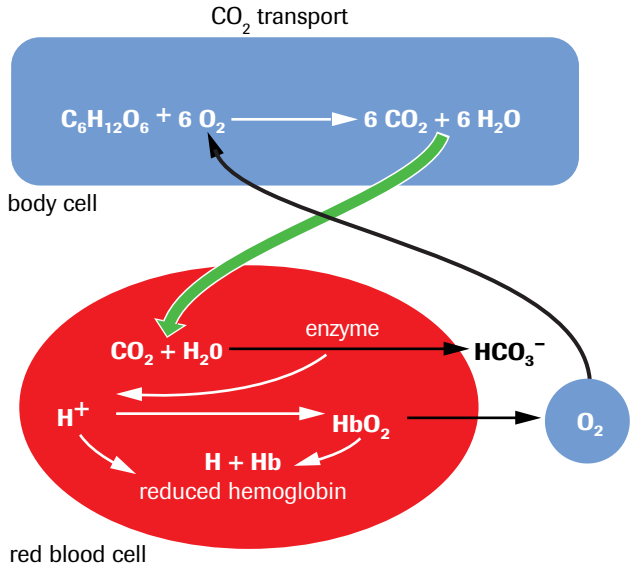


Figure 3
Under the influence of carbonic anhydrase, an enzyme found in red blood cells, carbon dioxide combines with water to form carbonic acid (H_2CO_3), which then, dissociates into H^+ and HCO_3^- ions.

CHEMISTRY CONNECTION

Acids and Bases

When carbon dioxide dissolves in the water in plasma, it forms carbonic acid. You can learn more about acids and bases in your chemistry course.

www.science.nelson.com GO

The formation of acids, such as carbonic acid, can create problems. Because acids can change the pH of the blood and eventually bring about death, they must be buffered. This is where the second function of hemoglobin comes into effect. Being unstable, the carbonic acid dissociates into bicarbonate ions (HCO_3^-) and hydrogen ions (H^+):

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

The hydrogen ions help dislodge oxygen from the hemoglobin, and then combine with the hemoglobin to form reduced hemoglobin. When hemoglobin combines with the hydrogen ions, it is removing H^+ from the solution; that is, the hemoglobin is acting as a **buffer**. Meanwhile, the bicarbonate ions are transported into the plasma. Oxygen is released from its binding site and is now free to move into the body cells.

buffer a substance capable of neutralizing acids and bases, thus maintaining the original pH of the solution

Once the venous blood reaches the lungs, oxygen dislodges the hydrogen ions from the hemoglobin binding sites. Free hydrogen and bicarbonate ions combine to form carbon dioxide and water:

$$H^+ + HCO_3^- \rightarrow H_2O + CO_2$$

The highly concentrated carbon dioxide diffuses from the blood into the alveoli and is eventually eliminated during exhalation.

DID YOU KNOW ?

Andean Aboriginals

There is less air at high altitudes, than at sea level, so a person inhales fewer oxygen molecules with each breath. Andean highlanders, the Quechua and Aymara, have adapted to living high in the mountains. Their red blood cells contain more hemoglobin than people living at sea level. Although both groups breathe at the same rate, the Andean highlanders deliver oxygen to their cells more efficiently.

Maintaining Gas Levels

A variety of mechanisms exist to help maintain appropriate levels of oxygen and carbon dioxide. For example, a chemical receptor helps ensure that carbon dioxide, the waste product of cellular respiration, does not accumulate. During exercise, cellular respiration increases, causing carbon dioxide levels to increase. This stimulates chemical receptors in the brainstem. The activated nerve cells from the brain carry impulses to muscles that increase breathing movements. Increased breathing movements help flush excess carbon dioxide from the body. Other chemical receptors in the walls of the carotid artery are able to detect low levels of oxygen in the blood. A nerve is stimulated and a message is sent to the brain. The brain relays the information, by way of another nerve, to the muscles that control breathing. Thus, a system of "turning on" and "turning off" mechanisms is used to help maintain equilibrium.

EXPLORE an issue

Using Erythropoietin to Increase Oxygen-Carrying Capacity

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

In the past, drug use in sports was most often linked to power sports such as weightlifting and sprinting. Steroids increase muscle mass and strength.

In the late 1980s, endurance athletes turned to erythropoietin (EPO), a naturally occurring hormone that promotes the production of red blood cells in the bone marrow. By increasing red blood cell production, the oxygen-carrying capacity of the blood is improved and more oxygen can be delivered to the tissues. You know the saying about "too much of a good thing"? In the case of EPO, the problem is too many red blood cells in the blood. Although oxygen delivery is improved, the blood becomes thicker and more difficult to move through the blood vessels. This, in turn, can cause an increased incidence of stroke, heart attack, and heart failure. In 1988, EPO was linked to the death of at least 20 cyclists.

Despite the adverse effects, athletes continue to use EPO for many different sports, and deaths associated with the hormone continue. In the 2002 Olympic Games, Canadian cross-country skier Beckie Scott (**Figure 4**, next page) had her bronze medal elevated to gold when both the gold and silver medallists in the event tested positive for EPO.

Figure 4
Beckie Scott's bronze medal was elevated to a gold medal in cross-country skiing because the two other winning athletes had used performance-enhancing drugs.

Statement
Although individual athletes are banned for drug use in Olympic sports, it continues to be a problem. The ban should be extended to all athletes from that country in that particular sport for a defined number of years.

1. Form a group and research the issue.

www.science.nelson.com GO

2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statement. Should an entire country be banned from a sport for the actions of one individual?
5. Defend your position in the debate.

SUMMARY Gas Exchange and Transport

- Gases diffuse from an area of higher pressure to an area of lower pressure.
- The partial pressure of oxygen is highest in the atmosphere and lowest in the veins and tissues.
  - Oxygen diffuses from the atmosphere into alveoli and then, into the blood.
  - Hemoglobin bonds to oxygen molecules to form oxyhemoglobin. Hemoglobin and oxygen dissociate in the capillaries, and oxygen diffuses into the tissues.
- The partial pressure of carbon dioxide is highest in the tissues and veins and lowest in the atmosphere.
  - Some carbon dioxide combines with water from plasma to form carbonic acid; this decreases the carbon dioxide concentration in the blood, ensuring that carbon dioxide continues to diffuse into the blood.
  - Carbonic acid dissociates into HCO_3^- and H^+. Hemoglobin combines with H^+, releasing oxygen and acting as a buffer.
  - In the lungs, H^+ and HCO_3^- combine to form carbon dioxide and water. Carbon dioxide is highly concentrated; it diffuses from the blood into alveoli and is eliminated through exhalation.
- To help maintain equilibrium, chemical receptors detect a change in gas levels and send a message to increase or decrease breathing rate.

CAREER CONNECTION

Commercial Diver
Commercial divers need to know about the partial pressure of gases. These divers work in constructing or inspecting underwater machinery, including offshore oil and gas rigs. Breathing atmospheric concentrations of oxygen can cause problems when commercial divers do deep dives. Learn how someone would become a commercial diver, and explore the types of work done.

www.science.nelson.com GO

Section 9.2 Questions

1. How does partial pressure affect the movement of oxygen from the alveoli to the blood?
2. How is carbon dioxide transported in the blood?
3. Describe the importance of hemoglobin as a buffer.
4. Trace the pathway of an oxygen molecule from the atmosphere to its combination with a hemoglobin molecule.
5. What is the function of carbonic anhydrase?

9.3 Regulation of Breathing Movements

chemoreceptor a specialized nerve receptor that is sensitive to specific chemicals

Breathing movements are controlled by nerves from the medulla oblongata in the brain (**Figure 1**). Information about the accumulation of carbon dioxide (CO_2) and acids and the need for oxygen is detected by **chemoreceptors**. Two different types of receptors are oxygen chemoreceptors and carbon dioxide, or acid, chemoreceptors. The carbon dioxide receptors are the most sensitive and are the main regulators of breathing movements.

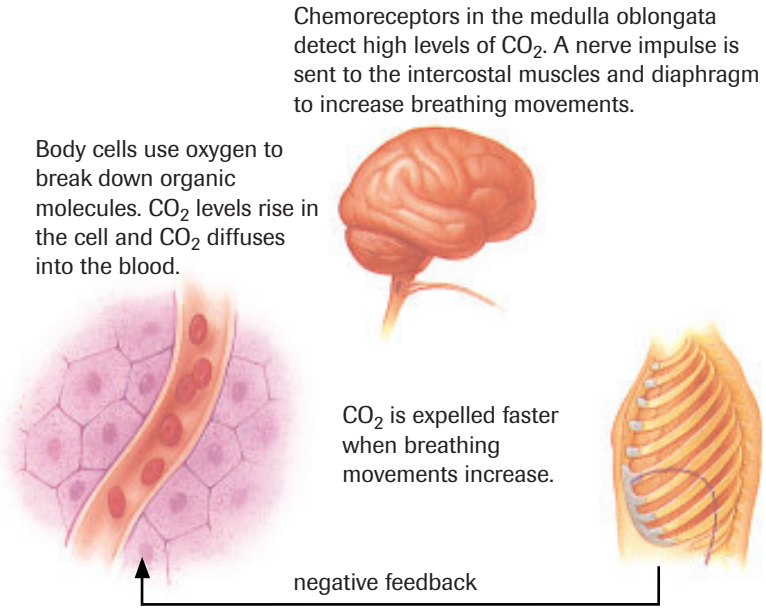


Figure 1
Carbon dioxide control

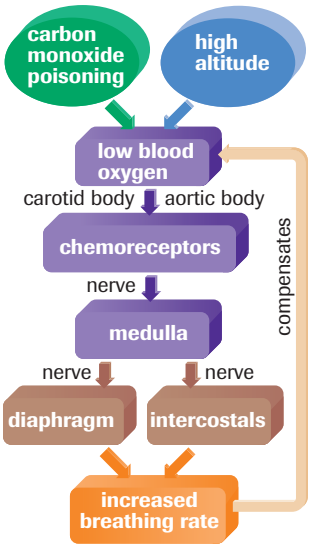


Figure 2
Low blood oxygen levels are detected by special oxygen chemoreceptors in the aorta and carotid arteries.

CO_2 dissolves in the blood and forms an acid. Should the CO_2 accumulate, special chemoreceptors in the medulla oblongata become activated. Once activated, the medulla oblongata relays messages to the intercostal muscles and diaphragm to increase breathing movements. The acceleration of the breathing rate decreases the levels of CO_2 in the blood. Once CO_2 levels fall, the chemoreceptors become inactive, and the breathing rate returns to normal.

A second monitoring system, which relies on chemoreceptors sensitive to oxygen, is found in the carotid and aortic arteries (**Figure 2**). Referred to as the *carotid* and *aortic bodies*, these specialized receptors are primarily responsible for detecting low levels of oxygen. When stimulated, the oxygen receptors send a nerve impulse to the medulla oblongata. Once activated, the medulla sends nerve impulses to the intercostal muscles and diaphragm to increase breathing movements. Increased ventilation increases blood oxygen, thereby, compensating for low levels of oxygen. A secondary function of these bodies is to detect high blood CO_2 or high levels of acidity, although the medulla oblongata is the more sensitive receptor of CO_2.

Because the CO_2 receptors are more sensitive to changes in blood chemistry, the oxygen receptors act as a backup system. The oxygen receptors are only called into action when oxygen levels fall and CO_2 levels remain within the normal range. For example, when you hold your breath, CO_2 levels rise and oxygen levels drop—the high CO_2 levels would initiate increased breathing movements. However, the situation differs at high altitudes, where the air is thinner and fewer oxygen molecules are found. Since low oxygen levels are not accompanied by higher CO_2 levels, the

chemoreceptors in the carotid and aortic bodies stimulate breathing movements. Increased ventilation helps establish normal blood oxygen levels.

Response of the Respiratory System to Exercise

The ventilation of the alveoli can increase up to 20 times with heavy exercise to keep up with the demands for increased oxygenation and the need to expel CO_2. Although all the factors that cause increased ventilation of the lungs are not known, three factors play an important role: decreased O_2, increased CO_2, and increased H^+. **Figure 3** outlines some of the body's responses to exercise.

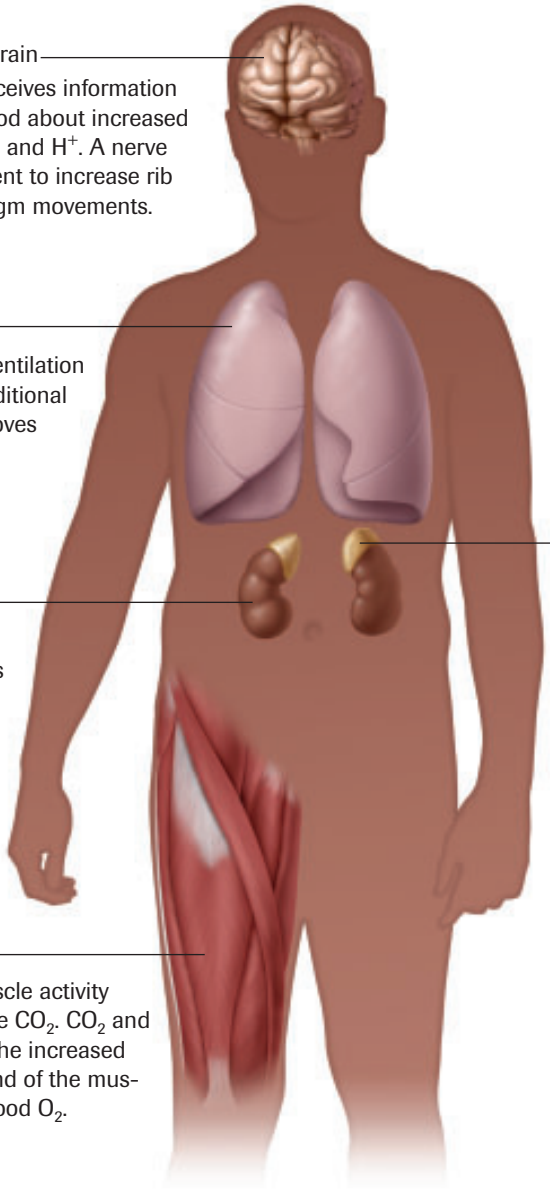


Figure 3
The body's response to exercise

DID YOU KNOW?

Carbon Monoxide Poisoning

Carbon monoxide (CO) poisoning is another example of how falling blood oxygen levels stimulate increased breathing rate. Carbon monoxide competes with oxygen for the active site on the hemoglobin molecule. Unfortunately, CO gains faster access. As more hemoglobin molecules bind with CO, less oxygen is carried to the tissues. The carbon dioxide level tends not to increase. Eventually, the low oxygen level is detected by the chemoreceptors and breathing movements increase.

INVESTIGATION 9.2 *Introduction*

The Effects of Exercise on Lung Volume

Different factors can affect the volume of a single breath. In this investigation, you will design and carry out an experiment on how exercise affects lung volume.

To perform this investigation, turn to page 306.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Figure 4
Dr. Malcolm King

bronchitis an inflammation of the bronchial tubes

emphysema a respiratory disorder characterized by an overinflation of the alveoli

EXTENSION

CBC radioONE

QUIRKS & QUARKS

Pillow Fungus

Professor Ashley Woodcock describes her discovery of an entire ecosystem that exists in our pillows. This ecosystem includes multiple species of potentially allergenic fungus, bacteria and dust mites. While this is definitely a problem for individuals with respiratory ailments such as asthma and allergies, research continues to see if it is problem for others without any previous allergies.

www.science.nelson.com GO

WEB Activity

Canadian Achiever—Dr. Malcolm King

Dr. Malcolm King (**Figure 4**), a Professor in the Department of Medicine at the University of Alberta, began his career as a chemist, studying polymers. He now applies this knowledge to studies of the role of mucus from the lungs in two serious disorders of the respiratory system, cystic fibrosis and chronic obstructive lung disease. Dr. King is a leader in his field, having published over 160 papers, and is the recipient of many awards. A member of the Mississaugas of the New Credit First Nation in Southern Ontario, Dr. King is also interested in training Aboriginal students in medicine, and in examining traditional medicines used to treat respiratory diseases. Conduct additional research on Dr. Malcolm King, his research, and his leadership role in science and Aboriginal issues.

www.science.nelson.com GO

Disorders of the Respiratory System

All respiratory disorders share one common characteristic: they all decrease oxygen delivery to the tissues.

Bronchitis

Bacterial or viral infections, as well as reactions to environmental chemicals, can cause a variety of respiratory problems. **Bronchitis** is an ailment characterized by narrowing of the air passages and inflammation of the mucous lining in the bronchial tubes. This leads to excess production of mucus, tissue swelling, a narrowing of the air passages, and decreased air movement through the bronchi. The condition becomes even more serious in the bronchioles. Unlike the trachea and the bronchi, the bronchioles are not supported by bands of cartilage to help keep them open.

Emphysema

In **emphysema**, the walls of the alveoli become inflamed. Over time, this destroys the air sacs, causing them to lose their elasticity, stretch, and eventually rupture. As a result, it becomes difficult to exhale and air becomes trapped in the lungs. The fact that there are fewer alveoli means there is less surface area for gas exchange which, in turn, leads to decreased oxygen levels. The most common cause of emphysema is smoking. Emphysema is associated with chronic bronchitis. Together they are known as chronic obstructive pulmonary disease (COPD). Like bronchitis, COPD involves an increased resistance to airflow through the bronchioles. Although air flows into the alveoli fairly easily, the decreased diameter of the bronchioles creates resistance to the movement of air out of the lungs and exhalation becomes laboured. In the body's attempt to maintain equilibrium, the breathing rate increases. The circulatory system adjusts by increasing the heart rate.

Practice

1. What is bronchitis? What are its effects on the respiratory system?
2. Describe the pressure changes that occur in the lungs during breathing for someone with emphysema.

WEB Activity

Simulation—Asthma

Bronchial asthma is associated with the inflammation of the bronchioles. In asthma, greater effort is required to exhale than to inhale. The imbalance between the amount of air entering the lungs and the amount of air leaving the lungs must be met by increasing the exertion of expiration. In this activity, you will view the events that occur in the lung during an asthma attack. Why does the imbalance in the amount of air entering and leaving the lungs occur?

bronchial asthma a respiratory disorder characterized by reversible narrowing of the bronchial passages

www.science.nelson.com GO

Case Study

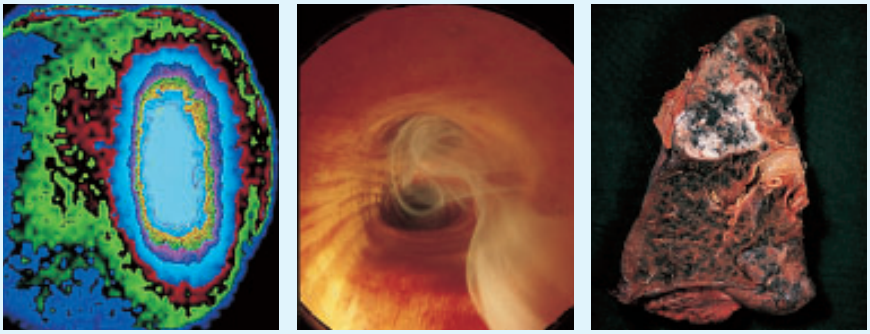
Smoking and Lung Cancer

More Canadian men and women die from lung cancer than from any other form of the disease (**Figure 5**). As in other cancers, there is uncontrolled growth of cells. The solid mass of cancer cells in the lungs greatly decreases the surface area for diffusion. Tumours may actually block bronchioles, thereby reducing airflow to the lungs and potentially causing the lung to collapse.

In contrast to skin cancers, lung cancers are almost always fatal—the five-year survival rate is not much better than 15 %. Lung cancer is the second most common cancer, yet it is one of the most preventable. Prior to the use of tobacco, lung cancer was relatively rare. Smoking increased in popularity in the 1920s and it was usually men who smoked. In the 1940s, lung cancer began to increase at a dramatic rate, becoming the most common cancer in men. As more and more women began to smoke, lung cancer cases among women also rose significantly. In 1995, lung cancer surpassed breast cancer as the number one cancer killer of women. The World Health Organization estimates that, every year, 4 million people die as a result of smoking tobacco. This figure is expected to rise to 10 million by 2010.

When smokers quit, their risk of developing lung cancer lessens over time (**Figure 6**, next page). Also, as with most cancers, if lung cancer is detected at an early stage, there is a greater chance of survival. Some common symptoms include an unusual cough, sputum containing blood, hoarseness, and shortness of breath which is noticeable during physical activity. **Figure 7**, on the next page, shows how the bronchioles and alveoli of a smoker appear in comparison to those of a nonsmoker.

How does smoking lead to lung cancer? Cancer usually begins in the bronchi or bronchioles. Components of cigarette smoke contribute to the development of cancerous tumours. The four diagrams in **Figure 8**, on the next page, show the development and progression of lung cancer. Cigarette smoke travels through the bronchioles and irritates the cells. Special



(a) (b) (c)

Figure 5
(a) A lung scan reveals cancer of the lung. The colours in the healthy lung indicate normal ventilation. On the left side, the absence of the normal colours and the presence of the purple colour indicate a nonfunctioning lung.
(b) Smoke descends toward the lungs.
(c) Postmortem specimen of a human lung shows a cancerous tumour of the upper lobe as a black and white area. The entire lung is permeated with black, tarry deposits, suggesting a history of heavy smoking.

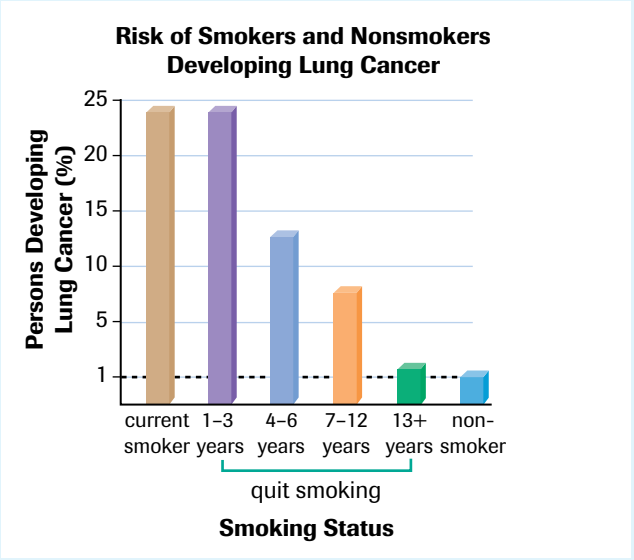


Figure 6
When smokers stop smoking, their risk of lung cancer decreases with time.

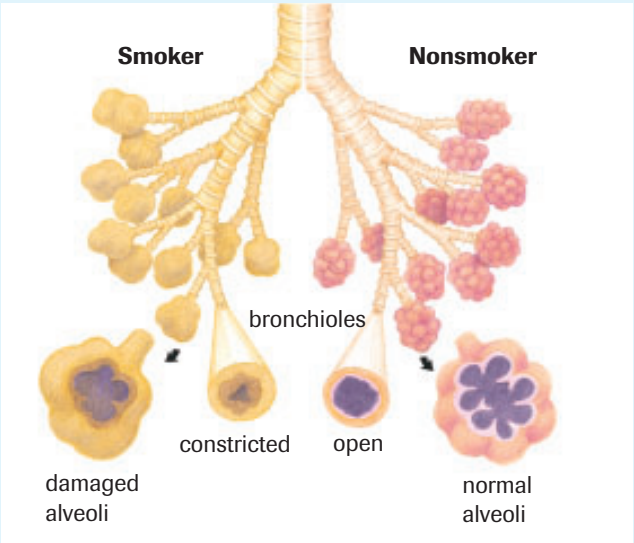


Figure 7
A comparison of the bronchioles and alveoli of a smoker and a nonsmoker

cells produce mucus, which is designed to trap foreign particles. Compare the mucous layers in **Figures 8 (a)** and **(c)**. Ciliated cells line the bronchioles. Cilia sweep away the debris trapped by the mucus. Unfortunately, the tar found in cigarette smoke slows the action of the cilia. The sludgelike tar becomes trapped in the mucus. **Figure 8 (b)** shows the beginning of a cancerous tumour and **Figure 8 (c)** shows how the tumour advances. Note the location of the tumour and its growth. While the tumour is still walled in by the basal membrane in **Figure 8 (c)**, it has broken through the membrane in **Figure 8 (d)**.

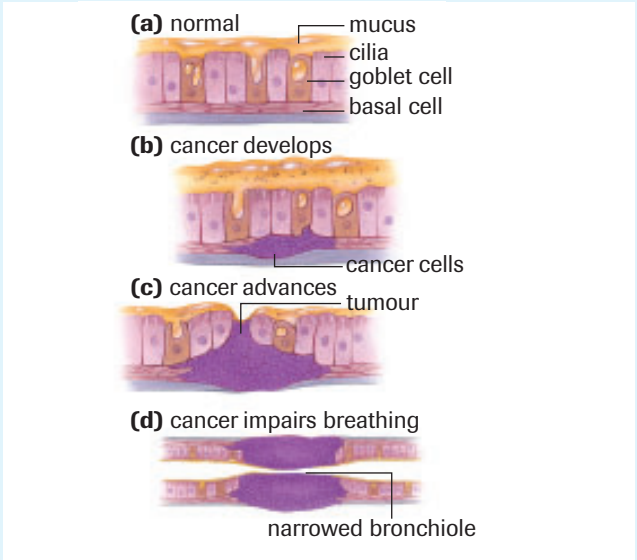


Figure 8
Development of a tumour in the tissues of the bronchiole walls

Case Study Questions

1. How does cigarette smoke affect the mucous layer in the bronchioles?
2. Why does the buildup of tar in the bronchioles limit airflow?
3. In what area does a tumour begin to develop?
4. Why has the mucous layer in **Figure 8 (c)** decreased in size?
5. Cancer cells often travel in lymph vessels to other parts of the body, where they continue to divide. Why does this characteristic make cancer especially dangerous?
6. At what stage might cells break away and cause a tumour in another area of the body?
7. The Canadian tobacco industry employs thousands of full-time and part-time workers. Thousands of seasonal workers are also employed, and thousands of wholesale and retail workers profit from the sale of tobacco products. The government also raises money through tobacco taxation, and the tobacco industry's contributions to the Canadian economy are large. However, the costs associated with smoking are also large. Do you think that the government should ban the sale of tobacco products? Defend your position.

www.science.nelson.com GO

WEB Activity

Web Quest—Smokeless Tobacco

Most people agree that smoking is bad for your health. This Web Quest takes a look at an alternative to smoking—smokeless tobacco! What are the issues surrounding the use of this drug? Is it really an acceptable alternative or is it just as unhealthy? Explore this issue and compose a letter outlining whether you agree or disagree with using federal money to support research on smokeless tobacco.

www.science.nelson.com GO

SUMMARY *Regulation of Breathing Movements*

- Breathing movements are regulated by the medulla and by chemoreceptors in the carotid artery and the aorta.
- All respiratory disorders decrease oxygen delivery to the tissues. Healthy lungs are much more efficient at gas exchange than unhealthy lungs are.
- Bronchitis is an inflammation of the bronchioles, which results in narrowed air passages and decreased air movement.
- Emphysema is inflammation and overinflation of the alveoli, causing them to rupture and reducing the surface area available for diffusion.
- Bronchial asthma is characterized by narrowing of the bronchial passages.
- Lung tumours reduce the surface area for diffusion.

EXTENSION

Search for a Safe Cigarette

The tobacco industry's quest for a "safer" cigarette is filled with promise and pitfalls, as presented in this *NOVA* video.

www.science.nelson.com GO

Section 9.3 Questions

1. How do CO_2 levels regulate breathing movements?
2. Why does exposure to carbon monoxide (CO) increase breathing rates?
3. How does emphysema affect the lungs?
4. How does partial pressure affect the movement of oxygen from the alveoli to the blood?
5. How is CO_2 transported in the blood?
6. Why is the slowing down of the cilia in smokers dangerous?
7. Nicotine, one of the components of cigarettes, slows the cilia lining the respiratory tract, causes blood vessels to constrict, and increases heart rate. Another component of cigarette smoke is carbon monoxide. Carbon monoxide competes with oxygen for binding sites on the hemoglobin molecule found in red blood cells. Analyze the data presented in this chapter, and describe the potential dangers associated with smoking.
8. Survey several people who smoke and calculate the amount of tar taken in each day. Most cigarettes contain about 15 mg of tar, with 75 % of the tar being absorbed. Show your calculations.
9. On an X ray, a cancerous tumour shows up as a white spot (**Figure 9**). A healthy lung appears dark. Why would the tumour appear white?

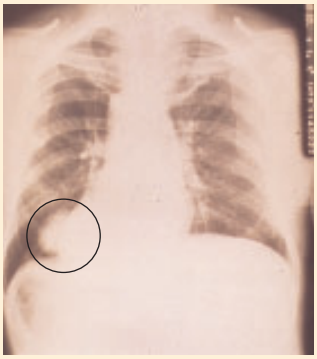


Figure 9
An X ray showing the presence of a tumour in the lower right lung

9.4 Muscles

cardiac muscle the involuntary muscle of the heart

smooth muscle the involuntary muscle found in the lining of many organs

skeletal muscle the voluntary muscle that makes the bones of the skeleton move

tendon a band of connective tissue that joins muscle to bone

antagonistic muscles a pair of skeletal muscles that are arranged in pairs and that work against each other to make a joint move

Your body has more than 600 muscles that can be divided into three basic types (**Figure 1**). **Cardiac muscle** is the muscle that makes the heart beat, and it is found only in the heart. Cardiac muscle contracts and relaxes automatically (involuntarily) because it is controlled by nerves of the autonomic nervous system. **Smooth muscle** is found in the lining of organs such as the stomach, the esophagus, the uterus, and the walls of blood vessels. Smooth muscle contractions move food through the digestive system and help push a baby through the vagina during delivery. Smooth muscle contraction is also involuntary. Unlike cardiac muscle and smooth muscle, the muscles that are attached to the bones of the skeleton are under conscious (voluntary) control, and are called **skeletal muscle**. **Figure 2**, on the next page, shows some of the main skeletal muscles of the body. These are the muscles that allow you to walk, talk, and hit a baseball with a bat. Skeletal muscles are attached to bones by **tendons**.

Muscles shorten when they contract and lengthen when they relax. A body part moves only when a contracting muscle pulls it. Many skeletal muscles are arranged in pairs that work against each other to make a joint move. These are called **antagonistic muscles**. The biceps and triceps muscles of the arm are an antagonistic pair of muscles (**Figure 3**, next page). When the biceps contracts and the triceps relaxes, the bones forming the elbow joint are brought closer together. When the biceps relaxes and the triceps contracts, the two bones are moved apart. The muscle that must contract to bend a joint is

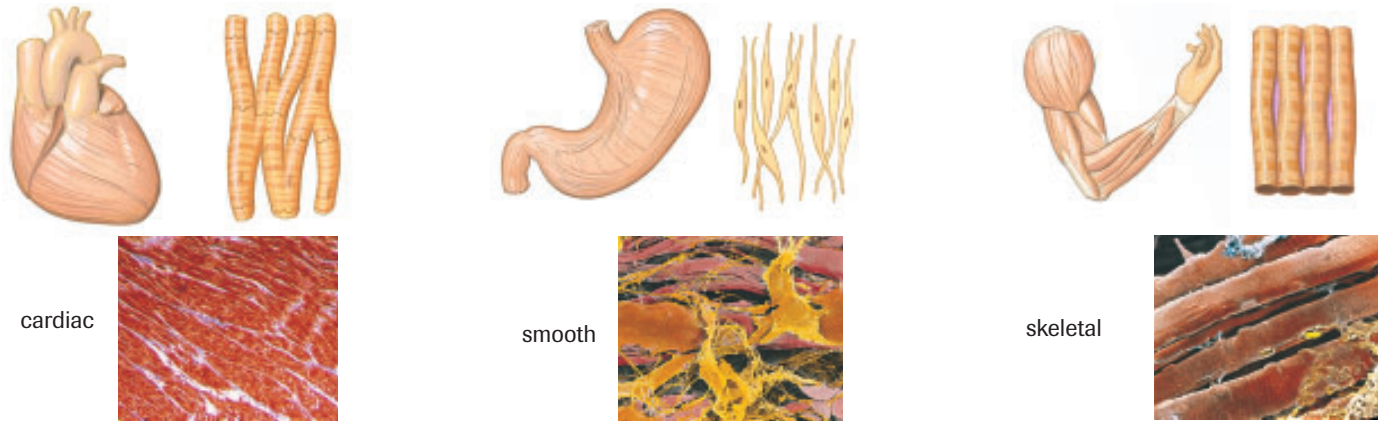


Figure 1
Types of muscle

mini Investigation — Microscopic Examination of Muscle

In this activity, you will examine and compare the structures of cardiac, smooth, and skeletal muscle.

Materials: prepared slides of cardiac, smooth, and skeletal muscle

- Examine the three types of muscle under low, medium, and high power magnification.

(a) Draw a diagram of each muscle type under low power magnification. Label the nuclei, cell membranes, and striation if visible.
(b) In a chart, describe the similarities and differences that you observed among the muscle types.

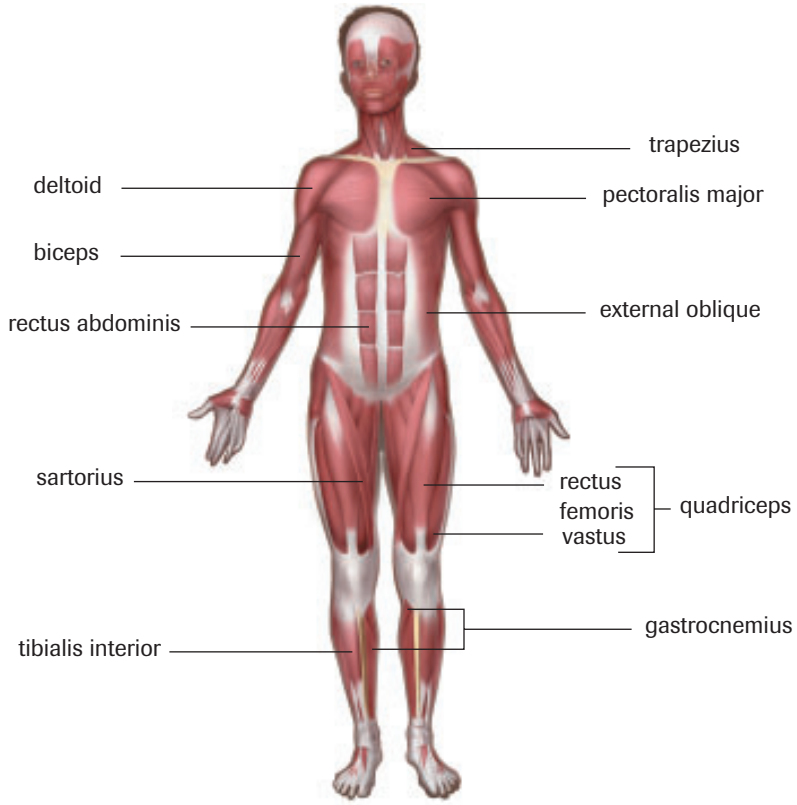


Figure 2
Some major muscles of the human body

DID YOU KNOW

The Triceps

Have you ever admired a bulging biceps? Although bodybuilders work hard to develop well-defined biceps muscles, it is the triceps that are used most often during sports that require throwing, such as baseball, javelin, and shot put.

called a **flexor**, so the biceps muscle is a flexor. The muscle that must contract to straighten a joint is called an **extensor**. The triceps muscle is an extensor muscle. The origin is the place where the muscle attaches to the stationary bone; the insertion is where it attaches to the moving bone.

The central nervous system ensures that the biceps and triceps do not attempt to pull against each other. Excitatory nerve impulses that cause the triceps to contract are accompanied by inhibitory nerve impulses that cause the biceps to relax.

flexor the muscle that must contract to bend a joint

extensor the muscle that must contract to straighten a joint

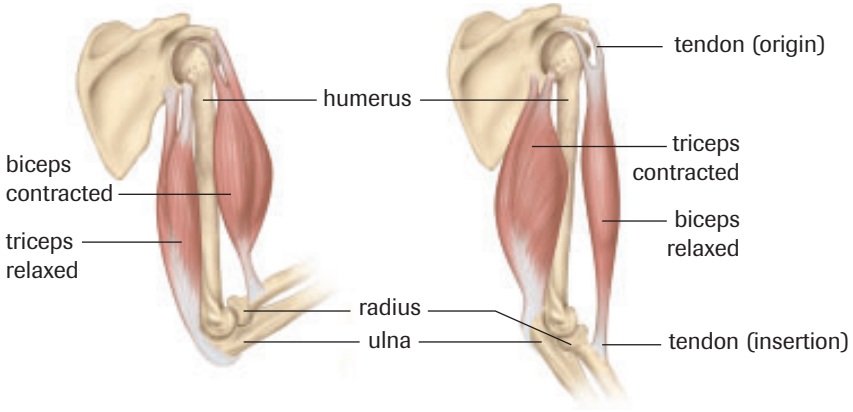


Figure 3
The biceps and triceps are an example of antagonistic muscles.

EXTENSION

The Role of the Skeleton

The skeleton is an important part of the motor system. Bones and muscles work together to permit movement. Go to the Nelson Web site to learn more about the role of the skeleton.

www.science.nelson.com GO

mini Investigation — Effect of Low Temperature on Muscle Contraction

Materials: ice, water, large beaker, pen and paper, stopwatch

- Write your name as many times as possible in 2 min. Use a stopwatch to keep track of time. Record the number of signatures.
- Immerse your hand in ice water for as long as you can, and once again write your name as many times as possible in 2 min. Record the number of signatures.
- Rub your hand until warm and repeat the procedure.

(a) Construct a data table that compares the number of signatures to hand temperature.
(b) Compare the quality of the signatures.
(c) Why does cold water affect the muscles?

EXTENSION

General Musculo-Skeletal Anatomy
This Audio Clip describes the anatomical references that identify the interrelationships between muscles and the skeleton.

www.science.nelson.com GO

Skeletal Muscle

Bend your elbow and squeeze your fist. The muscles in your forearm and the biceps, the large muscle above the elbow, bulge. These muscles are skeletal muscles. Skeletal muscle permits movement, enables smiling, and helps keep you warm. An estimated 80 % of the energy used in skeletal muscle contraction is lost as heat. Is it any wonder that you shiver when cold?

Skeletal muscle is composed of several bundles of cells called fibres. Unlike other cells, which contain one nucleus, many nuclei are found in each muscle cell. The fibres are enclosed within a membrane called the **sarcolemma**. Within the muscle fibres are tiny **myofilaments** bundled together (**Figure 4 (a)**). Two kinds of myofilaments can be seen under the electron microscope, each composed of a different contractile protein. Thin myofilaments are composed of actin, and thick myofilaments are composed of myosin. They overlap to produce a striated, or striped, appearance.

The alternating dark and light bands of the muscle fibres can be explained by examining the arrangement of the myofilaments. The length of the muscle fibre is defined by the Z lines that anchor the actin fibres. The area between the Z lines is the *sarcomere*. The thick myosin filaments form the darker A bands, while the thinner actin filaments allow more light to penetrate and form the lighter I bands shown in **Figure 4 (b)**.

sarcolemma the delicate sheath that surrounds muscle fibres

myofilament a thread of contractile proteins found within muscle fibres

EXTENSION

Troponin and Tropomyosin
Take a closer look at actin filaments in a skeletal muscle cell, and the two proteins which aid in muscle contraction.

www.science.nelson.com GO

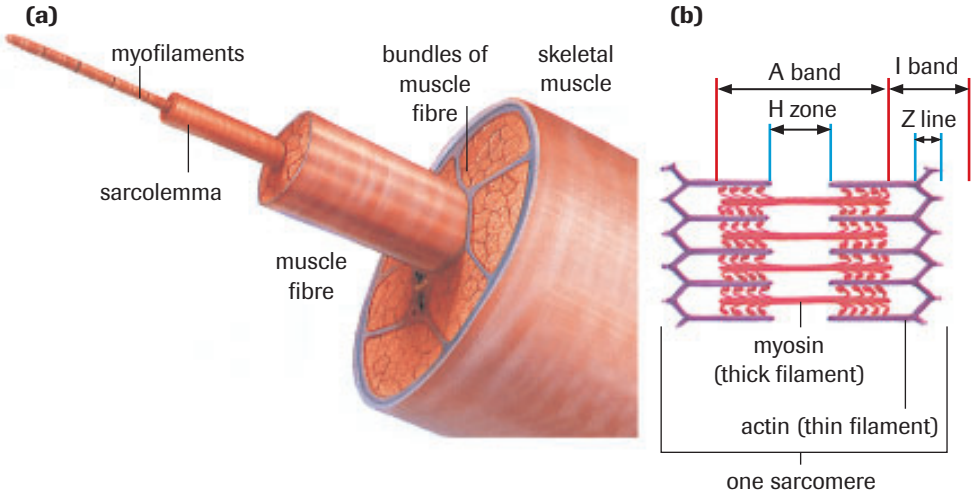


Figure 4
(a) The structure of skeletal muscle
(b) A sarcomere

The Sliding Filament Theory

As the word *theory* suggests, all is not known about muscle contraction. The sliding filament theory provides a working model that helps explain what scientists believe is happening.

Muscles cause movement by shortening. The actin filaments slide over the myosin filaments. Z lines move closer together when muscle fibres contract. As the actin and myosin filaments begin to overlap, the lighter I band becomes progressively smaller. But what causes the actin and myosin filaments to overlap? It is believed that knoblike projections on the thick myosin filaments form cross-bridges on receptor sites of the thinner actin filaments. A series of cross-bridges attach and detach as the actin filaments are drawn inward. **Figure 5** illustrates the sliding filament theory.

The energy required for muscle contraction comes from ATP, adenosine triphosphate. In the absence of ATP, the cross-bridges fail to detach and the muscle becomes rigid. A condition known as *rigor mortis* is due to the contraction of muscles following death. With death, ATP production ceases and skeletal muscle becomes fixed. The condition may last up to 60 hours after death.

The release of a transmitter chemical at the junction between the nerve and muscle initiates muscle contraction. Once the transmitter chemical reaches a specialized endoplasmic reticulum, found within the cytoplasm, calcium ions are released. The calcium ions bind to sites along the actin filaments and initiate the formation of cross-bridges with the myosin fibres. It is believed that the release of calcium ions begins the breakdown of ATP by the myosin filaments. ATP provides the energy for the filaments to slide over one another. Eventually, the calcium ions are actively taken up and stored in the specialized endoplasmic reticulum. The muscle then relaxes. When calcium ions are again released from the endoplasmic reticulum, the muscle contracts.

Muscle Fatigue

Have you ever felt your muscles begin to burn while skiing? Have your muscles ever failed you during a race? No matter how hard you try, you begin to lose control of your muscles. Muscle fatigue is caused by a lack of energy and the buildup of waste products within your muscles.

Unfortunately, very little ATP can be stored in muscle tissue. The energy demand is met by aerobic respiration. Glucose is systematically broken down by a series of enzymes found in the cytoplasm and mitochondria of your cells. Glucose is oxidized by oxygen to form ATP, carbon dioxide, and water. A high-energy compound called **creatine phosphate**, found in all muscle cells, ensures that ATP supplies remain high. Creatine phosphate supplies a phosphate to adenosine diphosphate (ADP) to replenish ATP supplies. If creatine phosphate levels remain high in muscle cells, ATP levels can be maintained.

As long as oxygen can be supplied and cellular respiration can meet the demands of muscle cells, the filaments will continue to be drawn together. However, should energy demand exceed ATP supply, lactic acid begins to accumulate. Lactic acid causes muscle pain and is associated with fatigue. The burning that you feel in your legs while skiing a difficult run or the pain the you feel in your rib muscles after prolonged heavy exercise is due to an accumulation of lactic acid. During this condition, referred to as oxygen debt, the fluids surrounding the muscles become acidic and eventually the muscle fails to contract. The rapid breathing that takes place after heavy exercise is designed to repay the oxygen debt.

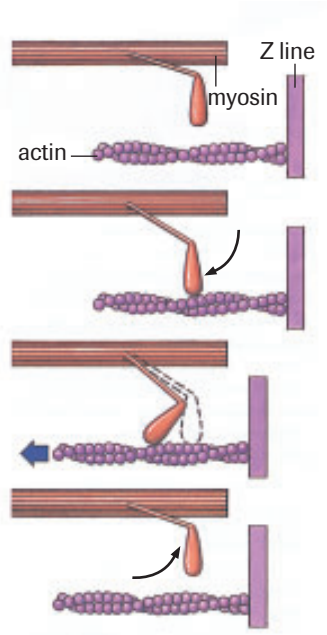


Figure 5
Sliding filament theory, showing one actin and one myosin filament

EXTENSION

Energy Sources for Contraction

In this animation, review the metabolic routes which produce ATP in muscle cells.

www.science.nelson.com GO

creatine phosphate a compound in muscle cells that releases a phosphate to ADP and helps regenerate ATP supplies in muscle cells

CAREER CONNECTION

Prosthetist and Orthotist

Prosthetists design and construct devices such as artificial limbs, and orthotists design and construct devices such as braces and supports. They work with physicians to improve the quality of life for patients who have injuries or deformities. Find out the educational requirements for a prosthetist and orthotist.

www.science.nelson.com GO

INVESTIGATION 9.3 *Introduction*

The Effects of Muscle Activity on Body Temperature

In this investigation, you will conduct an experiment to show the relationship between muscle activity and thermal energy.

To perform this investigation, turn to page 306.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

DID YOU KNOW?

Muscle Spasms

Muscle spasms are caused by involuntary contractions of muscles. A pinched nerve is often responsible for the spasm.

Muscle Contraction

A muscle twitch, or contraction, occurs when a nerve impulse stimulates several muscle cells. A pause between the impulse and the muscle contraction is referred to as the *latent period* (**Figure 6** (**a**)). Upon contraction, actin and myosin fibres slide over one another, causing the muscle to shorten. After the contraction phase, the actin and myosin filaments disengage and the muscle begins to relax. Once the relaxation phase is complete, each muscle cell usually returns to its original length. Should a muscle cell be stimulated once again, it will contract with equal force (**Figure 6** (**b**)).

An interesting phenomenon occurs when a stimulation happens before the relaxation phase is complete. Predictably, the actin and myosin filaments slide over one another, but because the relaxation has not yet been completed, the overlap is increased and greater muscle shortening can be observed. The sum of the shortening that remains from the first muscle twitch and the shortening produced by the second muscle twitch creates a greater force of contraction. The strength of the contraction depends on how close the second stimulus is to the first stimulus. The process, shown in **Figure 6** (**c**), is referred to as **summation**. Occasionally, repeated muscle stimulation prevents any relaxation phase. The state of constant muscle contraction, known as **tetanus**, is shown in **Figure 6** (**d**).

summation increased muscle contraction produced by the combination of stimuli

tetanus the state of constant muscle contraction caused by sustained nerve impulses

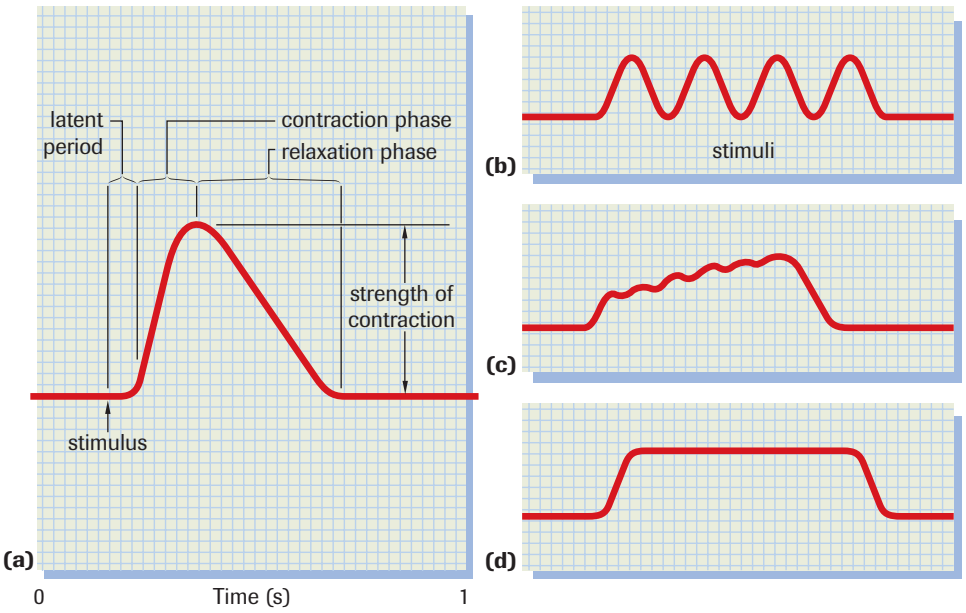


Figure 6

(a) Recording of a muscle twitch that lasts approximately 1 s

(b) Single muscle twitches approximately 1 s apart. The muscle returns to its original length before succeeding stimuli cause contractions.

(c) Summation of muscle twitches from about six stimulations every second. Following the contraction, the muscle does not have enough time to return to its original length before being stimulated again.

(d) Tetanus resulting from about 20 stimulations per second. The actin and myosin filaments remain overlapped.

Fast and Slow Twitch Muscle Fibres

It has often been said that great sprinters are born not made. Although training can improve technique, it can never make an ordinary person a world-class sprinter. The genetic factor appears too great to be overcome with increased fitness and improved technique.

Sprinters are born with a large amount of what is called fast twitch muscle fibre. It is the thick myosin filaments that determine the speed of muscle contraction. Three different forms of myosin, referred to as isomers, determine whether you have the potential to be a sprinter or a marathon runner. The fibres are referred to as type I, IIa, and IIx. Type I fibres cause slower muscle twitch and are found in greater abundance in distance runners. These fibres break down ATP slowly, but efficiently, to release energy. Type IIa and IIx fibres, the faster twitch myosin fibres, break down ATP faster, but less efficiently. The slower twitch type I fibres are required for endurance events in which aerobic metabolism is predominant. The fast twitch type IIa and IIx fibres rely predominantly on anaerobic respiration. Although all athletes have both slow and fast twitch fibres, the proportions vary dramatically, as shown in **Figure 7**.

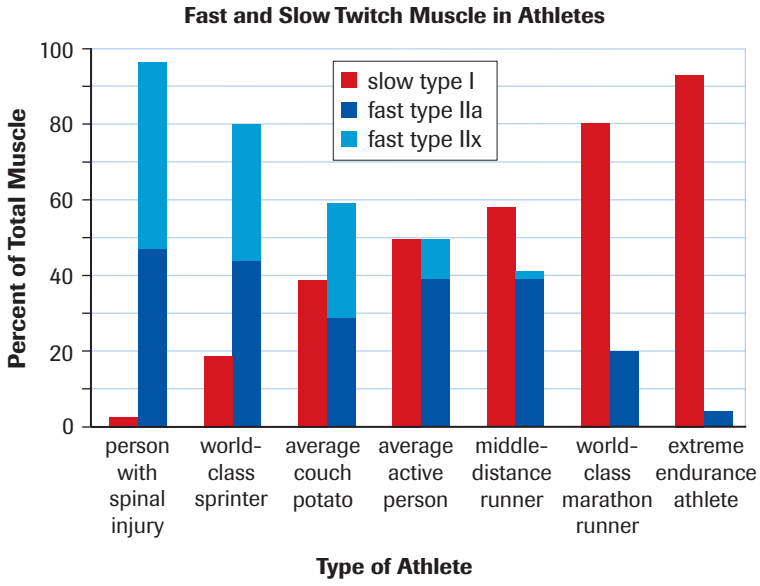


Figure 7
Different types of athletes have varying proportions of slow and fast twitch muscle fibres.

EXTENSION

Nervous System and Muscle Contraction
View this animation to see how signals from the nervous system control muscle contraction.

www.science.nelson.com GO

DID YOU KNOW

Red and White Muscle
There are two different types of muscle fibres. Red muscle fibres are well-suited for slow contraction, while white muscle fibres are designed for rapid contraction. Red muscle fibres appear red because they contain myoglobin, the protein that binds oxygen, which is used during cellular respiration. White fibres contain little myoglobin and, therefore, use less oxygen. They obtain energy from the breakdown of glycogen without oxygen.

Motor System Injuries

Muscles, like all living tissues, require nourishment from a balanced diet, including an adequate supply of protein. Regular exercise is necessary for maintaining healthy muscles. Studies done in the near zero-gravity environment of outer space show that astronauts lose muscle mass unless they exercise regularly.

Motor system injuries are common in people who perform heavy work or exercise. Torn muscles, stretched tendons, torn ligaments, joint sprains, and joint dislocations are common sports injuries.

EXTENSION

Comparing Fast and Slow Twitch Muscle Fibres
This Audio Clip describes the physiological differences between fast and slow twitch muscle fibres.

www.science.nelson.com GO

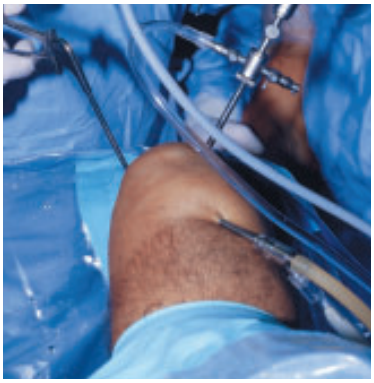


Figure 8
Arthroscopic surgery

Arthroscopic Surgery

Torn cartilage or ligament? An innovative technique called arthroscopic surgery (named after the viewing device, the arthroscope) has dramatically improved the prognosis for people who suffer knee injuries.

The first arthroscope was used in Japan in 1917—today's instruments barely resemble this early predecessor. An arthroscope is a needlelike tube, less than 2 mm wide, that is equipped with a fibreoptic light source (**Figure 8**). The needle can be inserted through a small puncture in the knee, which requires only local anesthesia. The fibreoptic lens can be linked with a television screen, providing a view of the inside of the damaged knee. The arthroscope is also fitted with thin surgical tools that can snip away unhealthy tissue. Under most circumstances, hospitalization is not required following the surgery, and activity can be resumed relatively quickly.

EXTENSION

Redesigning the Body for Motion

In this activity, you will re-engineer parts of the human body that are most susceptible to injuries from sports and aging.

www.science.nelson.com GO

SUMMARY Muscles

- The body contains three types of muscle: cardiac, smooth, and skeletal.
- The movement of bones at a joint is performed by skeletal muscles, which work in antagonistic pairs.
- Skeletal muscles are composed of muscle fibres, which contain myofilaments.
- Myofilaments are threads of contractile proteins, either actin or myosin.
- The fibres of skeletal muscle are encased in a membrane called the sarcolemma.
- The energy for muscle contraction is provided by ATP.

Section 9.4 Questions

1. What is the sarcolemma?
2. Name the two myofilaments found in muscle fibres and briefly outline their function.
3. Why does skeletal muscle appear striated, or striped?
4. Why is ATP needed for muscle contraction?
5. Why is creatine phosphate required for muscle contraction?
6. What is the term for extended muscle contraction, and what causes it?
7. Using **Figure 9**, make predictions about which athlete would be well-suited for sprinting and which for distance running. Give reasons for your prediction.

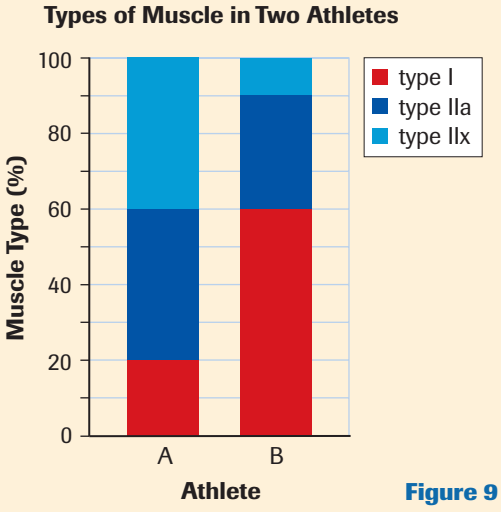


Figure 9

INVESTIGATION 9.1

Determining Lung Capacity

Healthy lungs can take in oxygen and expel carbon dioxide from the body with much greater efficiency than unhealthy lungs can. In this investigation, you will examine indicators of general respiratory health by measuring lung capacity at rest. Normal lung capacity (**Table 1**) varies with factors such as age, height, gender, and physical fitness.

Table 1 Approximate Lung Volumes for an Average 70-kg Male

Measure	Volume (L)
total lung capacity (TLC)	5
tidal volume (TV)	0.45 to 0.5
residual volume (RV)	1.5
expiratory reserve volume (ERV)	1.5
inspiratory reserve volume (IRV)	2.5

There are several measures that are important in determining lung capacity. The following four can be measured using a respirometer: Tidal volume (TV) is the amount of air inhaled and exhaled in a normal breath; expiratory reserve volume (ERV) is the amount of air that can be forcibly exhaled after a normal exhalation; and inspiratory reserve volume (IRV) is the amount of air that can be forcibly inhaled after a normal inhalation. Vital capacity (VC) is the maximum amount of air that can be exhaled after a full inhalation and is calculated from IRV, ERV, and TV.

Residual volume (RV) is the amount of air left in the lungs after a maximum exhalation. Total lung capacity (TLC) is the amount of air in the lungs after a maximum inhalation, or all the air that the lungs can hold. **Figure 1** illustrates the relationships among the different lung volume measurements.

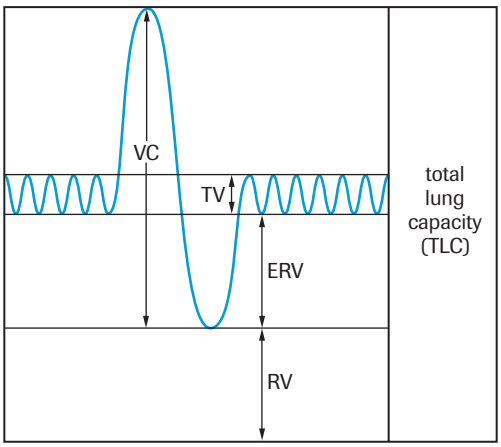


Figure 1
Lung volumes

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

Materials

respirometer with disposable mouthpieces

Procedure

1. Set the gauge to zero before you place a new, unused mouthpiece in the respirometer.
2. Be careful not to inhale at any time through the mouthpiece. Develop a regular, relaxed breathing pattern so you will obtain accurate results. After inhaling normally, place the mouthpiece attached to the respirometer in your mouth and exhale normally. Read the gauge on the respirometer. Record the volume exhaled as tidal volume.
3. Reset the respirometer to zero. Inhale normally, then place the mouthpiece attached to the respirometer in your mouth and exhale normally. Read the gauge on the respirometer and then exhale forcibly. Record the difference as expiratory reserve volume.
4. Reset the respirometer to zero. Inhale as much air as possible and then exhale for as long as you can into the respirometer. Read the gauge on the respirometer. Record the value as vital capacity.
5. Repeat Steps 1 to 4 for two more trials, without changing the mouthpiece.

Analysis and Evaluation

(a) Determine your inspiratory reserve volume by using the following formula:

$$VC = IRV + ERV + TV$$

(b) Using the above formula, indicate where IRV would be in **Figure 1**.

Synthesis

(c) Predict how the tidal volume and vital capacity of a marathon runner might differ from that of the average Canadian.

(d) How might bronchitis affect your expiratory reserve volume? Provide your reasons.

(e) Predict how the respiratory volumes collected for a person with emphysema would differ from those you collected.

INVESTIGATION 9.2

The Effects of Exercise on Lung Volume

The total lung capacity of fully grown, healthy lungs is about 5 L. However, a person normally inhales and exhales only about 0.5 L. Various factors can affect the lung volume of a single breath. In this investigation, you will design ways to test the effects of exercise on lung volume during one inhalation and exhalation.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To determine how exercise affects lung volume during a single breath

Do not perform this activity if you are not allowed to participate in physical education classes.

Design

Design a controlled experiment that includes the following:

- a prediction and a hypothesis
- the manipulated, responding, and fixed variables
- a step-by-step description of the procedure
- a list of safety precautions
- a table to record observations

Submit your design to your teacher for approval. Then, carry out your investigation.

Analysis

(a) State how exercise affects lung volume.

Evaluation

(b) Was your prediction correct? Was your hypothesis supported?

(c) Describe any problems in carrying out the procedure.

(d) Suggest ways to improve your current design.

(e) If you were to repeat this experiment, what new factors would you investigate? Write a brief description of the new procedure.

INVESTIGATION 9.3

The Effects of Muscle Activity on Body Temperature

Liquid crystals can be used to measure changes in body temperature. ATP supplies muscles with energy. However, some of the ATP is converted to thermal energy, which increases body temperature.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To investigate the relationship between muscle activity and thermal energy

Do not perform this activity if you are not allowed to participate in physical education classes.

Design

Design an experiment to show the relationship between muscle activity and thermal energy. You may want to use a thermometer to calibrate the liquid crystal colours.

- Identify the controlled variables, manipulated variable, and responding variable.
- Write a prediction and a hypothesis for the experiment.
- Create a step-by-step procedure that includes any safety precautions.

Present your design to your teacher for approval. Then, conduct your experiment.

Complete an analysis and evaluation of your experiment. Communicate your results in a written report.

Evaluation

(a) Present your data in tables and graphically if appropriate.

(b) Present conclusions based on the data collected.

(c) Evaluate your experimental design.

Chapter 9 SUMMARY

Outcomes

Knowledge

- identify the principal structures of the respiratory systems, i.e., nasal passages, pharynx, larynx, epiglottis, trachea, bronchi, bronchioles, alveoli, diaphragm, rib muscles, pleural membranes (9.1)
- explain how gases and heat are exchanged between the human organism and its environment, i.e., mechanism of breathing, gas exchange, removal of foreign material (9.2, 9.3)
- explain how the motor system supports body functions, referencing smooth, cardiac, and striated muscle, i.e., digestive, circulatory, respiratory, excretory, and locomotory (9.4)
- describe, in general, the action of actin and myosin in muscle contraction and heat production (9.4)

STS

- explain that the goal of technology is to provide solutions to practical problems (9.2, 9.3, 9.4)
- explain that the products of technology are devices, systems, and processes that meet given needs; however, these products cannot solve all problems (9.3, 9.4)
- explain that concepts, models, and theories are often used in interpreting and explaining observations, and in predicting future observations (9.4)

Skills

- ask questions and plan investigations (9.1, 9.3, 9.4)
- conduct investigations and gather and record data and information (9.1, 9.3) and by identifying smooth, cardiac, and striated muscle tissue under magnification (9.4)
- analyze data and apply mathematical and conceptual models (9.1, 9.3, 9.4)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

9.1

breathing
respiratory membrane
respiration
trachea
cilia
epiglottis
larynx
bronchi
bronchiole
alveoli
pleural membrane
diaphragm
intercostal muscle

9.2

hemoglobin
oxyhemoglobin
carbonic anhydrase
buffer

9.3

chemoreceptor
bronchitis
emphysema
bronchial asthma

9.4

cardiac muscle
smooth muscle
skeletal muscle
tendon
antagonistic muscles
flexor
extensor
sarcolemma
myofilament
creatine phosphate
summation
tetanus

MAKE a summary

1. Create a flow chart or diagram that shows how the respiratory system exchanges matter and energy with the environment. Label the diagram with as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 9
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The following structures are involved in respiration:

NR

1. muscle cell
2. bronchiole
3. capillary
4. trachea

List these structures in the order in which oxygen reaches them during respiration. (Record all four digits of your answer.)

2. An increase in breathing rate is caused by
- A. elevated levels of blood oxygen
- B. elevated levels of blood carbon dioxide
- C. reduced levels of blood carbon dioxide
- D. reduced levels of blood carbon monoxide

Use the following information to answer questions 3 and 4.

Changes in the partial pressure of gases in the blood were monitored at 1-second intervals and then graphed (**Figure 1**).

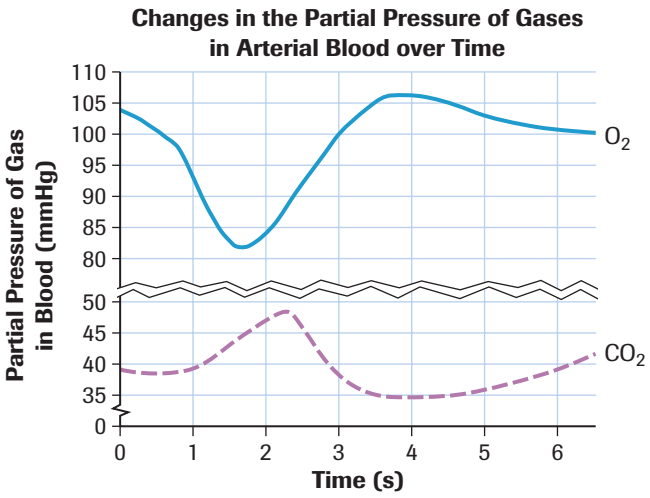


Figure 1

3. Select the time at which the chemoreceptors in the medulla will receive a message to initiate breathing movements.
- A. 1.6 s
- B. 2.2 s
- C. 3.5 s
- D. 4.0 s

4. Identify the time that would immediately follow a breathing movement and the reason why.
- A. 1.7 s, because oxygen and carbon dioxide leave the blood
- B. 3.5 s, because oxygen is entering the blood and carbon dioxide is leaving the blood
- C. 4.5 s, because oxygen and carbon dioxide enter the blood
- D. 4.5 s, because oxygen is entering the blood and carbon dioxide is leaving the blood

5. Identify the factors that would increase the delivery of oxygen to the tissues.
- A. high blood volume and high altitude
- B. low blood volume and high altitude
- C. high hemoglobin and low altitude
- D. low hemoglobin and low altitude

6. Identify the diagram in **Figure 2** that correctly depicts a contracted muscle fibre.

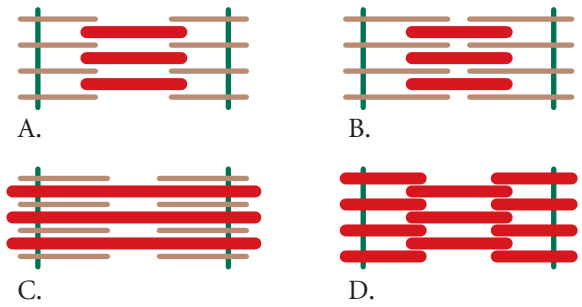


Figure 2

Use the following information to answer questions 7 and 8.

Different types of athletes have different amounts of type IIa and type IIx muscle fibres.

1. sprinter
2. marathon runner
3. average active person
4. extreme endurance athlete

7. NR List all of the given athletes in the order of increasing amount of type IIa and type IIx muscle fibres. (Record all four digits of your answer.)

8. NR List all of the given athletes in the order of their increasing oxygen demand. (Record all four digits of your answer.)

Part 2

Use the following information to answer questions 9 to 11.

Figure 3 shows the components of the human respiratory system.

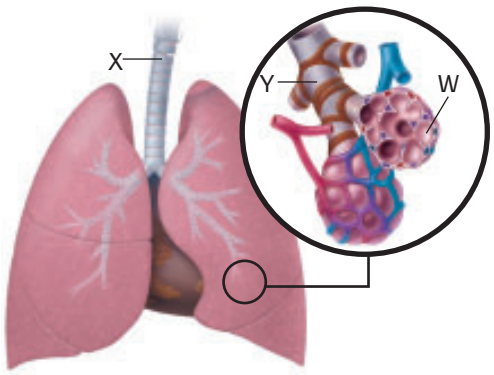


Figure 3

9. **Identify** the structures labelled W, X, and Y in **Figure 3**, and **describe** the function of each. DE

10. **Identify** the structure(s) in **Figure 3** that have cartilaginous bands. DE

11. The inflammation or restriction of airflow in one of the structures in **Figure 3** is associated with asthma. **Identify** this structure. DE

12. **Describe** the pressure changes that occur during inhalation and exhalation.

Use the following information to answer questions 13 to 15.

The composition of air was analyzed from inhaled and exhaled air (**Table 1**).

Table 1 Composition of Inhaled and Exhaled Air

Air component	Inhaled air (%)	Exhaled air (%)
oxygen	20.71	14.60
carbon dioxide	0.41	4.00
water	1.25	5.90
nitrogen	78.00	75.50

13. **Explain** why more water is found in exhaled air. DE

14. **Explain** the difference in oxygen levels in inhaled and exhaled air. DE

15. If nitrogen is not used by the cells of the body, **explain** the different composition between inhaled and exhaled air. DE

16. Changes in the partial pressure of gases in arterial blood were monitored over time as a subject began to perform light exercise (**Figure 1**, previous page).
    (a) At which time would the breathing rate likely be greatest? **Justify** your answer.
    (b) **Predict** when the subject began exercising. **Describe** your reasons.
    (c) When would the breathing rate return to normal? **Explain**.

17. According to the data shown in **Figure 4**, **identify** which hemoglobin is more effective at absorbing oxygen. **Describe** the adaptive advantage that is provided by hemoglobin that allows it to combine readily with oxygen.

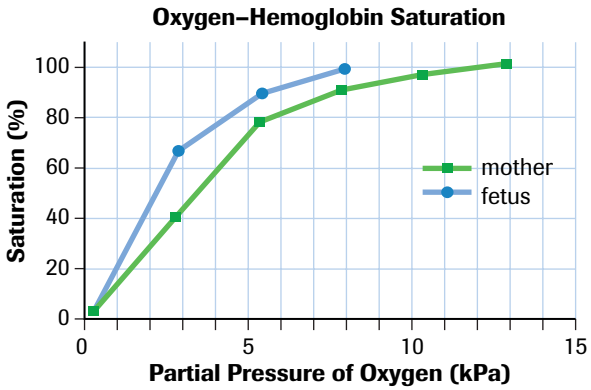


Figure 4

18. Cigarette smoke has the following effects:
    - There is destruction of many of the cilia that line the bronchi and bronchioles.
    - There is a buildup of mucus along the walls of the bronchioles. This reduces their interior diameter.
    - There is an increase in blood pressure that causes the rupturing of the walls of some of the alveoli.

    Refer to each of the effects listed above. **Describe** specific ways in which the normal functioning of the respiratory tract is altered by smoking tobacco.

19. **How** does the fact that muscles shorten when excited help support the sliding filament theory of muscle contraction?

20. **Why** does the condition of rigor mortis support the theory that ATP is required for muscle relaxation?

21. **Explain** how the motor system supports
    (a) the digestive system
    (b) the respiratory system

Extension

22. Allan Becker of the University of Manitoba studies dogs to learn more about how asthma works in people. Research how allergies have been linked with asthma. **Describe** the advantages and disadvantages of using modelling experiments on dogs.

www.science.nelson.com GO

chapter

10 Circulatory System

In this chapter

Your circulatory system moves blood throughout your body. It carries nutrients to cells, wastes away from cells, and chemical messages from cells in one part of the body to distant target tissues. It distributes heat throughout the body and, along with the kidneys, maintains levels of body fluid.

Your circulatory system has 96 000 km of blood vessels to sustain your 100 trillion cells. No larger than the size of your fist and with a mass of about 300 g, the heart beats about 70 times/min from the beginning of life until death (**Figure 1**). During an average lifetime, the heart pumps enough blood to fill two large ocean tankers.

Every minute, 5 L of blood cycles from the heart to the lungs, picks up oxygen, and returns to the heart. Next, the heart pumps the oxygen-rich blood to the tissues of the body. The oxygen aids in breaking down high-energy glucose into low-energy compounds, which releases energy within the tissue cells. The cells use the energy to build new materials, repair existing structures, and for a variety of other energy-consuming reactions. Oxygen is necessary for these processes to occur, and the circulatory system plays a central role in providing that oxygen.

The circulatory system is also vital to human survival because it transports cellular wastes and helps defend against invading organisms. It permits the transport of immune cells throughout the body. You will learn about the immune system in the next chapter.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. People with heart problems often experience a racing and pounding heart even after mild exercise. Why does this occur?
2. Elite athletes literally have "big hearts." How would the resting heart rate of someone with cardiovascular disease compare to that of an athlete? Suggest a reason for the difference.
3. If scientists wanted to grow a heart, would it be best to obtain cells from the individual who had the heart problem or another individual? Explain.
4. Although scientists have successfully grown cells to form certain heart components, these tissue cultures lack the arteries and veins found in a normal heart. Why are blood vessels necessary?

Career Connections:
Cardiology Technologist, Registered Nurse

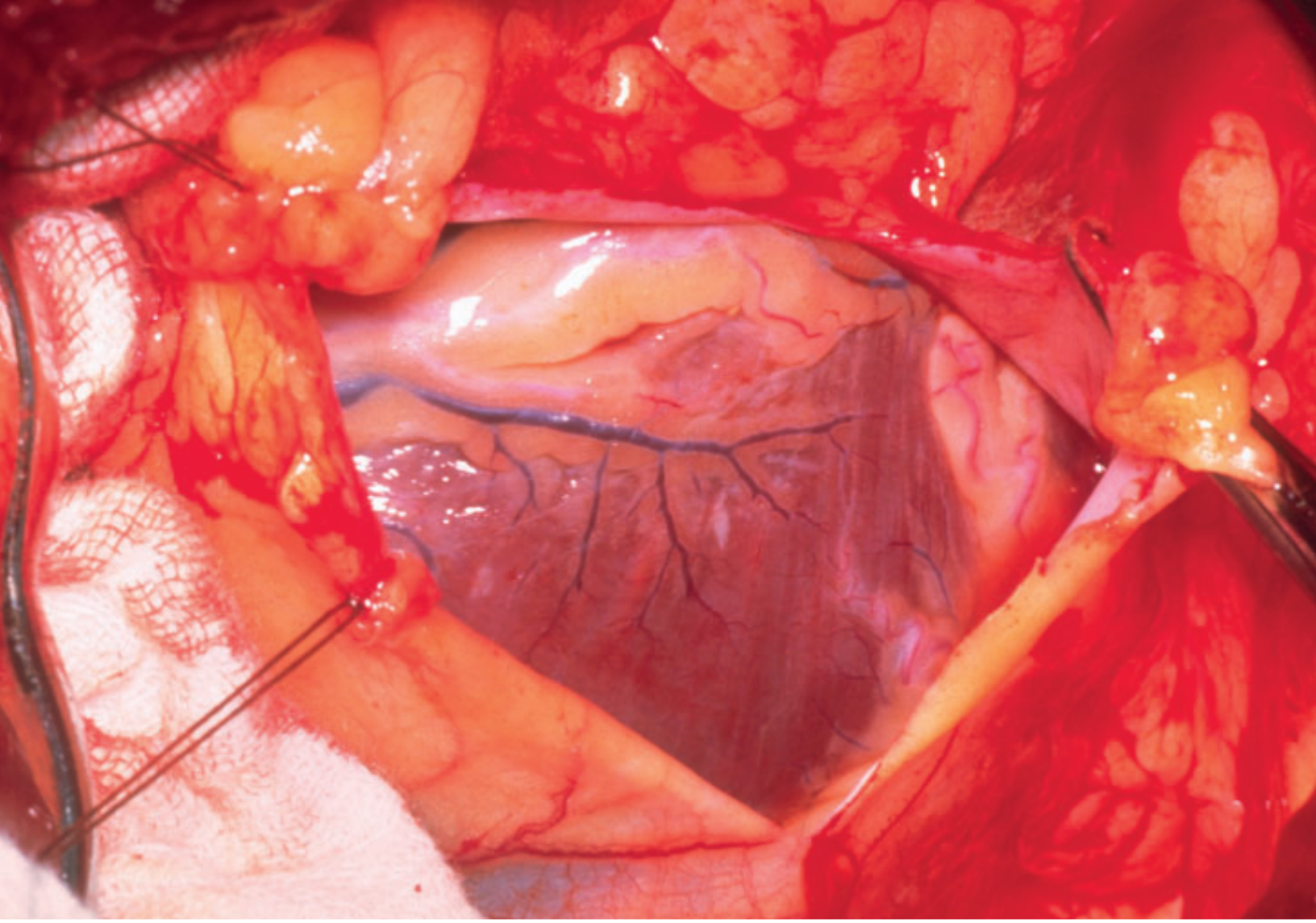


Figure 1
In this photo of a heart during surgery, you can see the coronary artery that supplies the muscle cells of the heart with the oxygen and nutrients they require. A blocked coronary artery can greatly reduce the ability of the heart to function.

Exploration — Listening to Heart Sounds

Medical workers use stethoscopes to measure blood pressure and to listen to the heart, lungs, and intestines. You will use a stethoscope to listen to your heart.

Disinfect the earpieces of the stethoscope with rubbing alcohol before and after use.

- Place a stethoscope on your own chest and listen for a heart sound (**Figure 2**). Locate the area where the heart sounds are loudest and clearest.
- After 1 min of moderate exercise (e.g., walking on the spot), listen for your heart sounds again.

(a) Draw a diagram of a chest showing where you located the clearest sound.
(b) Did the sound of your heartbeat change after exercise? Describe what differences you heard.

Figure 2
A stethoscope

10.1 Blood Vessels

Figure 1
William Harvey (1578–1657)

The ancient Greeks believed that the heart was the centre of human intelligence, an "innate heat" that generated four humours: black and yellow bile, phlegm, and blood. Galen, the personal physician of Roman emperor Marcus Aurelius in the second century C.E., influenced early physiology. Although he provided many enlightening theories, Galen is best known for steering scientists in the wrong direction. Galen believed that blood did not circulate. Although he believed that blood might ebb like the tides, he never thought of the heart as a pump. Galen's theory was generally accepted until the 17th century. Some science historians have suggested that his failure to consider the pumping action of the heart could be attributed to a lack of a technical model: the water pump had not been invented when Galen applied his theory.

William Harvey (1578–1657), the great English physiologist (**Figure 1**), questioned Galen's hypothesis. Harvey, like many Europeans during that period, was influenced by the astronomer Galileo. Galileo's new principles of dynamics became the foundation of Harvey's work. By applying Galileo's theories of fluid movement to blood, Harvey reasoned that blood must circulate.

Harvey attempted to quantify the amount of blood pumped by the heart each minute. He began his research by dissecting cadavers and observing blood vessels. Using mathematics, he calculated that the heart contains approximately 57 mL of blood. Harvey then concluded that 14.8 L must be pumped from the heart each hour. However, much less blood could be found in the body; the heart must be pumping the same blood over and over again. Harvey's estimates were at best conservative—he greatly underestimated the capacity of the heart to pump blood. However, by using empirical data, Harvey tested and challenged a theory that had been accepted for 1400 years.

Although William Harvey was convinced that blood must pass from the arteries to the veins, there was no visible evidence of how this was accomplished. He speculated that blood vessels too small to be seen by the human eye might explain how blood circulates. Four years after his death, an Italian physiologist, Marcello Malpighi, used a microscope to observe the tiniest blood vessels, the capillaries (from Latin, meaning "hairlike"). Malpighi's observations confirmed Harvey's theory of circulation. **Figure 2**, on the next page, shows the major blood vessels of the circulatory system, as they are known today.

DID YOU KNOW ?

Was Harvey First?

Evidence from an ancient Egyptian papyrus discovered in the 19th century suggests that the Egyptians correctly mapped the flow of blood from the heart 3300 years before William Harvey.

Arteries and Arterioles

artery a blood vessel that carries blood away from the heart

pulse change in the diameter of the arteries following heart contractions

Arteries are the blood vessels that carry blood away from the heart. They have thick walls composed of distinct layers. The outer and inner layers are primarily connective tissue, while the middle layers are made up of muscle fibres and elastic connective tissue, as shown in **Figure 3 (a)**, on page 314. Every time the heart contracts, blood surges from the heart and enters the arteries. The arteries stretch to accommodate the inrush of blood. The **pulse** you can feel near your wrist and on either side of your neck is created by changes in the diameter of the arteries following heart contractions. Heart contraction is followed by a relaxation phase. During this phase, pressure drops and elastic fibres in the walls of the artery recoil. It is interesting to note that the many cells of the artery are themselves supplied with blood vessels that provide nourishment. Blood from the arteries passes into smaller arteries, called arterioles. The middle layer of arterioles is composed of elastic fibres and smooth muscle.

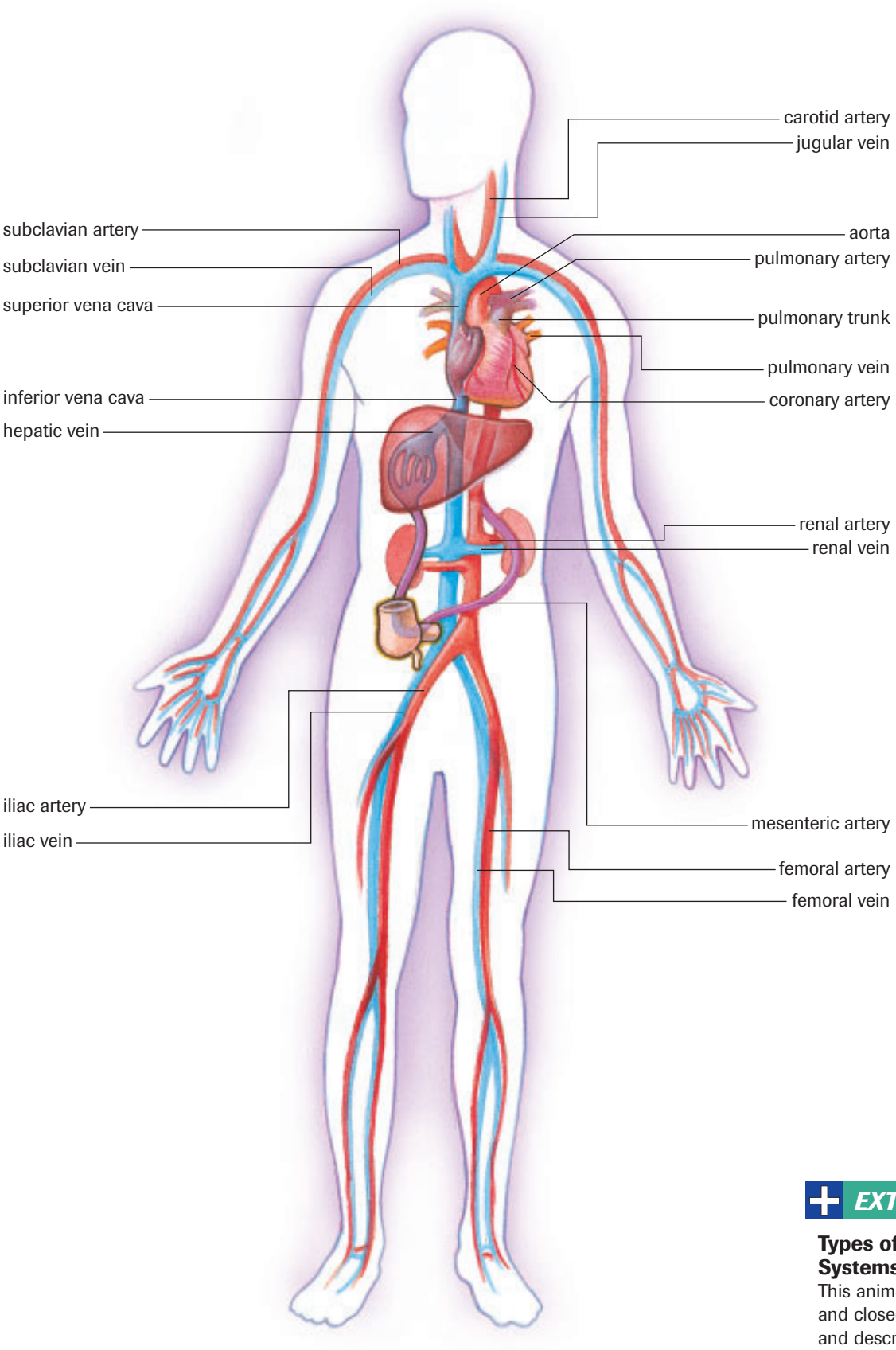


Figure 2
The major blood vessels of the circulatory system

EXTENSION

Types of Circulatory Systems
This animation compares open and closed circulatory systems and describes how each works.

www.science.nelson.com GO

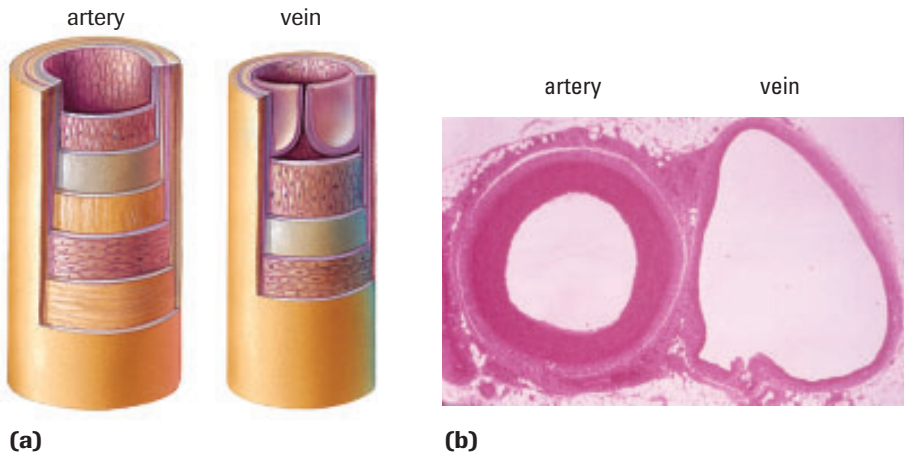


Figure 3
(a) Arteries have strong walls capable of withstanding great pressure. The middle layer of arteries contains both muscle tissue and elastic connective tissue. The low-pressure veins have a thinner middle layer.
(b) The photo shows a cross section of an artery and a vein.

autonomic nervous system the part of the nervous system that controls the motor nerves that regulate equilibrium, and that is not under conscious control

vasoconstriction the narrowing of blood vessels, allowing less blood to the tissues

vasodilation the widening of blood vessels, allowing more blood to the tissues

The **autonomic nervous system**, which controls the motor nerves that maintain equilibrium, regulates the diameter of the arterioles. A nerve impulse causes smooth muscle in the arterioles to contract, reducing the diameter of the blood vessel. This process is called **vasoconstriction**. Vasoconstriction decreases blood flow to tissues. Relaxation of the smooth muscle causes dilation of the arterioles, and blood flow increases. This process, called **vasodilation**, increases the delivery of blood to tissues. This, in turn, permits the cells in that localized area to perform energy-consuming tasks.

Precapillary sphincter muscles regulate the movement of blood from the arterioles into capillaries. Blushing is caused by vasodilation of the arterioles leading to skin capillaries. Red blood cells close to the surface of the skin produce the pink colour. Vasodilation helps the body release some excess heat that is produced when you become nervous. Have you ever noticed someone's face turn a paler shade when they are frightened? The constriction of the arteriolar muscles diverts blood away from the outer capillaries of the skin toward the muscles. The increased blood flow to the muscles provides more oxygen and glucose to meet the energy demands of a response to a threat or danger.

Arterioles leading to capillaries open only when cells in that area require blood. It has been estimated that the body would need 200 L of blood if all the arterioles were open at one time. Although the majority of brain capillaries remain open, as few as one fiftieth of the capillaries in resting muscle remain open.

EXTENSION

Atherosclerosis and the Positive Feedback Cycle
Listen to this Audio Clip to understand the accelerating influence that positive feedback has on the development of atherosclerotic plaque and coronary artery disease.

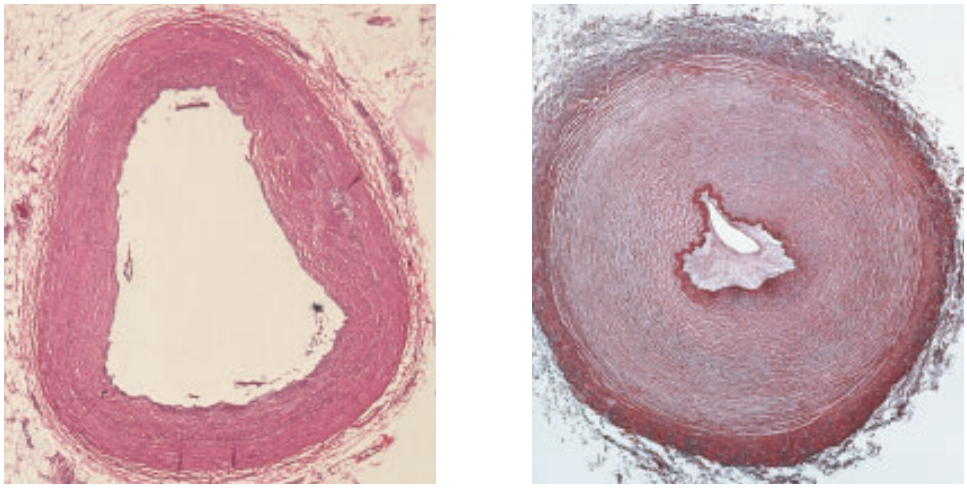
www.science.nelson.com GO

Atherosclerosis

Anyone who has ever washed dishes is aware of how fat floats on water. You may have noticed that when one fat droplet meets another, they stick together and form a larger droplet. Unfortunately, the same thing can happen in your arteries. Excess lipid in your blood is deposited in the walls of the arteries, slowly narrowing the inside diameter of the blood vessel. Calcium and other minerals deposit on top of the lipid, forming plaque. This condition is known as **atherosclerosis**, the most common form of a group of disorders called **arteriosclerosis**, or arterial disease. Arteriosclerosis can narrow arteries and lead to high blood pressure (**Figure 4**, next page). To make matters worse, blood clots, which are normally a life-saving property of blood, form in the blood vessel when the plaque gets so big that it bursts through the wall of the artery. This can totally block the artery and cut off blood flow. In the heart, as the arteries become narrowed and blocked, inadequate amounts of blood and oxygen are delivered to the heart muscle, resulting in chest pains and possibly a heart attack.

atherosclerosis a degeneration of blood vessels caused by the accumulation of fat deposits in the inner wall

arteriosclerosis a group of disorders that cause the blood vessels to thicken, harden, and lose their elasticity



(a) **(b)**

Figure 4
(a) Cross section of a normal artery
(b) Cross section of an artery from a person with atherosclerosis. Notice that fat deposits have narrowed the passageway.

Every year heart disease kills more Canadians than any other disease. Lifestyle changes must accompany any medical treatment. A low-fat diet plus regular exercise are keys to prevention.

Aneurysm

An **aneurysm** is a bulge that forms in the wall of a weakened blood vessel, usually an artery. The most common sites are the aorta of the heart, the abdominal aorta, and arteries in the brain. Aneurysms are often due to atherosclerosis. In much the same way as the weakened wall of an inner tube begins to bulge, the weakened segment of the artery protrudes as blood pulses through. The thinner wall offers less support and eventually ruptures. Less oxygen and nutrients are delivered to the tissues, resulting in cell death. An aneurysm in the brain is one of the conditions that can cause a stroke.

aneurysm a bulge in the weakened wall of a blood vessel, usually an artery

mini Investigation — Monitoring Your Pulse

Walking or mild exercise will increase your heart rate by 20 % to 30 %. For those in good health, increased energy demands during extreme exercise can raise the heart rate to an incredible 200 beats per minute. Although few individuals can sustain such a rapid heart rate, it indicates the capacity of the heart to adjust to changing situations.

Do not perform this activity if you are not allowed to participate in physical education classes.

- While sitting still, place your index and middle finger near your wrist, as shown in **Figure 5**. The pulse you feel is blood rushing through the brachial artery in your arm. Count the number of heartbeats in 30 s. Record your pulse at rest and then calculate the heart rate as beats per min.
- Remain sitting quietly and place your index finger and middle finger on the side of your neck just to the side your trachea. You will feel blood pulse through the carotid artery, which is an artery that carries blood to the head. Take your pulse for 30 s and then calculate the heart rate for 1 min.
- Run on the spot for approximately 2 min.
- Take your pulse immediately after exercise using either the carotid artery or the brachial artery. Record your heart rate.

(a) Compare the strength of the pulse in the carotid artery with that in your arm.
(b) Compare your heart rate before and after exercise.
(c) Do you think the difference between resting heart rate and the heart rate after exercise would be greater for athletes? Explain your answer.

Figure 5
Arteries near the surface permit taking of the pulse.

Capillaries

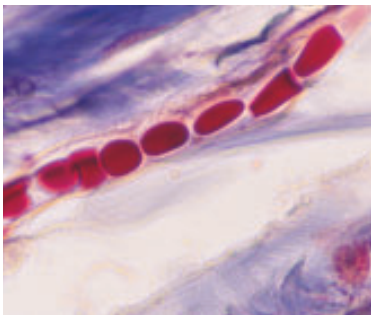


Figure 6
Red blood cells in a capillary. Notice that the capillary is only wide enough for cells to pass through one at a time.

Capillaries, composed of a single layer of cells, are the sites of fluid and gas exchange between blood and body cells. Many active cells, such as muscle cells, may be supplied by more than one capillary. Most capillaries are between 0.4 and 1.0 mm long with a diameter of less than 0.005 mm. The diameter is so small that red blood cells must travel through capillaries in single file (**Figure 6**). The single cell layer of capillaries, although ideal for diffusion, creates problems. Capillary beds are easily destroyed. High blood pressure or any impact, such as that caused by a punch, can rupture the thin-layered capillary. Bruising occurs when blood rushes into the spaces between tissues.

Oxygen diffuses from the blood into the surrounding tissues through the thin walls of the capillaries into the body cells. Oxygenated (oxygen-rich) blood appears red in colour, while deoxygenated (oxygen-poor) blood appears purple-blue as it leaves the capillary. The deoxygenated blood collects in small veins called venules and is carried back to the heart. Some protein is also exchanged, but this process is not believed to involve diffusion. Water-soluble ions and vitamins are believed to pass through spaces in the walls of the capillary vessels. Because some spaces are wider than others, some capillaries may be more permeable than others.

mini Investigation — Observing Blood Flow in a Fish Tail

William Harvey described the movement of blood through vessels in the early 1600s. He concluded that blood carried nutrients to tissues and transported wastes away from tissues to specialized organs. Unable to see capillaries, Harvey speculated that tiny blood vessels were the sites of diffusion of wastes and nutrients between cells and the circulating blood.

Materials: goldfish, net, absorbent cotton, Petri dish, cover slip, light microscope

- Using the net, carefully remove a small goldfish from the aquarium and place it in the Petri dish.
- Cover the goldfish, except the head and tail, with absorbent cotton that has been soaked with aquarium water. Place enough cotton to completely cover the fish. The gills must be covered and soaked with water.
- Add a cover slip to the tail (**Figure 7**).
- Position the Petri dish on the stage of a light microscope and observe the fish tail under low-power magnification.
- When you have completed your observations, gently remove the cotton and submerge the Petri dish into the aquarium to release the fish unharmed.

(a) Describe the movement of blood in arterioles, capillaries, and venules.

(b) Explain why capillary walls are much thinner than those of the arterioles or venules.

(c) Blood cells squeeze through capillaries, moving in single file. Explain the advantage of single-file motion and the slowing of blood cells through the capillary.

(d) Where would you expect to find more capillaries: muscle tissue or fat tissue? Give reasons for your answer.

(e) Live animals are used in many research experiments. Comment of the use of live animals in research.

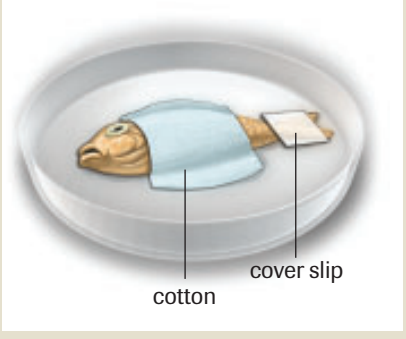


Figure 7
Experimental setup

Practice

1. What causes a pulse?
2. Define vasodilation and vasoconstriction.
3. What are the functions of capillaries?

Veins and Venules

Capillaries merge and become progressively larger vessels, called venules. Unlike capillaries, the walls of venules contain smooth muscle. Venules merge into **veins**, which have greater diameter. Gradually, the diameter of the veins increases as they approach the heart. However, the process of returning the blood to the heart is difficult. As blood flows from arteries to arterioles to capillaries, blood flow is greatly reduced. As blood passes through a greater number of narrower vessels with weaker walls, fluid pressure is reduced. (See **Figure 3** on page 314 for a comparison of the walls of arteries and veins.) By the time blood enters the venules, the pressure is between 15 mmHg and 20 mmHg. This pressure is not enough to drive the blood back to the heart, especially from the lower limbs.

vein a blood vessel that carries blood toward the heart

How then does blood get back to the heart? William Harvey, the English physiologist, conducted experiments to answer that question. In one experiment, he tied a band around the arm of one of his subjects, restricting venous blood flow. The veins soon became engorged with blood and swelled. Harvey then placed his finger on the vein and pushed blood toward the heart. The vein closed up or collapsed. Harvey repeated the procedure, but this time he pushed the blood back toward the hand. Bulges appeared in the vein at regular intervals. What caused the bulges? Dissection of the veins confirmed the existence of valves.

The valves open in one direction, steering blood toward the heart. They do not allow blood to flow back in the other direction (**Figure 8 (a)**). When Harvey tried to push blood toward the hand, the valves closed, causing blood to pool in front of the valves and distend the vein. When he directed blood toward the heart, the valves opened and blood flowed from one compartment into the next. The vein collapsed because the band tied around the arm prevented the blood from passing.

Skeletal muscles also aid venous blood flow. Venous pressure increases when skeletal muscles contract and push against the vein. The muscles bulge when they contract, thereby reducing the vein's diameter. Pressure inside the vein increases and the valves open, allowing blood to flow toward the heart. Sequential contractions of skeletal muscle create a massaging action that moves blood back to the heart (**Figure 8 (b)**). This may explain why you feel like stretching first thing in the morning. It also provides a reason why some people faint after standing still for long periods of time. Blood begins to pool in the lower limbs and cannot move back to the heart without movement of the leg muscles.

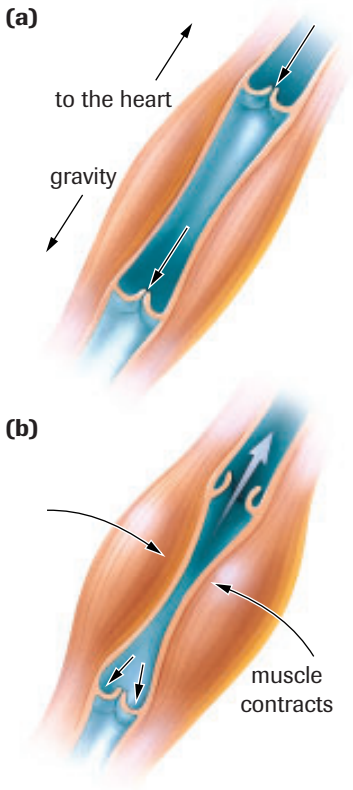


Figure 8
Venous valves and skeletal muscle work together in a low-pressure system to move blood back to the heart.

The veins serve as more than just low-pressure transport canals; they are also important blood reservoirs. As much as 65 % of your total blood volume can be found in the veins. During times of stress, venous blood flow can be increased to help you meet increased energy demands. Nerve impulses cause smooth muscle in the walls of the veins to contract, increasing fluid pressure. Increased pressure drives more blood to the heart.

Unfortunately, veins, like other blood vessels, are subject to problems. Large volumes of blood can distend the veins. In most cases, veins return to normal diameter, but if the pooling of blood occurs over a long period of time, the one-way valves are damaged. Without proper functioning of the valves, gravity carries blood toward the feet and greater pooling occurs. Surface veins gradually become larger and begin to bulge. This disorder is known as varicose veins. Although there is a genetic link to weakness in the vein walls, lifestyle can accelerate the damage. Prolonged standing, especially with restricted movement, increases pooling of blood. Prolonged compression of the superficial veins in the leg can also contribute to varicose veins.

mini Investigation — Mapping Veins

CAUTION: Do not leave the sphygmomanometer inflated past 30 mmHg or on longer than 5 min.

- Place a pressure cuff (sphygmomanometer) over a subject's upper arm and inflate it to 30 mmHg.
- Locate one of the veins on the inside of the subject's arm and use your index finger to push blood in the vein toward the elbow.
- Describe the appearance of the vein. Draw a diagram to illustrate your description.
- Now push the blood in the vein toward the fingers.
- Describe the appearance of the vein. Draw a diagram to illustrate your description.

(a) How do you know that the blood vessel is a vein and not an artery?

SUMMARY — Blood Vessels

- Arteries carry blood away from the heart.
- Vasoconstriction is a reduction in the diameter of the blood vessel, decreasing blood flow and the amount of oxygen to the tissues. Vasodilation is an increase in the diameter of the blood vessel, increasing blood flow and the amount of oxygen to the tissues.
- Atherosclerosis is a narrowing of the arteries due to a buildup of plaque that contains fat.
- Capillaries are the site of fluid and gas exchange between the blood and the cells.
- Veins carry blood toward the heart.
  - Pressure in the veins is much lower than in the arteries.
  - One-way valves and skeletal muscles help venous blood flow.

Section 10.1 Questions

1. Explain what happens in the blood vessels when someone blushes. Why does this happen?
2. Are all the capillaries open all the time? Why or why not? What determines whether a capillary is open?
3. What are the advantages and disadvantages of capillaries being composed of a single cell layer?
4. Explain the importance of William Harvey's theory of blood circulation.
5. Why are aneurysms dangerous?
6. Prepare a table comparing arteries and veins.
7. Fluid pressure is very low in the veins. Explain how blood gets back to the heart.
8. What causes varicose veins? What lifestyle changes could prevent the development of varicose veins?
9. Atherosclerosis is a disease caused by the buildup of plaque inside an artery.
   (a) Explain how it occurs.
   (b) What problems can be created by the buildup of plaque?
   (c) Suggest a treatment for the disorder.

The Heart 10.2

The heart is a muscular organ that pumps to circulate blood throughout the body. A fluid-filled membrane called the pericardium surrounds the heart. The fluid bathes the heart, preventing friction between its outer wall and the covering membrane.

The heart consists of two parallel pumps separated by the **septum**. The pumping action is synchronized; muscle contractions on the right side mirror those on the left. The pump on the right receives deoxygenated blood from the body tissues and pumps it to the lungs. The pump on the left receives oxygenated blood from the lungs and pumps it to the cells of the body. Vessels that carry blood to and from the lungs make up the **pulmonary circulatory system**. Vessels that carry blood to and from the body make up the **systemic circulatory system**. **Figure 1** illustrates the two systems.

The four-chambered human heart is composed of two thin-walled **atria** (singular: **atrium**) and two thick-walled **ventricles**. Blood from the systemic system enters the right atrium, and blood from the pulmonary system enters the left atrium. The stronger, more muscular ventricles pump the blood to distant tissues.

septum a wall of muscle that separates the right and left sides of the heart

pulmonary circulatory system the system of blood vessels that carries deoxygenated blood to the lungs and oxygenated blood back to the heart

systemic circulatory system the system of blood vessels that carries oxygenated blood to the tissues of the body and deoxygenated blood back to the heart

atrium (plural: **atria**) a thin-walled chamber of the heart that receives blood from veins

ventricle a muscular, thick-walled chamber of the heart that delivers blood to the arteries

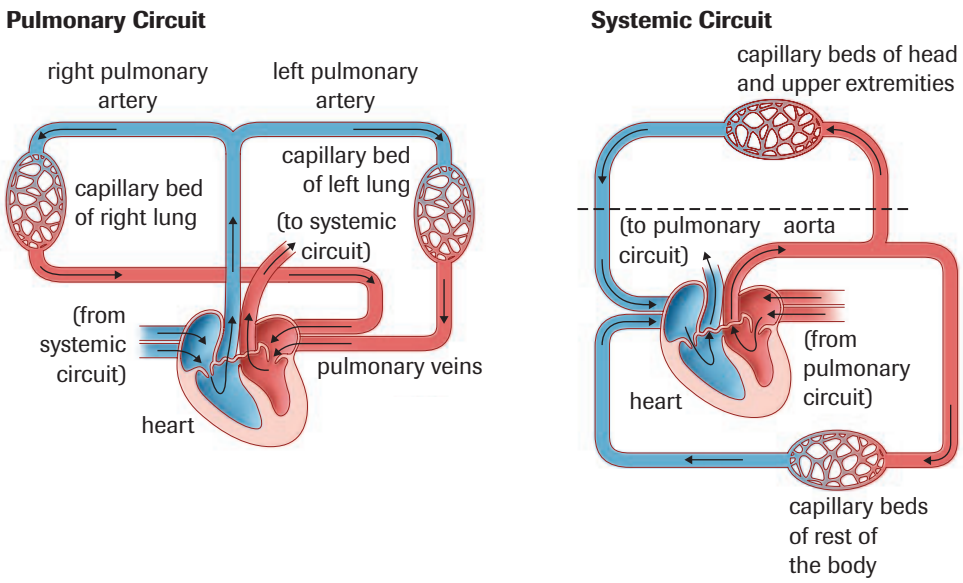


Figure 1
The pulmonary and systemic circuits of the circulatory system. The blood vessels carrying oxygenated blood are in red; the vessels carrying deoxygenated blood are in blue.

One-Way Blood Flow

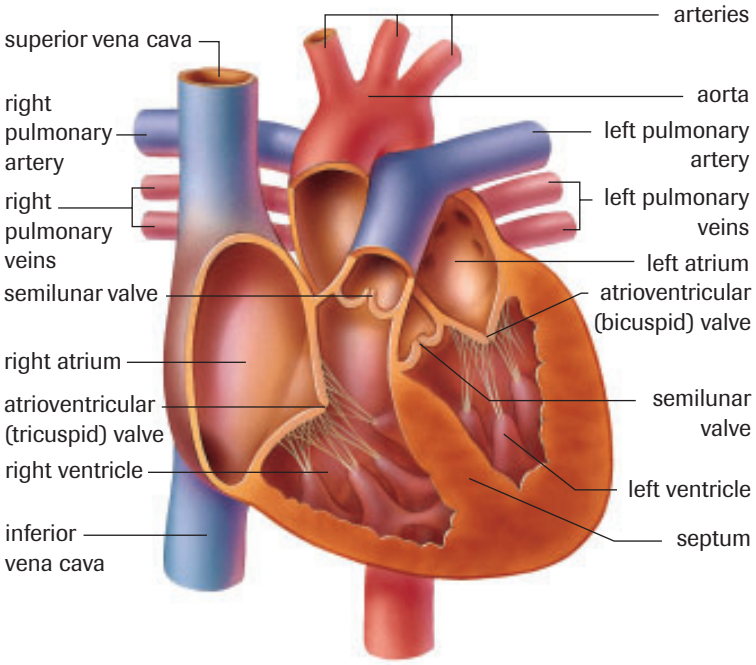
Blood is carried to the heart by veins. The superior vena cava carries deoxygenated blood from the head and upper body to the right atrium. The inferior vena cava carries deoxygenated blood from all veins below the diaphragm to the same atrium. Oxygenated blood flowing from the lungs enters the left atrium by way of the pulmonary veins. Blood from both atria is eventually pumped into the ventricles.

Valves called **atrioventricular (AV) valves** separate the atria from the ventricles. In much the same way as the valves within veins ensure one-directional flow, the AV valves prevent the flow of blood from the ventricles back into the atria. The AV valves are supported by bands of connective tissue called chordae tendinae. A second set of valves, called **semilunar valves**, separate the ventricles from the arteries. These valves are half-moon shaped (hence, the name *semilunar*), and they prevent blood that has entered the arteries from flowing back into the ventricles (**Figure 2**, next page).

atrioventricular (AV) valve a heart valve that prevents the backflow of blood from a ventricle into an atrium

semilunar valve a valve that prevents the backflow of blood from an artery into a ventricle

Figure 2
Anatomy of the human heart



aorta the largest artery in the body; carries oxygenated blood to the tissues

coronary artery an artery that supplies the cardiac muscle with oxygen and nutrients

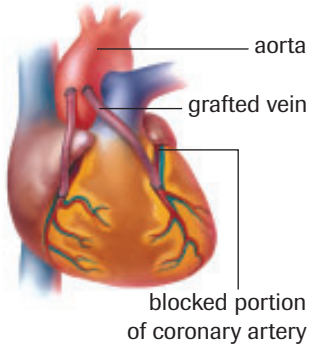


Figure 3
Coronary bypass operation. Blood flow is rerouted around the blockage.

Blood is carried away from the heart by arteries. The **aorta**, the largest artery in your body, carries oxygenated blood away from the heart. The **coronary arteries**, arteries that form an important branch of the aorta, supply the muscle cells of the heart with oxygen and nutrients. A blocked artery illustrates the importance of proper coronary circulation. Chest pain, or angina, occurs when too little oxygen reaches the heart. The heart, unlike other organs that slow down if they cannot receive enough nutrients, must continue beating no matter what demands are placed on it. It has been estimated that the heart may use 20 % of the body's total blood oxygen during times of stress.

As with other arteries, fat deposits and plaque can collect inside coronary arteries. Medications are often used to increase blood flow, but in severe situations blood flow must be rerouted. A coronary bypass operation involves removing a vein from another part of the patient's body and grafting it into the heart (**Figure 3**). However, for the vein to be grafted, the heart must be temporarily stopped. During the operation, the patient's heart is cooled and a heart–lung machine is used to supply oxygen and push blood to the tissues of the body.

Practice

1. Differentiate between the systemic and the pulmonary circulatory systems.
2. What is the function of the AV valves and the semilunar valves?
3. What is angina and what causes it?
4. What is a coronary bypass operation and why is it performed?

EXPLORE an issue

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Growing a New Heart

Cardiovascular disease is the leading cause of death in North America. About 44 000 Canadians, 40 % of them younger than 65 years, die each year from heart disease. Over 4000 patients in Canada and the United States are on the waiting list for a new heart. Only the sickest patients make the list, and not all of them will receive a new heart—some will die waiting. Aggressive campaigns to educate people about the importance of organ donation have resulted in increased numbers of donors. However, it may not be enough. Over the past few years, the demand for organs has been rising by about 15 % per year, and this rate will likely increase. Fewer than 3000 patients worldwide receive heart transplants annually.

Dr. Michael Sefton (**Figure 4**), director of the Institute of Biomaterials and Biomedical Engineering at the University of Toronto, has a solution that would provide an almost unlimited number of hearts for transplant. What Sefton calls a "heart in a box" is a transplantable heart that can be grown in the laboratory.

First, researchers must create scaffolding that the cells will grow around (**Table 1**). Typically, biodegradable plastics are used. The next step is to seed the scaffolding with living cells. The scaffolding and cells are then placed in a bioreactor—a sort of incubator that maintains constant temperature and provides the nutrients and oxygen required to support cell division. The cells secrete proteins and growth factors that bind them together to form living tissues. Although researchers have not yet been able to grow a complete living heart, they have successfully grown components of the heart.

Statement

Individuals who adopt unhealthy lifestyle choices that are dangerous to the health of their heart should not have the opportunity to have another one grown for them.

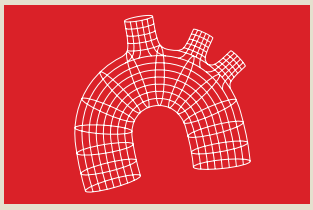
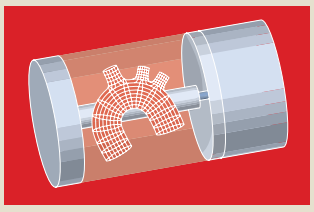
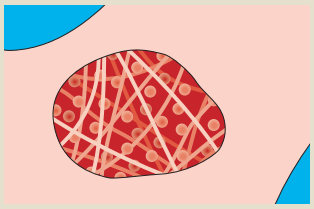
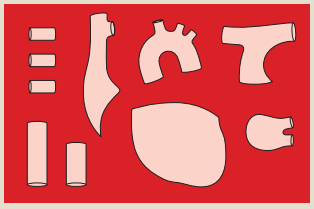
Figure 4
Dr. Michael Sefton

1. Form a group and research the issue.

www.science.nelson.com GO

2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statement.
5. Defend your position in the debate.
6. Should this technology be used to support people who have an unhealthy lifestyle?

Table 1 Procedure for Growing a Heart

1. Cells are placed on plastic scaffolding. 	2. The scaffolding, seeded with cells, is placed in a bioreactor that provides nutrients and oxygen. 
3. The cells divide and fill the open spaces of the scaffolding. 	4. This technique can be used to grow parts of the heart and perhaps, eventually, the entire organ. 

INVESTIGATION 10.1 *Introduction*

Fetal Pig Dissection

The organ systems of humans and pigs are arranged in the body in very similar ways. In this investigation, you will explore the arrangement of the digestive, respiratory, and circulatory systems that you have learned about in this unit.

To perform this investigation, turn to page 340.

Report Checklist

- ● Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ○ Synthesis

WWW *WEB Activity*

Simulation—Observing the Movement of Blood through the Heart

In this activity, you will follow the movement of blood through a virtual beating heart. Before you begin, write or draw a description of how you think blood moves through the heart. After you have finished, make any changes that are needed.

www.science.nelson.com GO

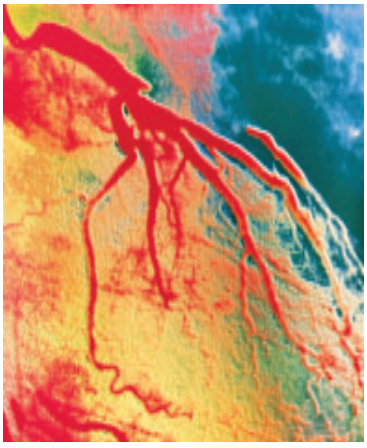


Figure 5
Dye showing the coronary arteries

Cardiac Catheterization

At one time, doctors had to rely on external symptoms to detect coronary artery blockage. An inability to sustain physical activity, rapid breathing, and a general lack of energy are three of the symptoms of coronary distress. However, these same symptoms can also indicate a wide variety of other circulatory and respiratory diseases. One way to determine whether or not a patient is suffering from coronary artery problems is to perform surgery. Unfortunately, the surgery is not without risks. Clearly, less invasive means for diagnosing the problem would be desirable.

One of the most useful techniques to detect coronary artery blockage is cardiac catheterization. In this procedure, a small, thin hollow tube, called a catheter, is passed into an artery in the groin as the patient lies on an examination table. The catheter is then pushed up through the aorta and into the heart. A dye visible on X-ray film is then injected into the catheter. The dye travels through the blood vessels while its image is traced by a fluoroscope (a fluorescent screen). The image can also be projected on a television monitor (**Figure 5**). An area of restricted blood flow pinpoints the region of blockage. The catheter helps direct the surgeon to the problem prior to surgery. In a technique known as angioplasty, the catheter has a tiny balloon attached that can be inflated to open up the blocked blood vessel.

Blood samples can also be taken with the catheter to determine how much oxygen is in the blood in the different chambers. This tells the physician how well the blood is being oxygenated in the lungs. Low levels of oxygen in the left side of the heart can provide information about whether the circulatory and respiratory systems are working together efficiently. The catheter can even be used to monitor pressures in each of the heart chambers.

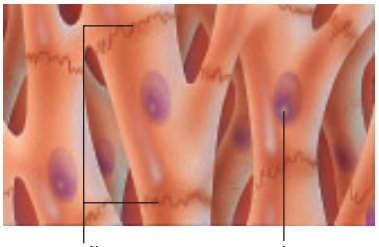


Figure 6
The heart is composed of cardiac muscle, which has a unique branching pattern.

myogenic muscle muscle that contracts without external nerve stimulation

Setting the Heart's Tempo

Heart, or cardiac, muscle differs from other types of muscle. Like skeletal muscle, cardiac muscle appears striated (striped) when viewed under a microscope. But unlike skeletal muscle, cardiac muscle displays a branching pattern (**Figure 6**). The greatest difference stems from the ability of this muscle to contract without being stimulated by external nerves. Muscle with this ability, called **myogenic muscle**, explains why the heart will continue to beat, at least for a short time, when removed from the body.

The remarkable capacity of the heart to beat can be illustrated by a simple experiment. When a frog's heart is removed and sliced into small pieces while in a salt solution that simulates the minerals found within the body, each of the pieces continues to beat, although not at the same speed. Muscle tissue from the ventricles follows a slower rhythm than muscle tissue from the atria. Muscle tissue closest to where the venae cavae enter the heart has the fastest tempo. The unique nature of the heart becomes evident when two separated pieces are brought together. The united fragments assume a single beat. The slower muscle tissue assumes the tempo set by the muscle tissue that beats more rapidly.

The heart's tempo or beat rate is set by the **sinoatrial (SA) node** (**Figure 7**). This bundle of specialized nerves and muscles is located in the upper right atrium. The SA node acts as a pacemaker, setting a rhythm of about 70 beats per minute for the heart. Nerve impulses are carried from the pacemaker to other muscle cells by modified muscle tissue. Originating in the atria, the contractions travel to a second node, the **atrioventricular (AV) node**. The AV node serves as a conductor, passing nerve impulses via two large nerve fibres, called **Purkinje fibres**, through the septum toward the ventricles. The Purkinje fibres run along the septum that separates the right and left ventricles, carrying impulses from the AV node to the bottom tip of the heart. From here, these branching fibres carry impulses up along the outer walls of the ventricles back toward the atria. A wave of cardiac contraction follows the nerve pathway. Both the right and left atria contract prior to the right and left ventricles. One of the greatest challenges for surgeons performing open-heart surgery is to make incisions at the appropriate location. A scalpel placed in the wrong spot could cut fibres that conduct nerve impulses.

Heart rate is influenced by autonomic nerves. Two regulatory nervous systems—the **sympathetic** and **parasympathetic nervous systems**—conduct impulses from the brain to the SA node. Stimulated during times of stress, the sympathetic nerves increase heart rate. This increases blood flow to tissues, enabling the body to meet increased energy demands. When the heart rate exceeds 100 beats per min, this is referred to as tachycardia. Tachycardia can result from exercise or from the consumption of such drugs as caffeine or nicotine. During times of relaxation, the parasympathetic nerves are stimulated to slow the heart rate.

sinoatrial (SA) node a small mass of tissue in the right atrium that originates the impulses stimulating the heartbeat

atrioventricular (AV) node a small mass of tissue in the right atrioventricular region through which impulses from the sinoatrial node are passed to the ventricles

Purkinje fibre a nerve fibre that branches and carries electrical impulses throughout the ventricles

sympathetic nervous system a division of the autonomic nervous system that prepares the body for stress

parasympathetic nervous system a division of the autonomic nervous system that returns the body to normal resting levels following adjustments to stress

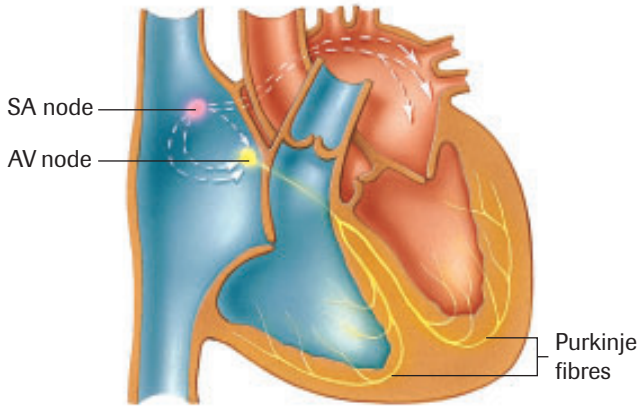


Figure 7
The SA node initiates heart contractions. Modified muscle tissue passes a nerve impulse from the pacemaker down the dividing septum toward the ventricles.

Practice

5. What is myogenic muscle?

6. What is the difference between the sympathetic and the parasympathetic nervous systems?

Case Study

Diagnosing Heart Conditions

Physicians can use electrocardiographs, which map electrical fields within the heart, to make tracings to diagnose certain heart problems. Electrodes that can detect the electrical impulses of the heart are placed on the body surface are connected to a recording device. The electrical impulses are displayed on a graph called an electrocardiogram (ECG) (**Figure 8**). Changes in electrical current reveal normal or abnormal events of the cardiac cycle. The first wave, referred to as the P wave, represents the electrical impulse that causes atrial contraction. The larger spike, referred to as the QRS wave, represents the electrical impulse that causes ventricular contraction. A final T wave signals that the ventricles have recovered. A patch of dead heart tissue, for example, will not conduct impulses and produces abnormal line tracings (**Figure 9**). By comparing the tracings, physicians are able to locate the area of the heart that is damaged.

The electrocardiograph is especially useful for monitoring the body's response to exercise. Stress tests are performed by monitoring a subject who is riding a stationary bike or running on a treadmill. Some heart malfunctions remain hidden during rest, but can be detected during vigorous exercise.

Physicians often refer to an irregular heartbeat as arrhythmia (**Figure 10**). One cause of arrhythmia is a blocked coronary artery. When a coronary artery is blocked, it delivers less blood and can cause the heart to beat in an irregular pattern. The buildup of toxic products associated with poor oxygen delivery can initiate contractions of the heart muscle. Rather than synchronized heartbeats, where muscle cells within the ventricles pick up electrical signals from surrounding muscle fibres, each cell within the ventricle responds to the toxins surrounding it and begins to contract wildly. This is referred to as ventricular fibrillation.

As the heart fibrillates, blood is not pumped in a coordinated fashion. The twitching heart pushes blood back and forth, reducing its ability to deliver needed oxygen. The heart responds by beating faster, but without a controlled pattern of muscle contraction, blood delivery to the tissues will not improve.

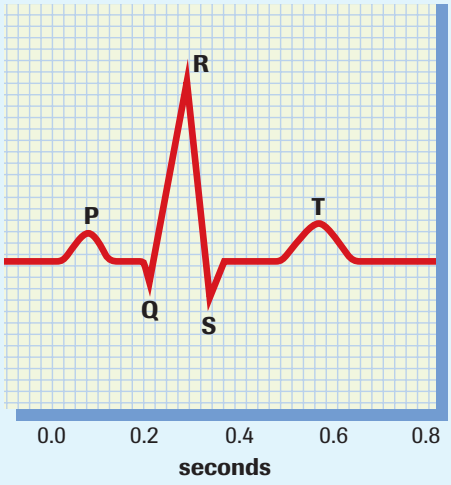


Figure 8
Electrocardiogram (ECG) showing the duration of a single beat. The flat lines show the resting period between beats.

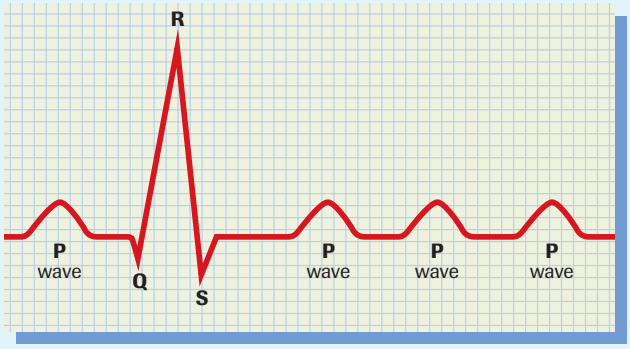
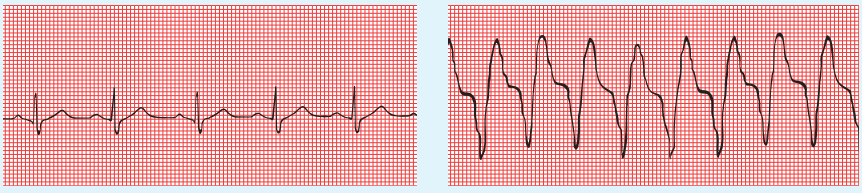


Figure 9
An abnormal electrocardiogram

Case Study Questions

1. What do the repetitive P waves in **Figure 9** indicate?
2. What would a small QRS wave indicate?
3. What is arrythmia?
4. Why is ventricular fibrillation dangerous?

Figure 10
Not all arrhythmias are abnormal. The ECG in **(a)** is a slowed heart rate associated with athletes. The ECG in **(b)** shows an uncontrolled heart rate, or ventricular fibrillation.



(a) **(b)**

Heart Sounds

The familiar *lubb-dubb* heart sounds are caused by the closing of the heart valves. The period of relaxation of the heart is called **diastole**, during which both the atria and the ventricles are relaxed. When the atria are relaxed, they fill with blood (**Figure 11 (a)**). The atria then contract, increasing fluid pressure and forcing the AV valves open. Blood flows from the atria into the ventricles (**Figure 11 (b)**). In turn, the filled ventricles contract. The pressure forces the AV valves shut, producing a heavy *lubb* sound and pushing blood through the semilunar valves and into the arteries (**Figure 11 (a)**). The period of contraction is called **systole**. The ventricles then relax, and their volume increases. With increased volume, pressure in the ventricles decreases and blood tends to be drawn from the arteries toward the area of lower pressure; however, the blood is prevented from re-entering the ventricles by the semilunar valves. The closing of the semilunar valves creates the lighter *dubb* sound.

diastole relaxation (dilation) of the heart, during which the atria fill with blood

systole contraction of the heart, during which blood is pushed out of the heart

Occasionally, the valves do not close completely. This condition is one cause of heart murmurs. The heart murmur occurs when blood leaks past the closed heart valve because of an improper seal. The AV valves, especially the left AV valve (the bicuspid valve), are especially susceptible to defects. The rush of blood from the ventricle back into the atrium produces a gurgling sound that can be detected with a stethoscope. Blood flowing back toward the atrium is inefficient because it is not directed to the systemic or pulmonary systems. The hearts of individuals who experience these murmurs compensate for decreased oxygen delivery by beating faster and eventually enlarging.

A second mechanism helps compensate for decreased blood flow in people with leaky heart valves. Like an elastic band, the more cardiac muscle is stretched, the stronger is the force of contraction. When blood flows from the ventricle back into the atrium, blood volume in the atrium increases. The atrium accepts the normal volume and the additional blood from the ventricle. The extra volume stretches the atrium and drives blood to the ventricle with greater force. The increased blood volume in the ventricle causes it to contract with greater force, driving more blood to the tissues.

DID YOU KNOW?

The First Stethoscope

In 1816, René Laennec, a young physician, was examining a patient for heart distress. The practice at the time was for the doctor to place his ear on the patient's chest and listen for the *lubb-dubb* sounds. However, Laennec decided to try another approach. He rolled up a paper and placed it to the patient's chest. The heart sounds became clearer. Later, wooden cylinders were used, eventually to be replaced by the modern Y-shaped stethoscope.

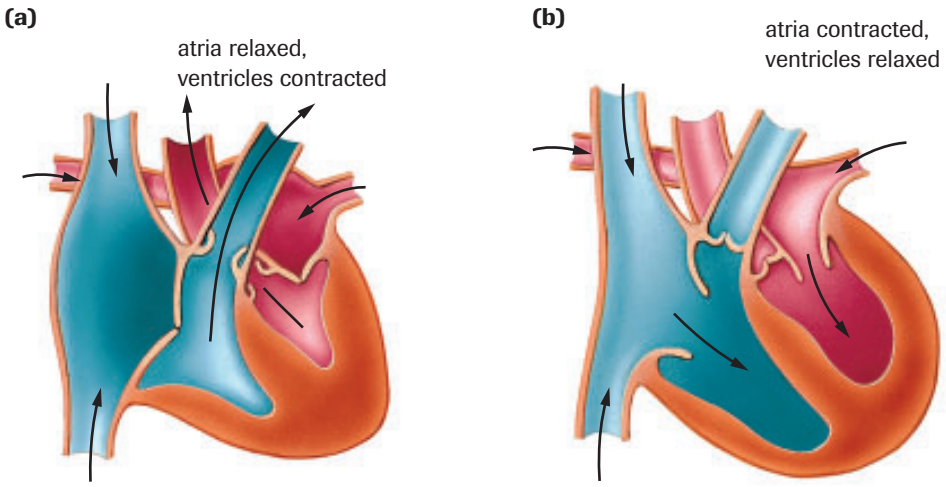


Figure 11
(a) The relaxed atria fill with blood. Ventricular contractions close the AV valves and open the semilunar valves.
(b) The relaxation of the ventricles lowers pressure and the right and left atria contract in unison, pushing blood into the right and left ventricles. The closing of the semilunar valves prevents blood from re-entering the ventricles.

Practice

7. Explain the terms *diastole* and *systole*.
8. What causes the characteristic heart sounds?
9. What is one cause of heart murmurs?

EXTENSION

CBC radio ONE

QUIRKS & QUARKS

The State of Statins

Researchers interviewed in this clip support the use of a class of drugs called statins to treat individuals with high cholesterol, to reduce the risk of heart disease. However, using drugs on otherwise healthy people, particularly before they change their eating and exercise habits, is controversial.

www.science.nelson.com GO

Medications and the Heart

Many traditional homeopathic medical treatments are now being supported by science. Foxglove *(Digitalis purpurea)*, a popular garden plant in Britain, has long been used in tea as a tonic. Scientists have found that the active ingredient in the plant, digitalis, initiates strong, regular heart contractions, and it is now used to treat congestive heart failure. Nitroglycerin, an explosive, has also been used to prevent heart attacks. It works by relaxing smooth muscle and dilating blood vessels.

Medical therapy for heart failure has improved greatly with the development of beta-blockers. These drugs are especially important for people with irregular heartbeats or who display the effects of high blood pressure.

Receptor sites located on the surface of cells receive molecules, such as hormones, that affect the way cells behave. Epinephrine, a stress hormone, attaches to receptors on the heart and blood vessels, increasing heart rate and narrowing the blood vessels. Both effects lead to an increase in blood pressure. Beta-blockers tie up receptor sites that accept epinephrine.

There are two types of beta-receptors on cell surfaces, beta 1 and beta 2. Beta 1 receptors are found on the surface of the cardiac muscle. These affect the speed and strength of heart contractions and directly influence blood pressure. Beta 2 receptors are found primarily in the blood vessels and the bronchioles leading into the lungs. When the effects of the stress hormone are blocked, the heart rate slows and blood vessels relax, leading to a reduction in blood pressure.

Like most medications, beta-blockers can have side effects. Since they reduce the effects of stress hormones by slowing the heart, patients may feel tired, be less able to exercise vigorously, or experience lightheadedness or dizziness due to low blood pressure.

mini Investigation — Effects of Caffeine on Heart Rate

Materials: concave depression slide, glycerin, cover slip, *Daphnia* culture, strong coffee (not hot), medicine dropper, pencil, paper, watch

- Place a few drops of glycerin into the depression slide.
- Using a medicine dropper, place a small drop of the *Daphnia* culture onto the glycerin.
- Prepare a wet mount by adding a cover slip and observe under low magnification.
- While observing the beating heart, have your lab partner indicate a start time and a stop time 30 s later. Mark with your pencil on a piece of paper every time the heart beats.
- Record the heart rate for *Daphnia.* Conduct two more trials.
- Remove the cover slip and add a drop of coffee. Replace the cover slip and repeat the same procedure.

(a) Record the data you have collected in a data table.
(b) Calculate the mean heart rate for the control and the caffeine.
(c) Present the data you have collected using a graph.
(d) How did caffeine affect heart rate?
(e) It was noted that two different groups did not have exactly the same data. Identify variables that could affect the heart rate.
(f) What changes would you suggest to produce repeatable data?

SUMMARY The Heart

- The pulmonary circulatory system is the system of blood vessels that carries blood to and from the lungs. The systemic circulatory system is the system of blood vessels that carries blood to and from the body.
- The heart consists of two parallel pumps separated by the septum.
  - Blood enters the heart through the atria.
  - Ventricles pump the blood to the body tissues.
  - Atrioventricular valves prevent the flow of blood from the ventricles back into the atria.
  - Semilunar valves prevent blood the flow of blood from arteries back into the ventricles.
  - Coronary arteries supply the heart with oxygen and nutrients.
- The heart rate is set by the sinoatrial (SA) node. Contractions in the SA node travel to the atrioventricular (AV) node and then travel along the Purkinje fibres to the rest of the heart.
- Diastole is heart relaxation. Systole is heart contraction.
- The *lubb-dubb* sound is caused by the AV valves and the semilunar valves closing in turn as blood is pushed from the atria through the ventricles and out of the heart. If the valves do not close completely, the heart compensates by beating faster and pumping blood with more force.

EXTENSION

Operation: Heart Transplant

Enter the virtual *NOVA* operating theatre, where you will be given a scalpel and perform a heart transplant.

www.science.nelson.com GO

Section 10.2 Questions

1. What are the atria and the ventricles? How do they differ in structure and function?
2. In what sense is blood flow in the body one way?
3. Draw and label the major blood vessels and chambers of the heart. Trace the flow of deoxygenated and oxygenated blood through the heart.
4. Describe cardiac catheterization and explain its usefulness.
5. Explain differences in the strength of a pulse between the carotid artery (neck area) and the brachial artery (wrist area).
6. Explain changes in the pulse after exercise.
7. Describe the pathway of nerve impulses through the heart. Refer to the terms *sinoatrial node, atrioventricular node,* and *Purkinje fibres.*
8. How does the heart compensate for the improper function of the AV valves?
9. What is an electrocardiogram? Why is it useful? Explain what the different waves of an electrocardiogram indicate.
10. Draw a flow chart or diagram to show how a beta-blocker works.
11. When researching the impact of scientific knowledge or technology on society, what kinds of sources do you consult? Do you think that medical or scientific sources will give an impartial point of view? Explain.
12. Medical technologies are often patented, bringing in great profits to the owners. Using print or electronic media, find out about some of these technologies. Do you think that technology such as an artificial heart should be owned? What are the social and moral implications of such ownership?

    www.science.nelson.com GO
13. Predict some advantages and disadvantages of artificial hearts over donor hearts.
14. All drugs that block beta 2 receptors also block beta 1 receptors. Some drugs work selectively by blocking beta 1 receptors without affecting the beta 2 receptors. Indicate which drug, a beta 2 nonselective or beta 1 selective drug, would produce fewer side effects. Give your reasons.

10.3 Regulation of Blood Flow

Blood surges through the arteries with every beat of the heart. Elastic connective tissue and smooth muscle in the walls of the arteries stretch to accommodate the increase in fluid pressure. The arterial walls recoil much like an elastic band as the heart begins the relaxation phase characterized by lower pressure. Even the recoil forces help push blood through arterioles toward the tissues.

Cardiac Output

Cardiac output is defined as the amount of blood that flows from the heart per minute. Unless some dysfunction occurs, the amount of blood pumped from the right side of the heart is equal to the amount of blood pumped from the left side of the heart. Two factors affect cardiac output: stroke volume and heart rate.

cardiac output the amount of blood pumped from the heart each minute

stroke volume the quantity of blood pumped with each beat of the heart

Stroke volume is the quantity of blood pumped with each beat of the heart. The stronger the heart contraction, the greater the stroke volume. Approximately 70 mL of blood per beat leave each ventricle while you are resting. *Heart rate* is the number of times the heart beats per minute. The equation below shows how cardiac output is determined using stroke volume and heart rate.

$$\begin{aligned} \text{cardiac output} &= \text{stroke volume} \times \text{heart rate} \\ &= 70 \text{ mL/beat} \times 70 \text{ beats/min} \\ \text{cardiac output} &= 4900 \text{ mL/min} \end{aligned}$$

DID YOU KNOW ?

What's Your Resting Heart Rate?

Due to greater stroke volume, some athletes have much slower heart rates. The tennis player Bjorn Borg once demonstrated a resting heart rate of 35 beats/min.

Individuals who have a mass of 70 kg must pump approximately 5 L of blood per minute. Smaller individuals require less blood and, therefore, have lower cardiac outputs. Naturally, cardiac output must be adjusted to meet energy needs. During exercise, heart rate increases to meet increased energy demands.

The cardiac output equation provides a basis for comparing individual fitness. Why do two people with the same body mass have different heart rates? If you assume that both people are at rest, both should require the same quantity of oxygen each minute. For example, Tom, who has a heart rate of 100 beats per minute, has a lower stroke volume. Lee, who has a heart rate of 50 beats per minute, has a higher stroke volume.

Table 1 Cardiac Output of Two People

Person	Stroke volume (mL/beat)	Heart rate (beats/min)	Cardiac output (stroke volume × heart rate)
Tom	50	100	5 L
Lee	100	50	5 L

Lee's lower heart rate indicates a higher stroke volume. Strong hearts can pump greater volumes of blood with each beat. This is why athletes often have low heart rates. Hearts that are less strong are unable to pump as much blood per beat, but compensate by increasing heart rate to meet the body's energy demands. It is important to recognize that heart rate is only one factor that determines physical fitness. You may also find that your heart rate will fluctuate throughout the day. Various kinds of food, stress, or a host of other factors can affect your heart rate.

Blood Pressure

Blood pressure is the force of the blood on the walls of the arteries. It can be measured indirectly with an instrument called a **sphygmomanometer** (**Figure 1**). A cuff with an air bladder is wrapped around the arm. A small pump is used to inflate the air bladder, thereby closing off blood flow through the brachial artery, one of the major arteries of the arm. A stethoscope is placed below the cuff and air is slowly released from the bladder until a low-pitched sound can be detected. The sound is caused by blood entering the previously closed artery.

sphygmomanometer a device used to measure blood pressure

Each time the heart contracts, the sound is heard. A gauge on the sphygmomanometer measures the pressure exerted by the blood during ventricular contraction. This pressure is called systolic blood pressure. Normal systolic blood pressure is less than 120 mmHg (**Table 2**). (Blood pressure is measured in the non-SI units of millimetres of mercury, or mmHg.) The cuff is then deflated even more, until the sound disappears. At this point, blood flows into the artery during ventricular relaxation, or filling. This pressure is called diastolic blood pressure. Normal diastolic blood pressure is less than 80 mmHg. A systolic pressure of 120 mmHg and a diastolic pressure of 80 mmHg would be reported as 120/80 (120 over 80). Reduced filling, such as that caused by an internal hemorrhage, will cause diastolic blood pressure to fall. **Figure 2** shows that fluid pressure decreases with distance from the ventricles; thus, blood pressure readings are not the same in all arteries.

Figure 1
A sphygmomanometer

Table 2 Blood Pressure Categories (for 18 years and older)

	Blood Pressure (mmHg)	
Category	**Systolic**	**Diastolic**
normal	< 120	< 80
pre-hypertensive	120 to 139	80 to 89
hypertensive		
stage 1	140 to 159	90 to 99
stage 2	≥ 160	≥ 100

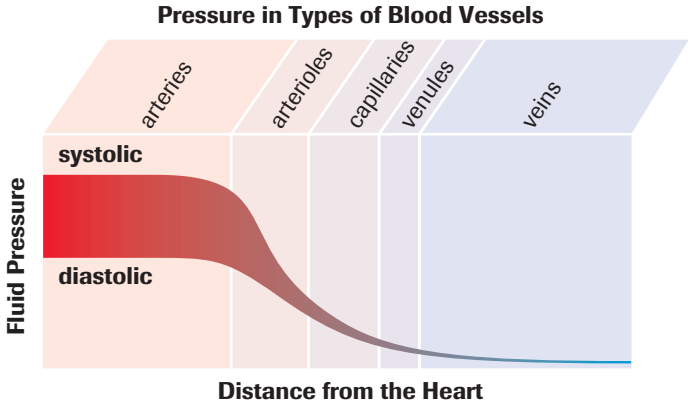


Figure 2
Fluid pressure decreases the farther blood moves from the heart.

Blood pressure depends on two factors. The first is cardiac output. Any increase in cardiac output will increase blood pressure. Another factor is arteriolar resistance. The diameter of the arteriole is regulated by smooth muscles. Constriction of the smooth muscles surrounding the arteriole closes the opening and reduces blood flow through the arteriole. With this reduced blood flow, more blood is left in the artery. The increased blood volume in the artery produces higher blood pressure. Conversely, factors that cause arteriolar dilation increase blood flow from the arterioles, thereby reducing blood pressure.

The smooth muscles in the walls of the arterioles respond to neural and hormonal controls that regulate blood pressure. The diameter of the arterioles also adjusts in response to metabolic products, such as those produced during the breakdown of glucose. When there is sufficient oxygen to break down glucose, carbon dioxide and water are produced. When there is insufficient oxygen, lactic acid is produced. Accumulation of carbon dioxide and lactic acid causes the relaxation of smooth muscles in the walls of the arterioles, dilating them. The dilated arterioles increase blood flow to local tissues, delivering more oxygen. Arteriolar dilation in response to increased metabolic

DID YOU KNOW

Blood Pressure Units

The SI metric unit for blood pressure is the kilopascal (kPa). However, in medicine, blood pressure is still measured in millimetres of mercury (mmHg). (1 mmHg = 0.133 322 4 kPa)

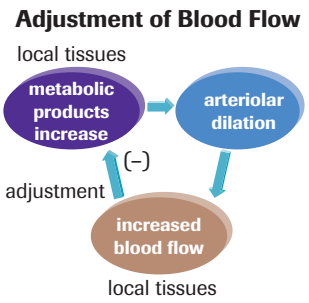


Figure 3
Control of arteriolar dilation

products is a good example of how the body maintains equilibrium (**Figure 3**). Activities such as exercise cause an increase in metabolic products. Because these products accumulate in the most active tissues, the increased blood flow helps provide greater nutrient supply and carries the potentially toxic materials away. Tissues that are less active produce fewer metabolic products. These arterioles remain closed until the products accumulate.

Hypertension: The Silent Killer

Hypertension (high blood pressure) is caused by increased resistance to blood flow, which results in a sustained increase in blood pressure. If blood pressure remains high, blood vessels are often weakened and may rupture. The body attempts to compensate for weakened vessels by increasing the support provided by connective tissues. Unfortunately, when the body increases the amount of connective tissue, arteries often become hard and less elastic. During systole, as blood pulses through these reinforced vessels, blood pressure increases more than usual, which in turn causes further stress and greater weakening.

Although hypertension is sometimes hereditary, diet is often a primary factor in the development of the disease. For example, in susceptible individuals, using too much salt can cause blood pressure to rise and the heart to work harder. Hypertension is often described as a silent killer because symptoms are usually not noticeable until the situation becomes very serious. A heart attack or stroke can be the first indication that something is wrong.

INVESTIGATION 10.2 ***Introduction***

Effects of Posture on Blood Pressure and Pulse

Blood pressure is affected by factors such as exercise, drugs, and even posture. In this investigation, you will explore whether changes in body position cause measurable changes in blood pressure and/or pulse.

To perform this investigation, turn to page 344.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

CAREER CONNECTION

Cardiology Technologist

Cardiology technologists carry out diagnostic testing and monitoring of the heart, and ensure that pacemakers are working properly. They operate equipment during electrocardiograms, exercise stress tests, and echocardiograms. Are you interested in a career as a cardiology technologist?

www.science.nelson.com GO

Regulation of Blood Pressure

Regulation of blood pressure is essential since low blood pressure reduces your capacity to transport blood. The problem is particularly acute for tissues in the head, where blood pressure works against the force of gravity. High blood pressure creates equally serious problems. High fluid pressure can weaken an artery and eventually result in its rupture.

Special blood pressure receptors are located in the walls of the aorta and the carotid arteries, which are major arteries found on either side of the neck. These receptors are sensitive to high pressures. When blood pressure exceeds acceptable levels, the receptors respond to the increased pressure on the wall of the artery. A nerve impulse travels to the medulla oblongata, the blood pressure regulator located in the brainstem. Sympathetic (stress) nerve impulses are decreased and parasympathetic (relaxation) nerve impulses are increased. In reponse to decreasing sympathetic nerve stimulation, arterioles dilate, increasing the outflow of blood from the artery. Stimulation of the parasympathetic nerve causes heart rate and stroke volume to decrease. The decreased cardiac output slows the movement of blood into the arteries, lowering blood pressure.

Low blood pressure is adjusted by the sympathetic nerves. Without nerve information from the pressure receptors of the carotid artery and aorta, the sympathetic nerves will continue to be stimulated, causing cardiac output to increase and arterioles to constrict. The increased flow of blood into the artery accompanied by decreased outflow raises blood pressure to acceptable levels.

EXPLORE an issue

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

Pre-teens and High Blood Pressure

For many years, high blood pressure was associated primarily with men over 40 years of age. High blood pressure creates health problems due to the stress exerted on blood vessels and the heart itself. Heart disease is the number one killer of North Americans over age 40. Insufficient physical exercise, increased daily stress, and poor eating habits have made hypertension more common in women and younger adults.

Ironically, in an era when we know more about the causes and effects of high blood pressure, more people seem to be at risk of developing future health problems.

What is even more disturbing is that younger people today are likely even more susceptible to high blood pressure than their grandparents. A survey of 5000 pre-teens conducted by the Heart and Stroke Foundation indicated that most of them were aware of the benefits of physical exercise and of eating five to ten portions of fruit and vegetables each day. The vast majority also identified smoking as harmful for the heart. However, that same survey indicated that just over 50 % had engaged in some physical exercise that day, nearly 33 % had been exposed to second-hand smoke, and only 14 % had consumed four or more servings of fruit and vegetables. Virtual computer games were identified as the main competition for physical games, and fast foods were preferred to fruit and vegetables.

The rate of obesity among pre-teen boys nearly tripled between 1981 and 1996, while the obesity rate for girls more than doubled during the same time frame. The heart must work harder to pump blood through extra blood vessels in order to provide oxygen and nutrients to the new fat cells.

High blood pressure and obesity contribute to the development of type 2 diabetes. Aboriginal peoples have an increased risk of diabetes compared to the general population. Knowing the risk factors is important for everyone. Researchers have shown that type 2 diabetes, once associated with middle-aged men and women, is now found in overweight adolescents.

Statement

Health ministers across Canada know that money spent on prevention to change lifestyle behaviours is less costly than treating disease. Some people have even speculated about providing tax credits for leading a healthy lifestyle. How can a healthy lifestyle be promoted? Should people receive tax credits or pay less medical insurance? What responsibility do governments have in promoting a healthy lifestyle?

1. Form a group and research the issue.

www.science.nelson.com GO

2. Discuss the issue with class members and others in preparation for a debate.
3. Write a list of points and counterpoints that your group has considered.
4. Take a stand. Decide if you agree or disagree with the statements.
5. Defend your position in the debate.

Response of the Circulatory System to Exercise

Your body's response to exercise is an excellent example of how the body maintains equilibrium. Exercise places considerable demands on the circulatory system, but this system does not act alone in monitoring the needs of tissues or in ensuring that adequate levels of oxygen and nutrients are delivered to the active cells. The nervous and hormonal systems also play important roles in adjustment.

During times of stress, the sympathetic nerves stimulate the adrenal glands. The hormone epinephrine (adrenaline) is released from the adrenal gland and travels in the blood to other organs of the body. Epinephrine stimulates the release of red blood cells from the spleen. Although the significance of the response is not yet understood, it is clear that increased numbers of red blood cells aid oxygen delivery. Epinephrine and direct stimulation from the sympathetic nerves increase heart rate and breathing rate. The increased heart rate provides for faster oxygen transport, while the increased breathing rate ensures

that the blood contains higher levels of oxygen. Both systems work together to improve oxygen delivery to active tissues. A secondary but important function is the increased efficiency of waste removal from the active tissues.

Blood cannot flow to all capillaries of the body simultaneously. The effect of dilating all arterioles at one time would be disastrous—blood pressure would plunge. Only the most active tissues receive priority in times of stress. As a result, epinephrine causes vasodilation of the arterioles leading to the heart, brain, and muscles, preparing the organism for the flight-or-fight reaction. At the same time, the blood vessels leading to the kidney, stomach, and intestines constrict, depriving these areas of blood until the stress situation has been overcome.

Practice

1. What is hypertension?
2. How does exercise affect your heart rate? Provide an explanation for any change.
3. How does exercise affect your blood pressure? Provide an explanation for any change.
4. How is it possible that two different people have different pulses after doing exactly the same exercise?

INVESTIGATION 10.3 ***Introduction***

Effects of Exercise on Blood Pressure and Pulse

How do you predict exercise will affect blood pressure and pulse? In this investigation, you will design and carry out a controlled experiment to test your prediction.

To perform this investigation, turn to page 344.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Regulating Body Temperature

thermoregulation maintenance of body temperature within a range that enables cells to function efficiently

Thermoregulation is the maintenance of body temperature within a range that enables cells to function efficiently. Different species of animals are adapted to different temperature ranges, and each animal has an optimal temperature range. To understand the mechanisms of temperature regulation, we first need to consider the exchange of heat between the body and the environment.

Humans are able to maintain a constant body temperature regardless of their surroundings. The body adjusts to decreases in environmental temperatures by increasing the rate of cellular respiration to generate heat. In humans, normal body temperature is usually 37 °C; however, there is variation within any population. Studies indicate that body temperatures vary slightly during the day. Temperature in most individuals falls slightly during the night. It should also be noted that core temperatures and peripheral temperatures of the body tend to vary from each other. Core temperatures, found in the chest cavity, the abdominal cavity, and the central nervous system, remain relatively constant and are usually higher than 37 °C. The peripheral temperatures can be as much as 4 °C lower on very cold days.

DID YOU KNOW?

Does Alcohol Warm You Up?

Many people believe that a drink of alcohol will warm them up on a cold day. Alcohol causes dilation of the arterioles leading to the skin capillaries, causing the sensation of warmth. However, the sensation is misleading. The dilation of these arterioles increases blood flow to the skin, which increases heat loss and speeds cooling.

Response to Temperature Stress

How does the body protect itself against excessive heat caused by exercise or high environmental temperatures? **Figure 4** shows what it does. When sensors in the brain detect a rise in body temperature, a nerve impulse is coordinated within the **hypothalamus**, and a signal is sent to the sweat glands to initiate sweating. The evaporation of perspiration from the skin causes cooling. At the same time, a nerve message is sent to the blood vessels in the skin, causing them to dilate. This allows more blood flow to the skin. Since the skin has been cooled by the evaporation of sweat, the blood loses heat to the skin. When blood from the skin returns to the core of the body, it cools the internal organs. Along with water, valuable salts are also carried to the skin's surface and lost with perspiration.

hypothalamus region of a vertebrate's brain responsible for coordinating many nerve and hormone functions

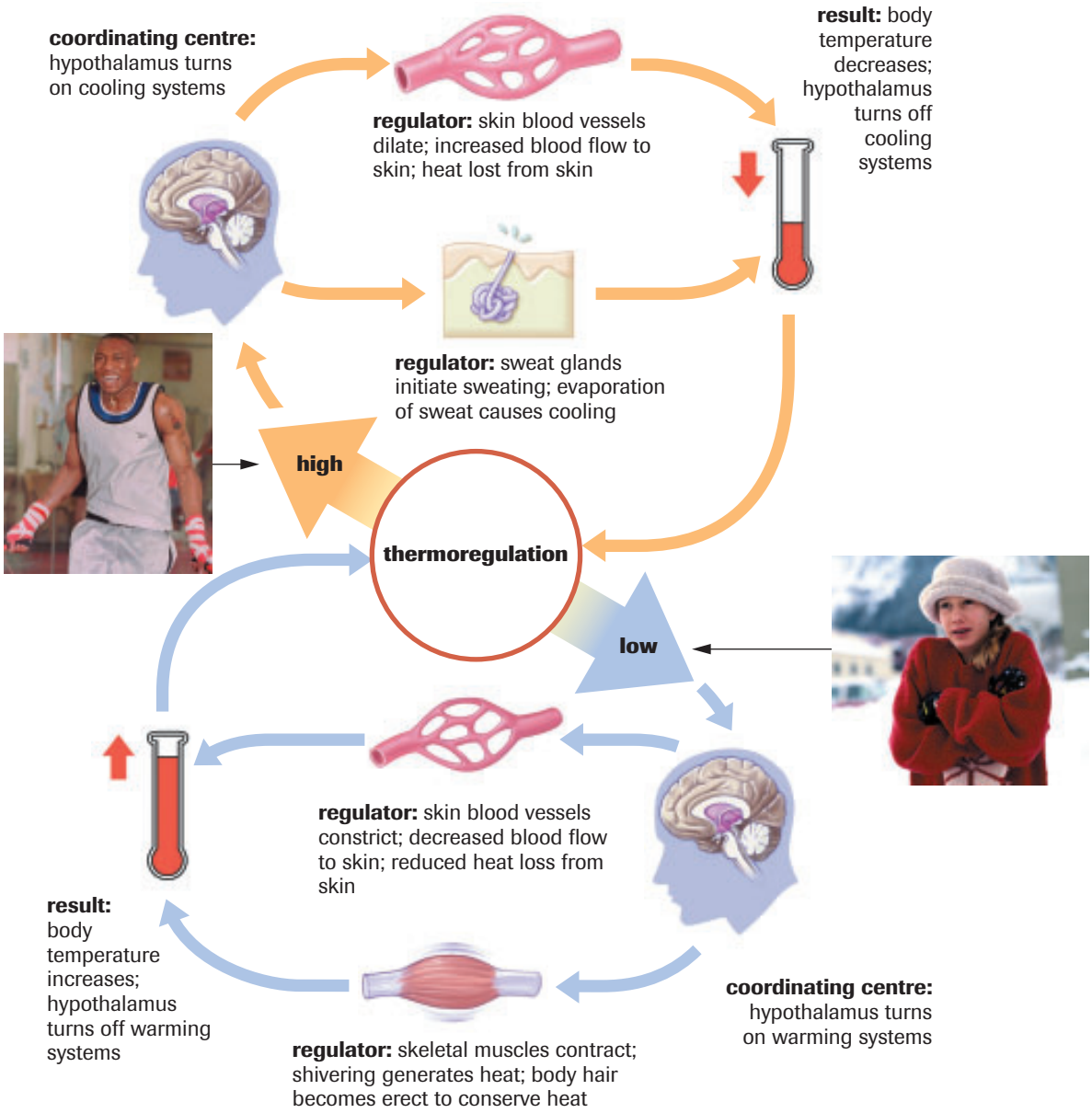


Figure 4

The evaporation of sweat and dilation of blood vessels provide a negative feedback response that cools the body. The constriction of blood vessels, shivering, and erection of the body hairs provide a negative feedback response that helps conserve heat.

In many ways, your response to cold mirrors your response to heat (**Figure 4**, previous page). When external temperatures drop, thermoreceptors in the skin send a message to the hypothalamus. Acting as a coordinating centre, the hypothalamus sends messages to the organs and tissues to increase body temperature. Nerves going to the arterioles of the skin cause smooth muscles to contract and the arterioles to constrict, limiting blood flow. This reduces heat loss from the skin and retains heat in the core of the body.

Nerve messages are also carried to the smooth muscle that surrounds the hair follicles in your skin, causing the hair to stand on end. The small bump made by the contraction of the muscle attached to the hair is often called a "goosebump." The erect hair traps warm, still air next to the surface of your skin and helps reduce heat loss. This response is particularly effective in mammals with a thick coat of body hair.

In addition, the hypothalamus also sends nerve messages that initiate shivering. The shivering response is a rhythmic contraction of skeletal muscle. Cycles of rapid muscle contractions of between 10 and 20 times per minute generate heat production by increasing metabolism.

Prolonged exposure to cold can create a hormonal response that also elevates metabolism. This type of heat production is most often associated with special adipose tissue called brown fat. Although its role in humans remains controversial, brown fat is especially capable of converting chemical energy into heat. Brown fat is important in newborns because they lack the ability to shiver. Babies have a small amount of brown fat in their neck and armpits and near their kidneys that insulates and generates heat.

Hypothermia is a condition in which the body's core temperature falls below the normal range. A drop in temperature of only a few degrees can lead to a coma and possibly death. However, some people, mainly small children, have survived sustained exposure to cold temperatures. This is often explained by the mammalian diving reflex. When a mammal is submerged in cold water, the heart rate slows and blood is diverted to the brain and other vital organs to conserve heat.

DID YOU KNOW ?

Self-Healing Behaviour

It has been discovered that sick lizards can intentionally give themselves a fever by resting in hot, sunny places. This behaviour raises their temperature to a slightly higher level, and the resulting fever helps fight infection.

SUMMARY Regulation of Blood Flow

- Cardiac output is the amount of blood the heart can pump each minute.
- Blood pressure is the force of blood on the walls of the arteries. It is measured as systolic and diastolic blood pressure in millimetres of mercury (mmHg).
- Blood pressure is higher in vessels closer to the heart.
- Increased cardiac output increases blood pressure. If arteries are constricted, blood flow is slower and blood pressure is higher.

Table 3 Summary of Stimulus–Response in Thermoregulation

Stimulus	Physiological response	Result
decreased environmental temperature	• constriction of blood vessels in skin • body hairs become erect • shivering	• heat is conserved • more heat is generated by increased metabolism
increased environmental temperature	• dilation of blood vessels of skin • sweating	• heat is dissipated

Section 10.3 Questions

1. How does stroke volume affect cardiac output?
2. How do metabolic products affect blood flow through arterioles? What causes the accumulation of metabolic products and where is accumulation most likely to occur?
3. Referring to the sympathetic and parasympathetic nerves, outline the adjustments to high blood pressure that help maintain equilibrium.
4. Would you expect blood pressure readings in all the major arteries to be the same? Explain your answer.
5. Why is systolic pressure lower when you are lying down than when you are standing up?
6. Why might diastolic blood pressure decrease as heart rate increases?
7. How do "goosebumps" help protect against rapid cooling?
8. What behavioural adjustments affect thermoregulation?
9. Explain why oral and rectal thermometers can give different readings.
10. Heat exhaustion caused by a person's exposure to heat can result in weakness or collapse. It usually involves a decrease in blood pressure. Explain why the thermoregulatory adjustment to heat can cause a drop in blood pressure.
11. The maximum suggested temperature of the water in a hot tub is about 38 °C. A higher temperature can seriously increase the risk of heat stroke. Explain why people will collapse in a hot tub set at 45 °C, but can survive temperatures of over 120 °C in heated rooms.
12. In **Figure 5 (a)**, beginning at the box labelled "increase in body temperature," replace the letters with the following feedback mechanisms for temperature control by the body: sweating, shivering, adjustment, evaporation. Do the same in **Figure 5 (b)**, beginning at the box labelled "decrease in body temperature."

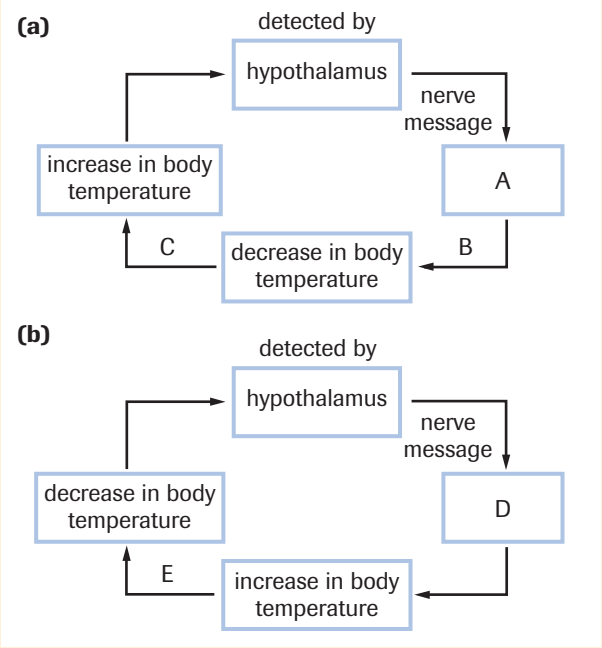


Figure 5

13. Arteriosclerosis is a group of disorders that can cause high blood pressure. How could lifestyle choices (e.g., related to nutrition or exercise) be changed to lessen a person's likelihood of getting the disorder?
14. Use the Internet or library to research how rapid cooling of the organs and tissues is used for surgery.

www.science.nelson.com GO

15. Drugs such as ecstasy interfere with the feedback mechanism that helps maintain a constant body temperature. Explain why these drugs are dangerous.

10.4 Capillary Fluid Exchange

extracellular fluid (ECF) fluid that occupies the spaces between cells and tissues; includes plasma and interstitial fluid

It is estimated that nearly every tissue of the body is within 0.1 mm of a capillary. Capillaries provide cells with oxygen, glucose, and amino acids and are associated with fluid exchange between the blood and surrounding **extracellular fluid (ECF)**. Most fluids simply diffuse through capillaries, whose cell membranes are also permeable to oxygen and carbon dioxide. Water and certain ions are thought to pass through spaces between the cells of the capillary while larger molecules and a very small number of proteins are believed to be exchanged by endocytosis or exocytosis. This section will focus on the movement of water molecules.

Two forces regulate the movement of water between the blood and ECF: fluid pressure and osmotic pressure. The force that blood exerts on the wall of a capillary is about 35 mmHg at the arteriole end of the capillary and approximately 15 mmHg at the venous end. The reservoir of blood in the arteries creates pressure on the inner wall of the capillary. Much lower pressure is found in the ECF. Although fluid bathes the cells, no force drives the extracellular fluid. Water moves from an area of higher pressure, the capillary, into an area of lower pressure, the ECF (**Figure 1**). The outward flow of water and small mineral ions is known as **filtration**. Because capillaries are selectively permeable, large materials such as proteins, red blood cells, and white blood cells remain in the capillary.

filtration the selective movement of materials through capillary walls by a pressure gradient

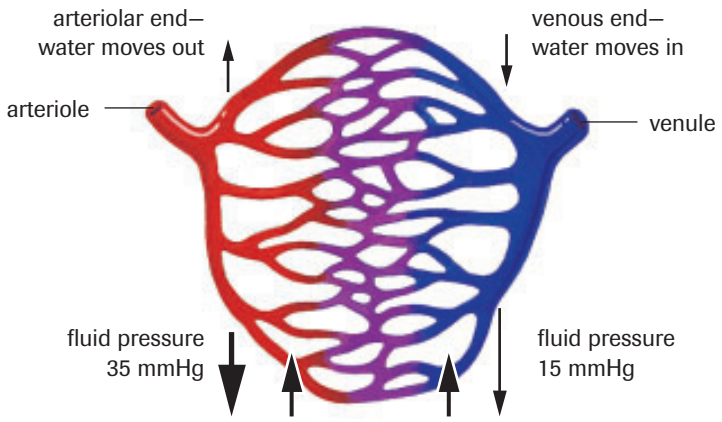
The movement of fluid out of the capillary must be balanced with a force that moves fluid into the capillary. The fact that large proteins are found in the blood but not in the ECF may provide a hint as to the nature of the second force. Osmotic pressure draws water back into the capillary. The large protein molecules of the blood and dissolved minerals are primarily responsible for the movement of fluid into capillaries. The movement of fluid into capillaries is called absorption. Osmotic pressure in the capillaries is usually about 25 mmHg, but it is important to note that the concentration of solutes can change with fluid intake or excess fluid loss caused by perspiration, vomiting, or diarrhea.

EXTENSION

Capillary Forces

In this animation, take a closer look at how fluid is moved in and out of capillaries by various forces.

www.science.nelson.com GO



Arteriolar end	
osmotic pressure	25 mmHg
fluid pressure	35 mmHg
absorption	–10 mmHg

Venous end	
osmotic pressure	25 mmHg
fluid pressure	15 mmHg
absorption	+10 mmHg

Figure 1
Fluid movement into and out of the capillaries

Application of the capillary exchange model provides a foundation for understanding adjustments that maintain equilibrium (**Figure 2**). The balance between osmotic pressure and fluid pressure is upset during a hemorrhage (excessive bleeding). The decrease in blood volume resulting from the hemorrhage lowers blood pressure. Although proteins are lost with the hemorrhage, so are fluids. Fewer proteins are present, but the concentration has not been changed. The force that drives fluid from the capillaries diminishes, but the osmotic pressure, which draws water into the capillaries, is not altered. The force drawing water from the tissues and ECF is greater than the force pushing water from the capillary. The net movement of water into the capillaries maintains equilibrium. As water moves into the capillaries, fluid volume is restored.

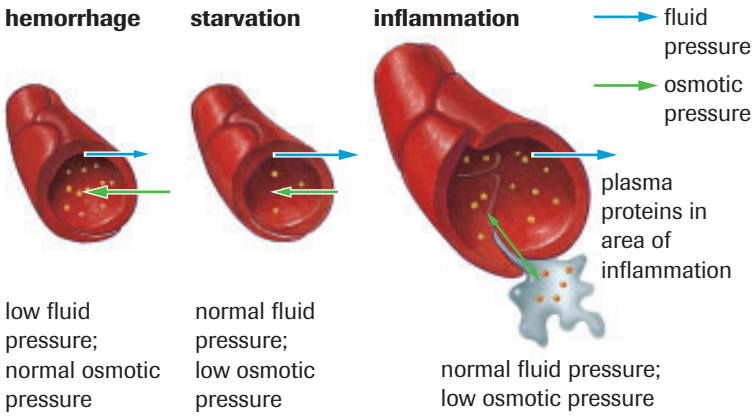


Figure 2
The balance between osmotic pressure and fluid pressure is upset during a hemorrhage, starvation, or inflammation.

Individuals who are suffering from starvation often display tissue swelling, or edema. Plasma proteins are often mobilized as one of the last sources of energy. The decrease in concentration of plasma proteins has a dramatic effect on osmotic pressure, which draws fluids from the tissues and ECF into the capillaries. The decreased number of proteins lowers osmotic pressure, thereby decreasing absorption. More water enters the tissue spaces than is pulled back into the capillaries, causing swelling.

Practice

1. Is fluid pressure greater in the arterioles or in the venules? Give reasons.
2. Is fluid pressure inside the capillary greater or less than the pressure in the ECF? How does this affect the movement of water?
3. What process allows water to flow out of the capillary but keeps proteins, red blood cells, and white blood cells inside the capillary?

EXTENSION

Nutrient and Waste Exchange

Fluid movement into and out of the capillaries greatly improves the efficiency of nutrient and waste exchange between the blood and the tissues. Listen to this Audio Clip for a deeper understanding of this process.

www.science.nelson.com GO

The Lymphatic System

Normally, a small amount of protein leaks from capillaries to tissue spaces. Despite the fact that the leak is very slow, the accumulation of proteins in the ECF would create a major problem: osmotic pressure would decrease and tissues would swell.

The proteins are drained from the ECF and returned to the circulatory system by way of another network of vessels: the lymphatic system (**Figure 3**, next page). **Lymph**, a fluid similar to blood plasma, is transported in open-ended lymph vessels that are similar to veins. This low-pressure return system operates by slow muscle contractions against the vessels, which are supplied with flaplike valves that prevent the backflow of fluids. Eventually, lymph is returned to the venous system via the right and left subclavian veins.

lymph the fluid found in lymph vessels that contains some proteins that have leaked through capillary walls

lymph node a mass of tissue that stores lymphocytes and removes bacteria and foreign particles from the lymph

lymphocyte a white blood cell that produces antibodies

Enlargements called **lymph nodes** are located at intervals along the lymph vessel (**Figure 3**). These house white blood cells that, by the process of phagocytosis, filter out any bacteria that might be present. The lymph nodes also filter damaged cells and debris from the lymph and store **lymphocytes**. The lymph nodes in your neck sometimes swell when you have a sore throat.

Lymphoid Organs

Red bone marrow (**Figure 3**) is where all types of blood cells are produced. Stem cells, which are contained in the marrow, divide at incredible rates and differentiate into different types of white blood cells to meet the needs of the body. These specialized blood cells enter the circulatory system from a variety of sinuses. In children, red bone marrow is found in most bones; by adulthood, however, the cranium, sternum (breastbone), ribs, spinal column, and the long bones of the arms and legs have become the primary locations for blood cell production.

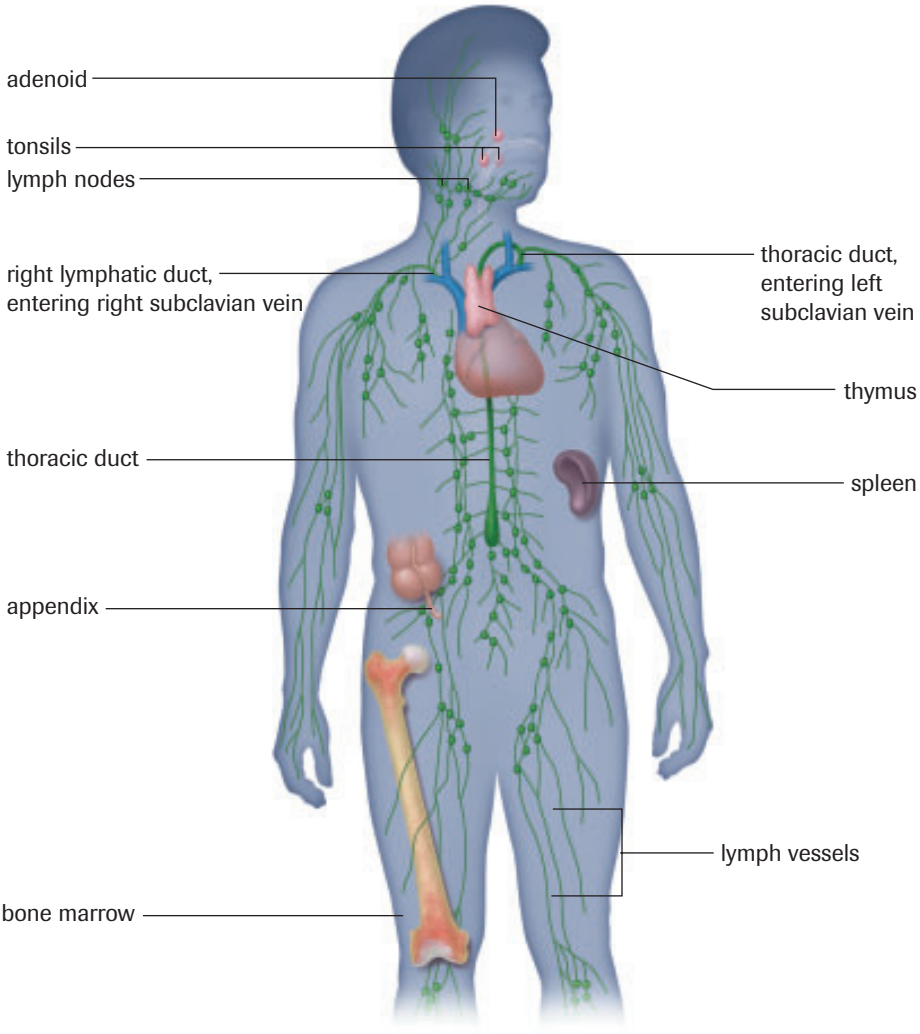


Figure 3
The lymphatic system. Debris is filtered out from the lymph, and the lymph is returned to the circulatory system.

CAREER CONNECTION

Registered Nurse

Registered nurses perform many duties, including administering medications, assisting surgeons, supervising nursing programs, treating illness and injury, and assessing/monitoring patient symptoms and reactions. Find out more about this exciting and challenging career.

www.science.nelson.com GO

The **spleen** is one of the body's largest lymphoid organs (**Figure 3**, previous page). Located in the upper left side of the abdominal cavity, just below the diaphragm, the spleen is richly supplied with blood sinuses. The sinuses allow the spleen to hold approximately 150 mL of blood, making it an excellent blood reservoir. The spleen releases red blood cells in response to low blood pressure or when blood oxygen levels drop dramatically.

spleen a lymphoid organ that acts as a reservoir for blood and a filtering site for lymph

The **thymus gland** is one of the few glands that tends to get smaller with age. Located in front of the trachea, just above the heart, the thymus gland is where T lymphocytes, or T cells, mature (**Figure 3**). The T cells that are released from the thymus gland have been selected to ensure that they will not initiate an immune response against the body's own proteins.

thymus gland a lymphoid organ in which T lymphocytes mature

SUMMARY Capillary Fluid Exchange

- Capillaries are associated with fluid exchange between blood and the extracellular fluid (ECF).
- The movement of water between blood and the ECF is regulated by fluid pressure and by osmotic pressure.
  - Water moves from an area of high fluid pressure, the capillary, to an area of low fluid pressure, the ECF.
  - Proteins and dissolved minerals in the blood cause fluid from the ECF to move into the blood by osmosis.
- Proteins in the ECF are returned to the circulatory system by the lymphatic system.
- Lymph nodes house white blood cells that filter bacteria.
- Red bone marrow is where all types of blood cells are produced.
- The spleen stores and purifies blood. The spleen releases red blood cells in response to low blood pressure or low oxygen levels in blood.

Section 10.4 Questions

1. What two factors regulate the exchange of fluid between capillaries and ECF?
2. Use the capillary exchange model to explain how the body maintains equilibrium following a hemorrhage.
3. Why does a low concentration of plasma protein cause edema?
4. What are lymph vessels and how are they related to the circulatory system?
5. What is lymph? How is lymph transported in the body? Where does lymph eventually go?
6. Why are lymphocytes important to the immune system?
7. What is the importance of the spleen?

INVESTIGATION 10.1

Fetal Pig Dissection

Report Checklist

● Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Like humans, the pig is a placental mammal, meaning that the fetus receives nourishment from the mother through the umbilical cord. Because the anatomy of the fetal pig resembles that of other placentals, this laboratory serves two important functions. It provides an overview of vertebrate anatomy and provides the framework for understanding functioning body systems.

Read and follow the procedure carefully. Accompanying diagrams are included for reference only. Use the appropriate dissecting instruments. This activity has been designed to minimize the use of a scalpel.

Materials

safety goggles	string	dissecting pins
lab apron	scalpel	scissors
dissecting gloves	hand lens	ruler
preserved fetal pig	dissecting tray	forceps and probe

Wear safety goggles and an apron at all times.

Wear plastic gloves when handling the preserved specimen and when performing a dissection to prevent any chemicals from coming in contact with your skin.

Wash all splashes of preservative from your skin and clothing immediately. If you get any chemical in your eyes, rinse for at least 15 min.

Work in a well-ventilated area. To reduce your exposure to any fumes from the preservative, make sure to avoid placing your face directly over the dissecting tray.

When you have finished the activity, clean your work area, wash your hands thoroughly, and dispose of all specimens, chemicals, and materials as instructed by your teacher.

Procedure

Part 1: External Anatomy

1. Place your pig in a dissecting tray. Use **Figure 1** to help you identify the four regions of the pig's body: the head, the neck, the trunk, and the tail.
2. Place the pig on its back (dorsal surface) and observe the umbilical cord.

Part 2: Abdominal Cavity

During the dissection, you will be directed to examine specific organs as they become visible. Remove only those organs indicated by the dissection procedure. Proceed cautiously to prevent damaging underlying structures.

3. With the pig still on its dorsal surface, attach one piece of string to one of the pig's hind legs, pull it under the dissecting pan, and tie it to the other hind leg. Repeat the procedure for the forelegs.
4. Using scissors, make the incision indicated as 1 in **Figure 2**. Start by cutting around the umbilical cord, and then cut straight toward the anterior (head) of the pig.

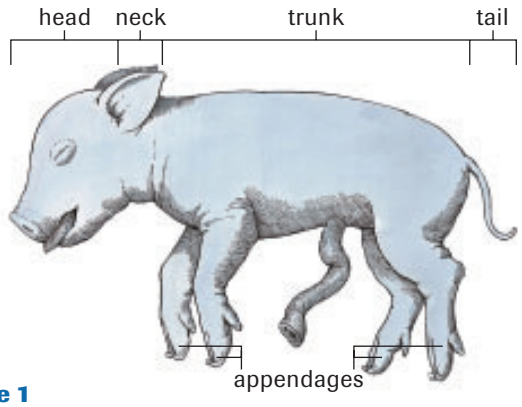


Figure 1
Regions of the body

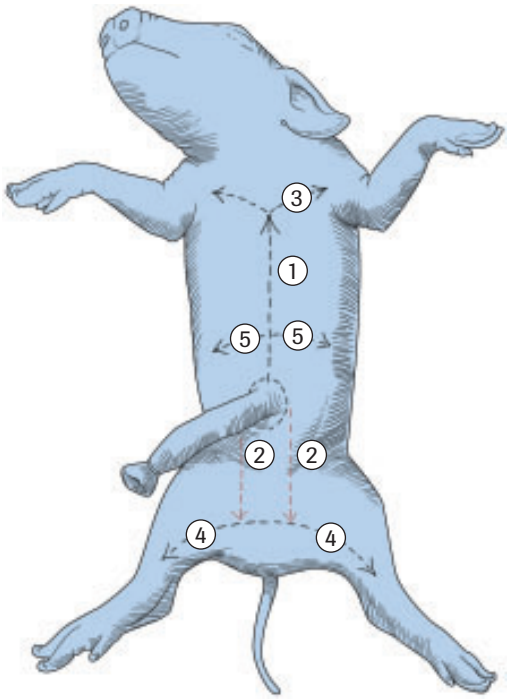


Figure 2
Ventral view of a fetal pig

5. Make incision 2 toward the posterior (tail) of the pig. Make incision 3 near the neck, and then incision 4. Make lateral incision 5; this incision runs parallel to the diaphragm, which separates the thoracic (chest) cavity from the abdominal cavity.
6. Pull apart the flaps along incision 5, exposing the abdominal cavity (**Figure 3**). Use the probe to open the connective tissue (peritoneum) that holds the internal organs to the lining of the body cavity. Now pull apart the flaps of skin covering incision 4 to expose the posterior portion of the abdominal cavity. Use pins to hold back the flaps of skin.
7. Locate the liver near the anterior of the abdominal cavity. Record the number of lobes in the liver.
8. Using a probe, lift the lobes and locate the saclike gallbladder. Describe the location of the gallbladder.
9. Follow the thin duct from the gallbladder to the coiled small intestine. Bile salts, produced in the liver, are stored in the gallbladder. The bile duct conducts the fat-emulsifying bile salt to the small intestine.
10. Locate the J-shaped stomach beneath the liver. Using forceps and a probe, lift the stomach and locate the esophagus attached near its anterior end. Locate the small intestine at the posterior junction of the stomach. The coiled small intestine is held in place by mesentery (a thin, somewhat transparent, connective tissue). Note the blood vessels that transport digested nutrients from the intestine to the liver.
11. Using a probe and forceps, lift the junction between the stomach and small intestine, removing supporting tissue. Uncoil the junction and locate the creamy-white pancreas. The pancreas produces a number of digestive enzymes and a hormone called insulin, which helps regulate blood sugar. Describe the appearance of the pancreas.
12. Locate the spleen, the elongated organ found around the outer curvature of the stomach. The spleen stores red and white blood cells. The spleen also removes damaged red blood cells from the circulatory system.
13. Using a scalpel, remove the stomach from the pig by making transverse (crosswise) cuts near the junction of the stomach and the esophagus, and near the junction of the stomach and small intestine. Make a cut along the midline of the stomach, and open the cavity. Rinse as instructed by your teacher. View the stomach under a hand lens. Describe the appearance of the inner lining of the stomach.

Part 3: Thoracic Cavity

14. Carefully fold back the flaps of skin that cover the thoracic cavity. You may use dissecting pins to attach the ribs to the dissecting tray. List the organs found in the thoracic cavity (**Figure 4**, next page).
15. Locate the heart. The coronary vessels carry blood to and from the heart itself (**Figure 5 (a)**, next page). Using forceps and a probe, remove the pericardium (a thin connective tissue covering the heart) from the outer surface of the heart.

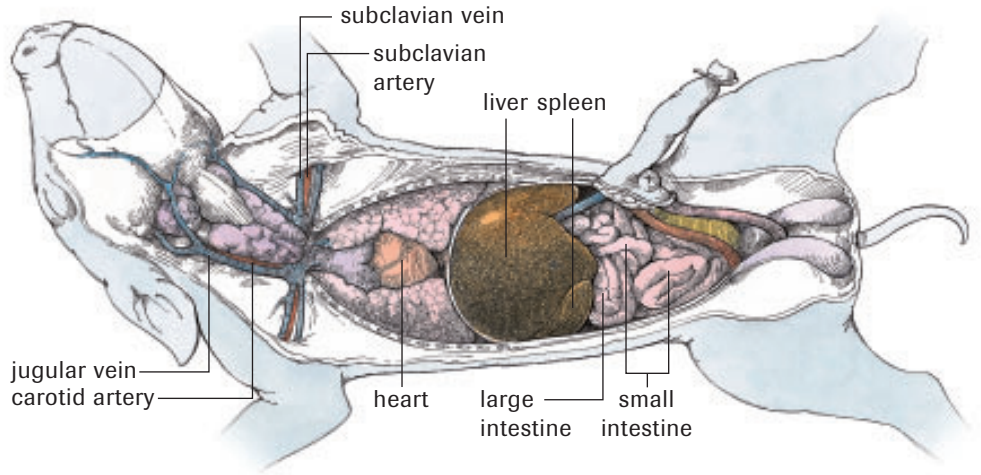
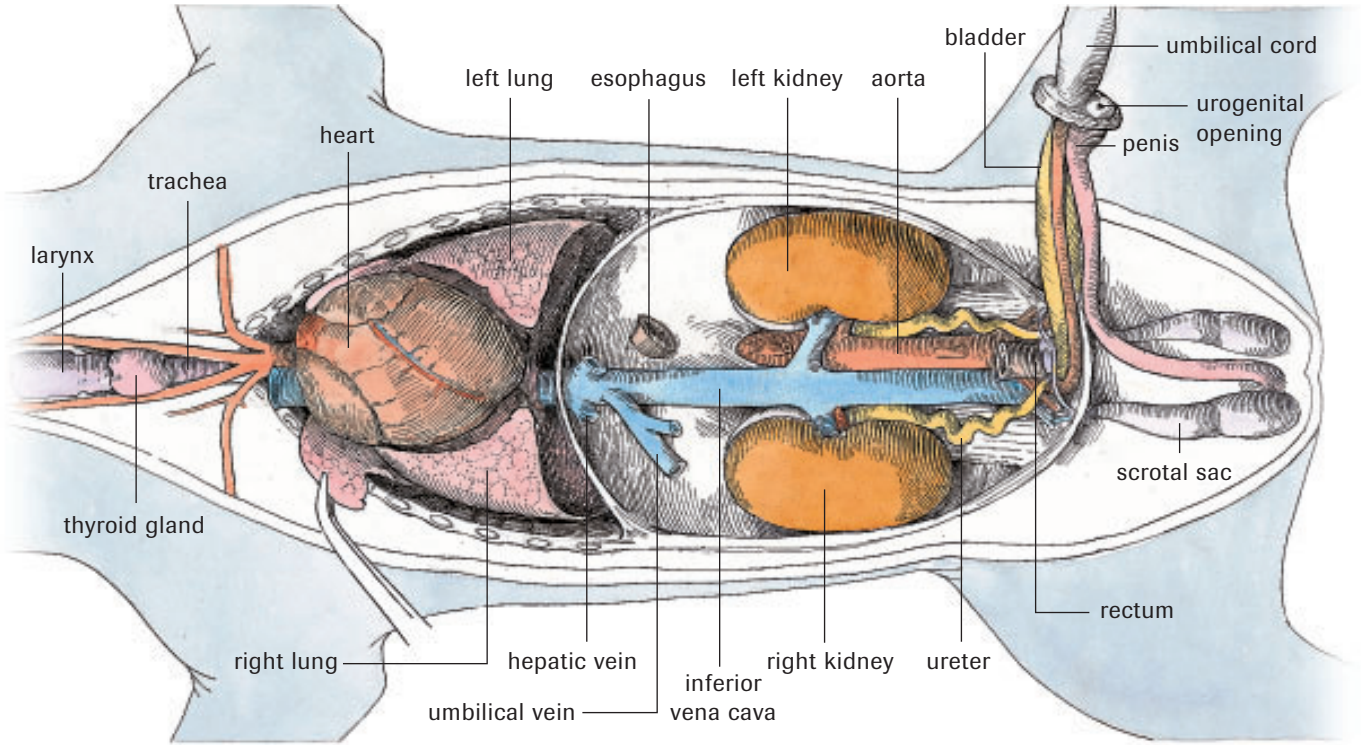


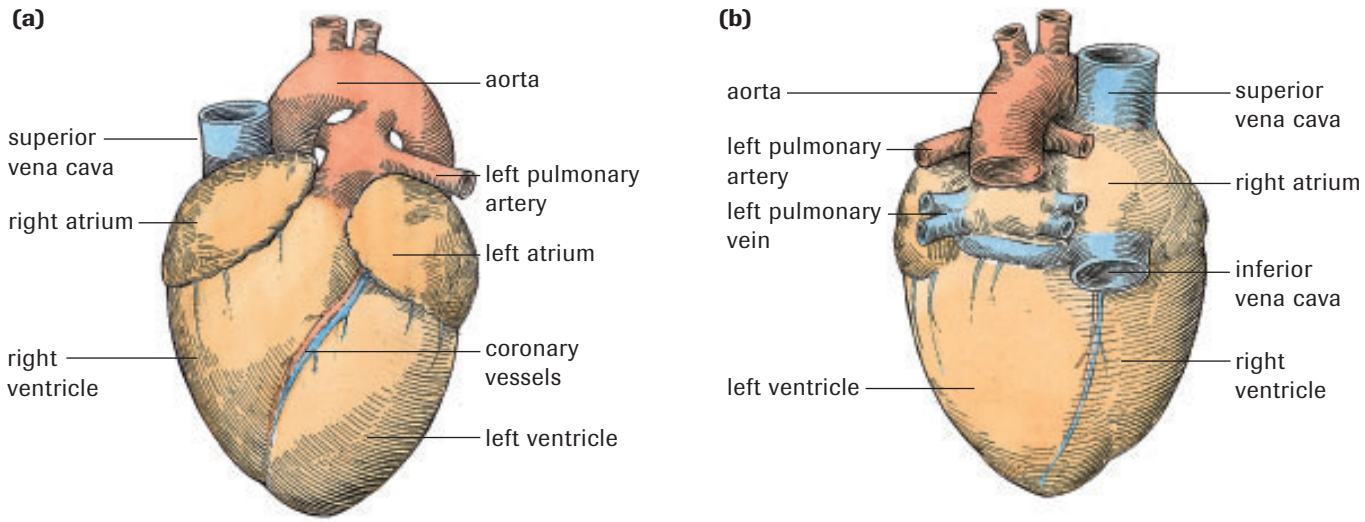
Figure 3
Abdominal cavity and thoracic cavity of the fetal pig. Organs of the digestive system and circulatory system are highlighted in the diagram.

Figure 4
Thoracic cavity and urogenital system



16. Blood from the head and upper body enters the right side of the heart through the superior vena cava. The large blood vessel that carries blood from the lower parts of the body to the right side of the heart is called the inferior vena cava (**Figure 5 (b)**). (The right side refers to the pig's right side.) Both the superior and inferior venae cavae are considered to be veins because they bring blood to the heart. Locate the superior and inferior venae cavae.

Figure 5
(a) Ventral view of the heart
(b) Dorsal view of the heart



17. Trace blood flow through the heart. Blood entering the right side of the heart collects in the right atrium. Blood from the right atrium is pumped into the right ventricle. Upon contraction of the right ventricle, blood flows to the lungs by way of the pulmonary artery. Arteries carry blood away from the heart. Blood, rich in oxygen, returns from the lungs by way of the pulmonary veins and enters the left atrium. Blood is pumped from the left atrium to the left ventricle and out the aorta.
18. Make a diagonal incision across the heart and expose the heart chambers. Compare the thickness of the wall of a ventricle to that of an atrium.
19. Locate the spongy lungs on either side of the heart and find the trachea leading into the lungs (**Figure 6**).
20. Place your index finger on the trachea and push downward. Describe what happens.

Analysis and Evaluation

(a) What is the function of the umbilical cord?

(b) State the function of the following organs: stomach, liver, small intestine, gallbladder, pancreas, large intestine, and spleen.

(c) What is the function of the mesentery?

(d) Why does the left ventricle contain more muscle than the right ventricle?

(e) Why do the lungs feel spongy?

(f) What function do the cartilaginous rings of the trachea serve?

(g) Make labelled diagrams of the following:
- digestive system
- heart and the blood vessels associated with it
- respiratory system

(h) Write a report in which you point out the similarities and differences between the anatomy of a pig and a human.

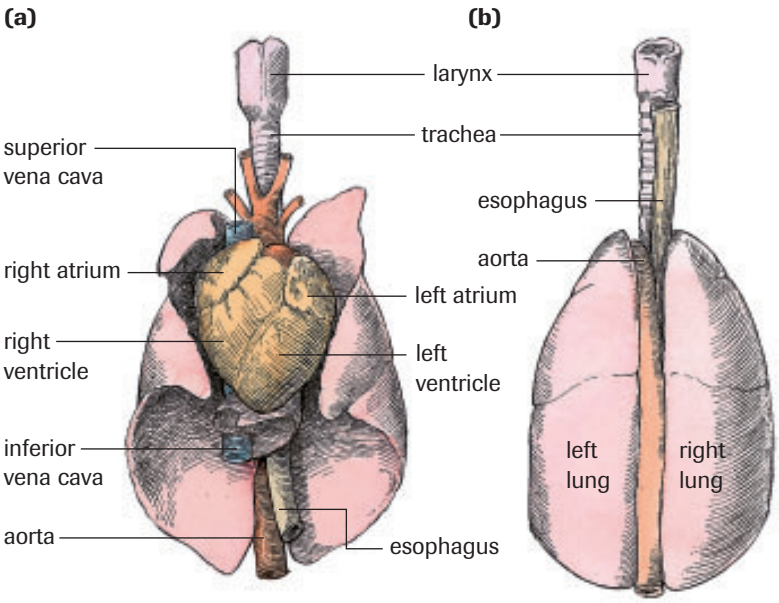


Figure 6
(a) Ventral view of heart and lungs
(b) Dorsal view of lungs

INVESTIGATION 10.2

Effects of Posture on Blood Pressure and Pulse

Blood pressure is affected by factors such as exercise, drugs, and even posture.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To determine the effect of posture on blood pressure and pulse

Materials

sphygmomanometer watch with second hand

Procedure

1. Ask your partner to sit quietly for 1 min.
2. Expose your partner's arm and place the cuff of the sphygmomanometer just above the elbow.
3. Close the valve on the rubber bulb. Inflate the cuff by squeezing the rubber bulb until a pressure of 180 mmHg registers.
4. Release the pressure by opening the valve on the sphygmomanometer and watch the readout. Record the systolic and diastolic blood pressures.

Do not leave the pressure on for longer than 1 min. If you are unsuccessful, release the pressure and try again on the opposite arm.

5. Completely deflate the cuff. If you are not using an electronic sphygmomanometer that provides the pulse, take and record your partner's pulse. Place your index and middle fingers on the inside arm near the wrist. Count the number of pulses in 1 min.
6. Repeat Steps 2 to 5 while your partner is in a standing position and then in a lying position.

Analysis

(a) Which varied more with the change in posture: systolic blood pressure or diastolic blood pressure? Explain.

(b) What factors other than posture might have contributed to the change in blood pressure?

INVESTIGATION 10.3

Effects of Exercise on Blood Pressure and Pulse

In this investigation, you will design and perform a controlled experiment to test the effects of exercise on blood pressure and pulse. Once your teacher has approved your design, carry out your procedure and record the evidence. You will then analyze the evidence to state how exercise affected blood pressure and pulse. In your lab report, include answers to the Evaluation questions.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Do not perform this activity if you are not allowed to participate in physical education classes.

Purpose

To determine the effects of exercise on blood pressure and pulse

Design

Your design must include:

- descriptions of the manipulated, responding, and controlled variables
- a step-by-step procedure
- a list of safety precautions
- an appropriate method to record the evidence

Evaluation

(a) Describe any problems or difficulties in carrying out the procedure.

(b) How could you improve your current design?

Chapter 10 SUMMARY

Outcomes

Knowledge

- identify the principal structures of the heart and associated blood vessels, i.e., atria, ventricles, septa, valves, aorta, vena cavae, pulmonary arteries and veins, and sinoatrial node, atrioventricular node, Purkinje fibres (10.2)
- describe the action of the heart, blood pressure, and the general circulation of the blood through coronary, pulmonary, and systemic pathways (10.2)
- describe the structure and function of blood vessels, i.e., arteries, veins, and capillaries (10.1)
- explain the role of the circulatory system at the capillary level in aiding the digestive, excretory, respiratory, and motor systems' exchange of energy and matter with the environment (10.3)
- explain the role of blood in regulating body temperature (10.3)
- explain how the motor system supports body functions, i.e., circulatory (10.1)
- describe and explain, in general terms, the function of the lymphatic system (10.4)

STS

- explain how Canadian society supports scientific research and technological development (10.2)
- explain that decisions regarding the application of scientific and technological developments involve a variety of perspectives, including social, cultural, environmental, ethical, and economic considerations (10.2)

Skills

- ask questions and plan investigations (10.3)
- conduct investigations and gather and record data and information by: measuring blood pressure (10.3) and observing blood flow in capillaries in a living organism or through demonstration in a virtual lab (10.1); selecting and integrating information to observe the principal features of a mammalian circulatory system and the direction of blood flow, and identifying structures from drawings (10.2) and; observing, through dissection or computer simulations, the respiratory and digestive systems of a representative mammal and identifying the major structural components (10.2)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

10.1

artery
pulse
autonomic nervous system
vasoconstriction
vasodilation
atherosclerosis
arteriosclerosis
aneurysm
vein

10.2

septum
pulmonary circulatory system
systemic circulatory system
atrium
ventricle
atrioventricular (AV) valve
semilunar valves
aorta
coronary artery
myogenic muscle
sinoatrial (SA) node
atrioventricular (AV) node
Purkinje fibre
sympathetic nervous system
parasympathetic nervous system
diastole
systole

10.3

cardiac output
stroke volume
sphygmomanometer
thermoregulation
hypothalamus

10.4

extracellular fluid (ECF)
filtration
lymph
lymph node
lymphocyte
spleen
thymus gland

MAKE a summary

1. Create a concept map that shows how the circulatory system maintains an internal equilibrium. Label the concept map with as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 10
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The pacemaker of the heart is the
   A. Purkinje fibres
   B. sinoatrial node
   C. atrioventricular node
   D. semilunar node

2. The pulmonary artery
   A. carries oxygenated blood to the heart from the lungs
   B. carries deoxygenated blood to the heart from the lungs
   C. carries oxygenated blood away from the heart to the lungs
   D. carries deoxygenated blood away from the heart to the lungs

Use the following information to answer questions 3 and 4.

The oxygen content of the blood was monitored in different blood vessels as blood moved away from the heart. The results of the study are shown in **Figure 1**.

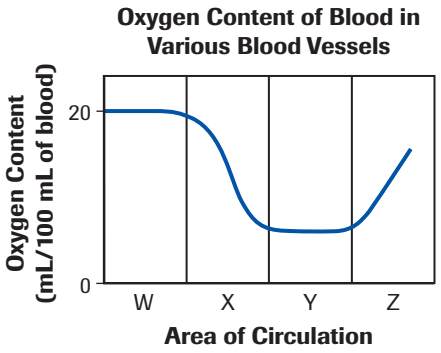


Figure 1

3. The area of the graph in **Figure 1** that would most likely represent capillaries within muscle cells would be
   A. W
   B. X
   C. Y
   D. Z

4. Identify the area of the graph in **Figure 1** where you would expect to find blood within a vein inside the brain.
   A. W
   B. X
   C. Y
   D. Z

Use the following information to answer questions 5 to 7.

Capillaries were observed within the tail of a fish. The capillaries were subjected to treatment with different chemicals, and the flow of blood cells through the capillary was observed 30 seconds later. **Table 1** shows the data that was collected.

Table 1 Blood Flow in Fish Tail Capillaries

Treatment	Average blood flow after treatment (cells/min)
control	60
epinephrine	40
lactic acid	90
alcohol	80
temperature reduced by 20 °C	30
nicotine	25

5. The number of blood cells that would normally pass through capillaries of the fish's tail at room temperature is
   A. 60 cells/min
   B. 40 cells/min
   C. 80 cells/min
   D. 30 cells/min

6. Nicotine is a drug found in cigarettes. Select the conclusion that is supported by the data provided in **Table 1**.
   A. Nicotine causes arteriolar constriction. Fewer blood cells move through capillaries after the treatment.
   B. Nicotine causes arteriolar constriction. More blood cells move through capillaries after the treatment.
   C. Nicotine causes constriction of the capillaries. Fewer blood cells move through capillaries after the treatment.
   D. Nicotine causes constriction of the capillaries. More blood cells move through capillaries after the treatment.

7. Lactic acid is produced in muscles during anaerobic respiration. Select the conclusion about lactic acid treatment that is supported by the data provided in **Table 1**.
   A. Lactic acid decreases blood flow to tissues. More oxygen is delivered to tissues, which decreases the amount of lactic acid in the blood.
   B. Lactic acid decreases blood flow to tissues. More oxygen is delivered to tissues, which increases the amount of lactic acid in the blood.
   C. Lactic acid increases blood flow to tissues. More oxygen is delivered to tissues, which decreases the amount of lactic acid in the blood.
   D. Lactic acid increases blood flow to tissues. More oxygen is delivered to tissues, which increases the amount of lactic acid in the blood.

8. NR Calculate the stroke volume of a person with a heart rate of 82 beats/min and a cardiac output of 4.6 L. (Record your answer as a value rounded to two decimal places.)

Part 2

Use the following information to answer questions 9 to 11.

Figure 2 shows the chambers of the heart, and blood vessels entering and exiting the heart.

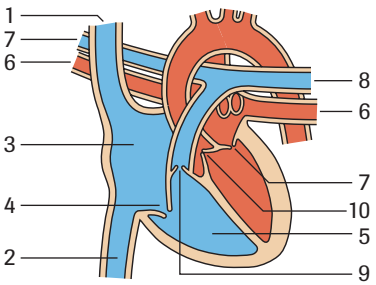


Figure 2

9. DE **Identify** the number(s) of the vein(s) that return blood to the heart from the body.
10. DE **Identify** the number of the ventricle that contains deoxygenated blood.
11. DE **Identify** the number of the heart valves that produce the *lubb* sound when closing.

12. **Identify** differences in the structures of veins, arteries, and capillaries and **describe** how they are related to the functions of each vessel.
13. "Oxygenated blood is found in all arteries of the body." Is this statement true or false? Give reasons to **explain** your answer.
14. **Why** does the left ventricle contain more muscle than the right ventricle?
15. Arteriosclerosis is a condition referred to as "hardening of the arteries." It results from a reduction in the elasticity of the arteries. **Describe** two circulatory problems that might arise from this effect on the vessels.
16. The victim of an accident has had a large blood vessel severed and bleeding is severe. **How** does excessive bleeding endanger life? **Outline** in a list two physiological responses that will help the victim to survive.
17. **Why** does the blockage of a lymph vessel in the left leg cause swelling in that area?

Use the following information to answer questions 18 and 19.

Table 2 is a record of a person's blood pressure taken in a sitting position before and after exercise.

Table 2 Effect of Exercise on Blood Pressure and Pulse

Condition	Systolic blood pressure (mmHg)	Diastolic blood pressure (mmHg)	Pulse (beats/min)
resting	120	80	70
after exercise	180	45	160

18. DE **Why** does systolic blood pressure increase after exercise?
19. DE **Why** does diastolic blood pressure decrease after exercise?

20. **How** does the respiratory system depend on the circulatory system?
21. DE Nicotine causes the constriction of arterioles. Write a unified response that addresses the following aspects of smoking during pregnancy.
    - **Explain why** pregnant women are advised not to smoke.
    - Mothers who smoke give birth to babies who are, on average, 1 kg smaller than normal. **Describe** a possible relationship between the effects of nicotine on the mother's circulatory system and the lower body mass of babies.
22. Heart disease is currently the number one killer of middle-aged males, accounting for billions of dollars every year in medical expenses and productivity loss. Should males be required by law to undergo heart examinations? **Justify** your answer. Consider the social and moral implications of such a law.
23. Caffeine causes heart rate to accelerate; however, a scientist who works for a coffee company has suggested that blood pressure will not increase due to coffee consumption. This scientist states that equilibrium adjustment mechanisms ensure that blood pressure readings will remain within an acceptable range. **Design** an experiment that will test the scientist's hypothesis. What other reasons might the scientist have for suggesting that caffeine does not increase blood pressure?

chapter

11 Blood and the Immune System

In this chapter

To appreciate the importance of the immune system, consider severe combined immunodeficiency (SCID), also known as the "boy in the plastic bubble" syndrome after David Vetter, an American boy who had to live in a sterile plastic bubble. SCID is a rare disease of the immune system, and those affected must live in a virtually germ-free environment or risk contracting life-threatening infections. In 2006, a baby in Ontario was born with SCID. Treatments for SCID include bone marrow transplants and gene therapy.

Unlike familiar infectious diseases caused by viruses and bacteria, bovine spongiform encephalopathy (BSE) is caused by a neurological invader that does not contain nucleic acids. The disease is caused by a *prion*, an abnormal infectious version of a protein. During the 1980s and early 1990s, thousands of people in Britain ate beef from cattle that had BSE, often called mad cow disease (**Figure 1**). By the mid-1990s, the human version of mad cow disease, known as variant Creutzfeldt–Jakob disease, surfaced, and scientists considered the possibility that the disease could be transmitted from cows to people through the food chain.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. How do you think the idea that a protein can cause an infectious disease has altered the way we think about disease?
2. Which of the following medical conditions have been linked with bacteria, viruses, or prions?
   (a) heart attack
   (b) ulcers
   (c) AIDS
   (d) measles
   (e) diabetes mellitus
3. Allergies are caused by an over-reaction of your immune system. Harmless agents, such as proteins in peanut butter, are recognized as harmful invaders and an immune response is mobilized. What other mistakes of the immune system can cause problems?

Career Connections:
Medical Laboratory Technologist; Pathologist

Figure 1
A prion causes BSE in cattle.

Exploration — Tracing an Infection

In this activity, you will simulate the spread of an infection. Each member of your class will be provided with a numbered plastic cup filled with a mystery fluid. One of these cups will contain an "infection."

Safety goggles and a lab apron must be worn for the entire laboratory.

Materials: index card, pen or pencil, numbered plastic cup of mystery fluid, dropper bottle of phenolphthalein indicator

- Write your name and cup number on your index card.
- Share your mystery fluid with a classmate. Pour all of your fluid into your partner's cup. Then, have your partner pour half of the combined fluids back into your cup. Both you and your partner then record the other person's cup number on your index card.
- Repeat the previous step until you have shared fluids with exactly three other students. Note that every class member will share fluids with three other students.
- Once all exchanges have occurred, your teacher will add a drop of phenolphthalein indicator to each of the cups. A pink colour indicates an infection.

(a) Can you identify the origin of the infection?
(b) If so, then identify the source. If not, why not?

11.1 Components of Blood

DID YOU KNOW ?

Water Content of Blood

Blood is not the most watery tissue of your body. It has been estimated that the grey matter of your brain is 85 % water.

plasma the fluid portion of the blood

The average 70-kg individual is nourished and protected by about 5 L of blood. Approximately 55 % of the blood is fluid; the remaining 45 % is composed of blood cells (**Figure 1**). All blood cells are produced by the bone marrow (**Figure 2**). The percentage of red blood cells in the blood is called the hematocrit. The fluid portion of the blood is referred to as the **plasma**, which is about 90 % water, allowing it to be described as a fluid tissue. As in other tissues, the individual cells in the blood work together for a common purpose.

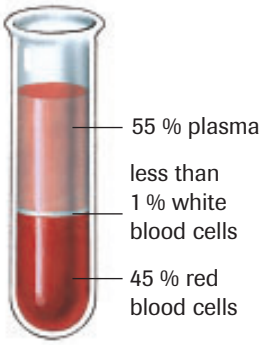


Figure 1
Proportions of fluid and cells in blood

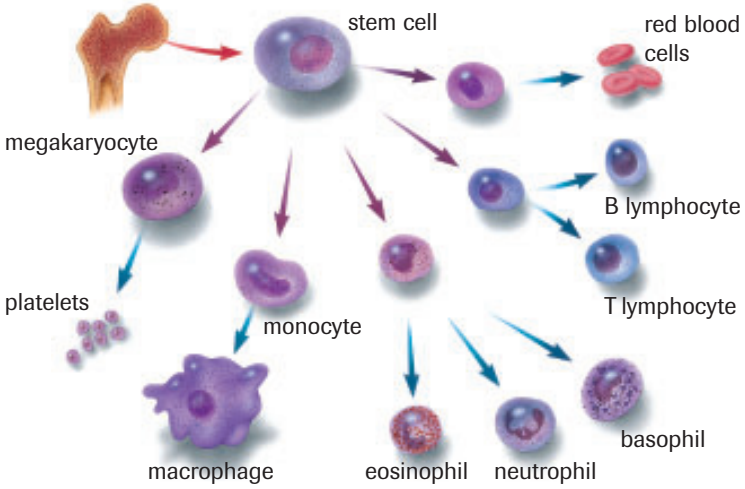


Figure 2
Stem cells of the bone marrow give rise to blood cells. The agranulocytes include the monocytes and lymphocytes. The granulocytes include the eosinophils, basophils, and neutrophils.

Table 1 Plasma Proteins

Type	Function
albumins	osmotic balance
globulins	antibodies, immunity
fibrinogens	blood clotting

The plasma also contains blood proteins, glucose, vitamins, minerals, dissolved gases, and waste products of cellular metabolism. The large plasma proteins help maintain homeostasis. One group of proteins is called the albumins; they, along with inorganic minerals, establish an osmotic pressure that draws water back into capillaries and helps maintain body fluid levels. A second group of proteins, the globulins, help provide protection against invading microbes. Fibrinogens, the third group of proteins, are important in blood clotting. **Table 1** summarizes the types of plasma proteins and their functions.

Erythrocytes

erythrocyte a red blood cell that contains hemoglobin and carries oxygen

The primary function of **erythrocytes**, red blood cells, is the transport of oxygen. Although some oxygen diffuses into the plasma, the presence of hemoglobin increases the ability of the blood to carry oxygen by a factor of almost 70. Without hemoglobin, your red blood cells would supply only enough oxygen to maintain life for approximately 4.5 s. With hemoglobin, humans can survive without oxygen for a few minutes. This is not much time, but remember that the blood returns to the heart and is pumped to the lungs, where oxygen supplies are continuously replenished. This might indicate why people survive even when the heart stops for short periods of time. Children who have been immersed in cold water for longer than a few minutes have survived with comparatively minor cell damage because colder temperatures slow body metabolism and decrease oxygen demand.

An estimated 280 million hemoglobin molecules are found in a single red blood cell. The hemoglobin is composed of heme, the iron-containing pigment, and globin, the protein structure. Four heme groups, each containing an iron atom, attach to the folded protein structure and bind with oxygen molecules. The oxyhemoglobin complex gives blood its red colour. Once oxygen is given up to cells of the body, the shape of the hemoglobin molecule changes, causing the reflection of blue light. This explains why blood appears blue in the veins.

Red blood cells are biconcave (concave on both sides) disks approximately 7 μm in diameter. This shape provides a greater surface area for gas exchange—between 20 % and 30 % more surface area than a sphere. The outer membranes of red blood cells become brittle with age, causing them to rupture as they file through the narrow capillaries. Since red blood cells live only about 120 days, cell reproduction is essential. One estimate suggests that at least five million red blood cells are produced every minute of the day.

Red blood cells do not contain a nucleus when mature, which allows more room for the cell to carry hemoglobin. This enucleated condition raises two important questions. First, since cells, by definition, contain a nucleus or nuclear material, are red blood cells actually cells? The second question addresses cell reproduction: how do cells without a nucleus and chromosomes reproduce? The answer to both of the above questions can be found in bone marrow, where red blood cells are produced by nucleated stem cells. The young cells lose their nuclei as they are discharged into the bloodstream.

The average male has about 5.5 billion red blood cells per millilitre of blood, while the average female has about 4.5 billion. Individuals living at high altitudes can have red cell counts as high as 8 billion per millilitre. How does the body ensure that adequate numbers of red blood cells are maintained? Specialized white blood cells, located primarily in the spleen and liver, monitor the age of red blood cells and remove debris from the circulatory system. Following the breakdown of red blood cells, the hemoglobin is released. Iron is recovered and stored in the liver and bone marrow for production of new red blood cells. The heme is transformed into bile pigments.

A deficiency in hemoglobin or red blood cells decreases oxygen delivery to the tissues. This condition, known as **anemia**, is characterized by low energy levels. The most common cause of a low red blood cell count is hemorrhage. Physical injury, bleeding due to ulcers, or hemorrhage in the lungs due to tuberculosis can cause anemia. If more than 40 % of the blood is lost, the body is incapable of coping. Anemia may also be associated with a dietary deficiency of iron, which is an important component of hemoglobin. The red blood cells must be packed with sufficient numbers of hemoglobin molecules to ensure adequate oxygen delivery. Raisins and liver are two foods rich in iron.

DID YOU KNOW?

Colour of Blood

The word *erythrocyte* comes from the Greek *erythros*, meaning "red." However, a single red blood cell does not appear red but pale orange—the composite of many red blood cells produces the red colour.

DID YOU KNOW?

How Old Is Your Blood?

Because red blood cells live only 120 days, they are continually breaking down and being replenished. The misconception that "young blood" is better than "old blood" persists even today. The blood of elderly people is virtually the same as the blood of young people.

anemia the reduction in blood oxygen due to low levels of hemoglobin or poor red blood cell production

Leukocytes

White blood cells, or **leukocytes**, are much less numerous than red blood cells. It has been estimated that red blood cells outnumber white blood cells by a ratio of 700 to 1. White blood cells have a nucleus, making them easily distinguishable from red blood cells. In fact, the shape and size of the nucleus, along with the granules in the cytoplasm, have been used to identify different types of leukocytes (**Figure 2**, previous page). The granulocytes are classified according to small granules in the cytoplasm that become visible when stained. The agranulocytes are white blood cells that do not have granules in their cytoplasm. Granulocytes and agranulocytes are both produced in the bone marrow, but agranulocytes are modified in the lymph nodes. The function of some leukocytes is to destroy invading microbes by phagocytosis; they squeeze out of capillaries and move toward the microbe like an amoeba. Once the microbe has been engulfed, the leukocyte releases enzymes that digest the microbe and the leukocyte itself. The function of other white blood cells is to form special proteins, called antibodies, which interfere with invading microbes and toxins.

leukocyte a white blood cell

DID YOU KNOW?

Average Blood Volume

The average male contains an estimated 80 mL of blood for every kilogram of body mass. The average female contains an estimated 65 mL of blood for every kilogram of body mass.

INVESTIGATION 11.1 ***Introduction***

Diagnosing Disease by Examining Blood Cells

White blood cells often provide physicians with information used in diagnosing disease. In this investigation, you will examine and count different types of white blood cells, then relate this information to disease diagnosis.

To perform this investigation, turn to page 369.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

platelet a component of blood responsible for initiating blood clotting

Platelets

Platelets, or thrombocytes, do not contain a nucleus and are produced from large nucleated cells in the bone marrow. Small fragments of cytoplasm break from the large megakaryocyte, a large cell in the bone marrow, to form platelets. Platelets play an important role in blood clotting. When a blood vessel is damaged, the cells of the vessel wall release a substance that makes them sticky, and platelets begin to stick to the injured site. As the platelets build up, they form a plug to stop the bleeding. The platelets change shape from round to spiny, and they release substances that trap more platelets and cause clotting proteins to form.

Practice

1. Name the two major components of blood.
2. List three plasma proteins and indicate the function of each.
3. What is the function of hemoglobin?
4. List factors that initiate red blood cell production.
5. What is anemia?
6. What is the role of platelets?

Blood Clotting

Blood clotting maintains equilibrium by preventing the loss of blood from torn or ruptured blood vessels. Blood clots also forestall the rupture of weakened blood vessels by providing additional support.

Trillions of platelets move through the blood vessels. When a blood vessel is damaged, platelets are activated and clump together to form a plug to stop the bleeding. The platelets release a protein called thromboplastin (**Figure 3**).

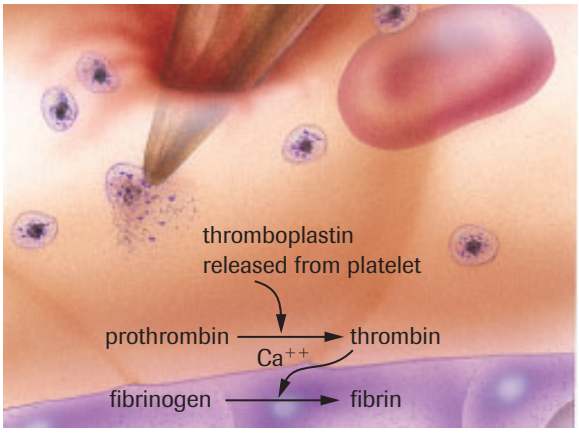


Figure 3
The thromboplastin released from the platelet initiates a series of reactions that produce a blood clot.

The thromboplastin, along with calcium ions present in the blood, activates a plasma protein called prothrombin. Prothrombin, along with another plasma protein, called fibrinogen, is produced by the liver. Under the influence of thromboplastin, prothrombin is transformed into thrombin. In turn, thrombin acts as an enzyme by splicing two amino acids from the fibrinogen molecule. Fibrinogen is converted into fibrin threads, which wrap around the damaged area, trapping red blood cells and more platelets to form a clot and stop bleeding (**Figure 4**).

Although blood clotting preserves life, it can also result in life-threatening situations. A **thrombus** is a blood clot that blocks a blood vessel. Because blood will not pass through the area, local tissues are not supplied with oxygen and nutrients. If a clot forms in the brain, cerebral thrombosis can cause a stroke. Coronary thrombosis—a clot in a coronary artery of the heart—can be equally dangerous.

Should a blood clot dislodge, it becomes an **embolus**. The embolus may travel through the body to lodge in a vital organ. Cerebral embolisms, coronary embolisms, and pulmonary embolisms can be life-threatening. What causes an embolus or thrombus is not completely understood, but scientists believe that genetic factors may be involved. It is known, however, that the incidence of thrombi and emboli increases as people get older.

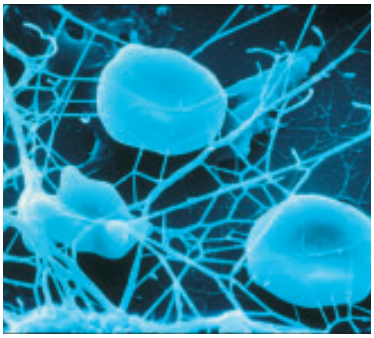


Figure 4
Formation of a blood clot. Red blood cells are caught in a mesh of fibrin.

thrombus a blood clot that forms within a blood vessel and blocks it

embolus a blood clot that dislodges and is carried by the circulatory system to another part of the body

Artificial Blood

On March 1, 1982, a precedent-setting legal case brought attention to an emerging medical technology. A man and woman, trying to push their car, were critically injured when they were hit by another car. For personal reasons, the couple chose not to have a blood transfusion. During the legal dispute that ensued, the wife died, and the courts ruled that action must be taken to save the husband's life. Five litres of fluosol—artificial blood—were transfused into the man over a period of five days. Doctors believed that the artificial blood could maintain adequate oxygen levels until the man's bone marrow began replenishing red blood cells.

Fluosol, a non-toxic liquid that contains fluorine, was developed in Japan. Fluosol carries both oxygen and carbon dioxide. It requires no blood matching, and when frozen, can be stored for long periods of time. Artificial blood, unlike human blood, does not have to undergo expensive screening procedures before being used in transfusions. Artificial blood will not carry human immunodeficiency virus (HIV), hepatitis, or any other virus. However, despite its advantages, artificial blood is not as good as the real thing. Although it carries oxygen, it is ill-suited for many of the other functions associated with blood, such as blood clotting and immunity. The real value of artificial blood is that it provides time until human blood can be administered. It could also serve as a supplement for patients with diseases like thalassemia (Cooley's anemia) or aplastic anemia, which require the patients to undergo multiple transfusions.

CAREER CONNECTION

Medical Laboratory Technologist

One of the many duties medical laboratory technologists (MLTs) perform is drawing blood for analysis. They also conduct routine lab tests and set up, clean, and maintain lab equipment. Survey Web sites for job opportunities for MLTs. Report on your findings.

www.science.nelson.com GO

ABO Blood Groups

In the 17th century, Jean-Baptiste Denis performed the first blood transfusion by injecting lamb's blood into a young boy. The youth survived, but a repeat of the experiment, on an older man, proved disastrous—the man died almost immediately. Denis attempted to explain what went wrong, but he lacked crucial information. Why do some transfusions help, while others kill?

At the turn of the 20th century, Karl Landsteiner discovered that different blood types exist. Therefore, the secret to successful transfusion was the correct matching of blood types. Markers called glycoproteins are located on the membrane of some of the red blood cells. Individuals with blood type A have a glycoprotein, the A marker, attached to their cell membrane. Individuals with blood type B have a glycoprotein, the B marker,

antigen a substance, usually protein, that stimulates the formation of an antibody

antibody a protein formed within the blood that reacts with an antigen

attached to their cell membrane. Individuals with blood type AB have both A and B markers attached to their cell membrane. Blood type O has neither marker.

Should an individual with blood type O receive blood from an individual with blood type A, the type O blood would recognize the A marker as a foreign invader (**Figure 5**). The A marker acts as an **antigen** in the body of the individual with blood type O. Special proteins, called **antibodies**, are produced in response to a foreign invader. The antibodies attach to the antigen markers and cause the blood to clump. It is important to note that antigen A would not cause the same immune response if transfused into the body of an individual with blood type A. The marker associated with blood type A would not be a foreign invader because A-type antigens are found on that individual's red blood cells. **Table 2** summarizes the antigens and antibodies for the four ABO blood groups.

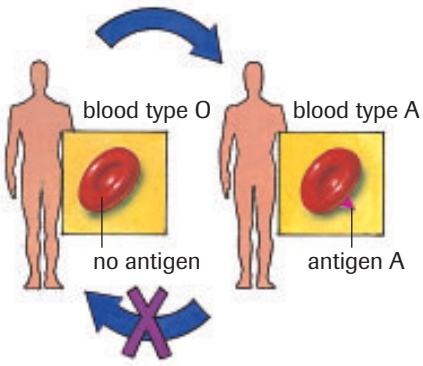


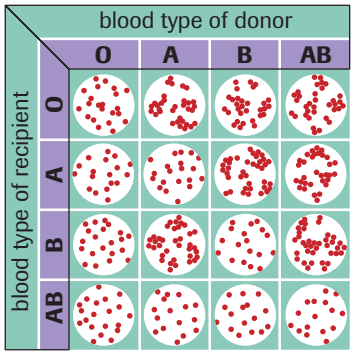
Figure 5
Individuals with blood type A can receive blood type O during a transfusion. However, individuals with blood type O cannot receive blood type A during a transfusion.

Table 2 Antigens and Antibodies Found in Blood Groups

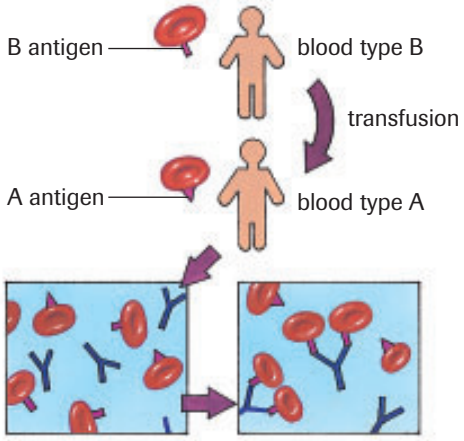
Blood group	Antigen on red blood cell	Antibody in serum
O	none	A and B
A	A	B
B	B	A
AB	A and B	none

The antibodies produced by the recipient act on the invading antigens. As shown in **Figure 6**, the antibodies cause **agglutination**, or clumping, of the blood. The importance of the correct transfusion is emphasized by the fact that agglutinated blood can no longer pass through the tiny capillaries. The agglutinated blood therefore clogs the capillaries and prevents the delivery of oxygen and nutrients. Individuals with type AB blood possess both antigens and, therefore, are able to receive blood from any donor. Blood type AB is the universal recipient. Blood type O is referred to as the universal donor because it can be donated to individuals of all blood types. Blood type O contains no antigen. Although antibodies will not be produced against type O, the immune system of individuals with blood type O can recognize antigens on other blood cells. Blood

agglutination the clumping of blood cells caused by antigens and antibodies



(a)



(b)

Figure 6
(a) Agglutination response of ABO blood groups
(b) Agglutination response of blood type A (recipient) to blood type B (donor)

type O, despite being the universal donor, may only accept blood from individuals with blood type O. Blood type AB, despite being the universal recipient, may only donate blood to individuals with blood type AB.

WEB Activity

Simulation—Blood Typing

Blood transfusions may be required during surgery or when a person loses blood due to trauma. Identifying a patient's blood type is critical to ensuring that the appropriate type of blood is provided. In this activity, you will follow an interactive animation in which you must identify the blood type of virtual patients and then give them a blood transfusion. You will also find additional information on the biology of blood types.

www.science.nelson.com GO

Rhesus Factor

During the 1940s scientists discovered another antigen on the red blood cell—the rhesus factor. Like the ABO blood groups, the rhesus factor is inherited. Individuals who have this antigen are said to be Rhesus positive (Rh+). Approximately 85 % of Canadians have the antigen. The remaining 15 % of individuals who do not have the antigen are said to be Rhesus negative (Rh–). Individuals who are Rh– may donate blood to Rh+ individuals, but should not receive Rh+ blood. The human body has no natural antibodies against Rh factors, but antibodies can be produced following a transfusion. Although Rh antibodies are produced in response to antigens, it should be pointed out that the immune reaction is subdued compared with that of the ABO group.

Rhesus-factor incompatibilities become important for Rh+ babies of Rh– mothers. If the baby inherits the Rh+ factor from the father, a condition called erythroblastosis fetalis can occur with the second and subsequent pregnancies. The first child is spared because the blood of the mother and baby are separated by the placenta (a membrane inside the uterus that exchanges materials between mother and baby). During birth, the placenta is shed from the uterus. Capillary beds rupture, and, for the first time, the blood of the baby comes into contact with the blood of the mother. The mother's immune system recognizes the Rh+ antigens and triggers the production of antibodies. But, by the time the antibodies are produced, the first baby is no longer connected to the placenta and has escaped the potentially dangerous situation. However, a second pregnancy presents problems if the fetus is Rh+. The mother retains many of the antibodies from her first encounter with Rh+ blood. If antibodies cross the placenta, they attach to the antigen on the red blood cells of the fetus, causing them to be destroyed. Symptoms of erythroblastosis fetalis include anemia, jaundice, and an enlarged liver.

SUMMARY *Components of Blood*

- Blood is composed mainly of plasma and blood cells.
- Plasma proteins play roles in maintaining homeostasis, in producing antibodies, and in blood clotting.

- Erythrocytes function primarily to transport oxygen.
  - Erythrocytes contain hemoglobin, which increases the amount of oxygen that can be carried in the blood.
  - Erythrocytes are produced in the bone marrow; once they leave, they have no nucleus and cannot reproduce.
- Leukocytes are an important part of the immune system.
- Platelets are cell fragments that clump together at the site of a damaged blood vessel to form a clot.
- Blood type A has the A antigen, type B has the B antigen, type AB has both, and type O has neither.
- Blood types must be matched before giving a blood transfusion.
  - An incompatible marker acts as an antigen in the recipient's body.
  - The recipient will produce antibodies against the antigen, causing agglutination.
  - AB is the universal recipient, and O is the universal donor.
- The Rhesus (Rh) factor is another potential source of blood incompatibility.

Section 11.1 Questions

1. What are erythrocytes and what is their primary function?
2. Explain the mechanism by which hemoglobin increases the ability of blood to carry oxygen.
3. Are erythrocytes true cells? Why or why not?
4. State two situations that result in a deficiency of hemoglobin.
5. How do white blood cells differ from red blood cells?
6. State two major functions associated with leukocytes.
7. How do platelets contribute to the formation of blood clots?
8. Differentiate between an embolus and a thrombus.
9. List the advantages and disadvantages associated with using artificial blood.
10. Cancer of the white blood cells is called leukemia. Like other cancers, leukemia is associated with rapid and uncontrolled cell production. Examine the test tubes shown in **Figure 7** and predict which subject might be suffering from leukemia. Give your reasons.
11. Most physicians would not diagnose leukemia on the basis of one test. What other conditions might explain the appearance of the test tube you chose in question 10? Give your reasons.
12. Lead poisoning can cause bone marrow destruction. Which of the subjects in **Figure 7** might have lead poisoning? Give your reasons.
13. Which subject in **Figure 7** lives at a high altitude? Give your reasons.

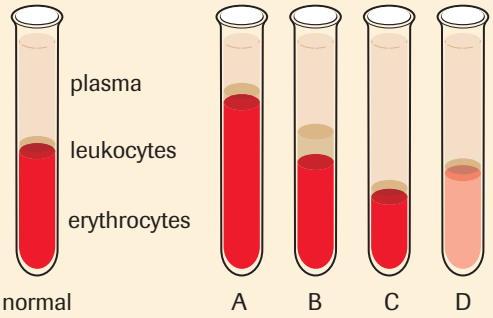


Figure 7

14. Athletes can take unfair advantage of the benefits of extra red blood cells. Two weeks prior to a competition, a blood sample is taken and centrifuged, and the red blood cell component is stored. A few days before the event, the red blood cells are injected into the athlete. Why would athletes remove red blood cells only to return them to their body later?
15. How does Rh+ blood differ from Rh– blood?
16. Explain why type O blood is considered the universal donor. Why is type AB the universal recipient?
17. What would happen if blood type A was transfused into people with blood types A, B, O, and AB? Provide an explanation for each case.
18. Why does a fetus with erythroblastosis fetalis develop anemia?

The Body's Lines of Defence 11.2

The human body must constantly defend itself against the many unwelcome intruders it encounters in the air, in food, and in water. It must also deal with abnormal body cells that sometimes turn into cancer. Three lines of defence have evolved to help resist infection and possible death from fatal illnesses. The first two lines of defence are considered nonspecific immune responses, meaning that they do not distinguish one microbe from another. The third line of defence—the immune system—is a specific immune response that reacts in specialized ways to various invaders. All the cells involved in the immune system develop from the bone marrow. (These cells were illustrated in **Figure 2**, Section 11.1, on page 350.)

The First Line of Defence

The body's first line of defence against foreign invaders is largely physical. Like a medieval city that used walls and moats to defend against attack from outsiders, the skin and mucous membranes defend against viral and bacterial invaders. Intact skin provides a protective barrier that cannot normally be penetrated by bacteria or viruses. The skin also has chemical defences in the form of acidic secretions, which keep it within a pH range of 3 to 5, acidic enough to inhibit the growth of microbes. Lysozyme, an antimicrobial enzyme secreted in human tears, saliva, mucous secretions, and perspiration, destroys the cell walls of bacteria, killing them.

In the respiratory tract, invading microbes and foreign debris become trapped in a layer of mucus and are filtered by tiny hairlike structures called cilia (**Figure 1**). The cilia move in waves, sweeping particles up toward the throat where coughing can expel them. Corrosive acids in the stomach and protein-digesting enzymes destroy most of the invading microbes carried into the body with food.

The Second Line of Defence

A second line of defence can be mobilized if the invader takes up residence within the body. Leukocytes, or white blood cells, may engulf invading microbes or produce antibodies.

The body's nonspecific defence mechanisms rely mainly on the process of **phagocytosis**, the ingestion of invading microbes by certain types of white blood cells. When a foreign particle penetrates the skin through an injury, special leukocytes, known as *monocytes*, migrate from the blood into the tissues, where they develop into **macrophages** (meaning "big eaters"). The macrophages extend long protrusions, called *pseudopods*, that attach to the surface of the invading microbe; the microbe is then engulfed and destroyed by enzymes within the macrophage.

In another phagocytic response, white blood cells called *neutrophils* are attracted to chemical signals given off by cells that have been damaged by microbes. In a process called *chemotaxis*, the neutrophils squeeze out of capillaries and migrate toward the infected tissue. The neutrophils then engulf the microbe and release lysosomal enzymes that digest both the microbe and the leukocyte. The remaining fragments of protein, dead white blood cells, and the digested invader are called **pus**. Tissue damage due to physical injury also initiates a localized **inflammatory response**—a nonspecific immune response resulting in swelling, redness, heat, and pain (**Figure 2**, next page). Pus and accompanying inflammation are sure signs that the second line of defence has been at work.

DID YOU KNOW ?

The Skin Is the Largest Organ

The skin is the largest organ of the body, accounting for as much as 15 % of the body's total mass. An area no larger than a dime will contain approximately 10 hairs, 15 oil glands, 3 blood vessels, 100 sweat glands, and 200 neurons.

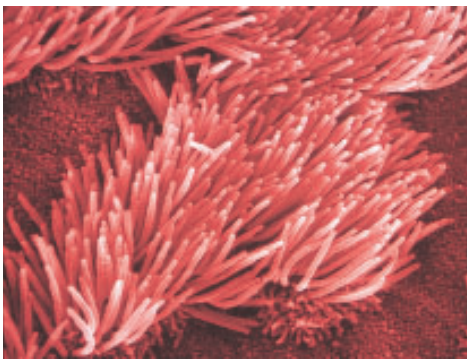


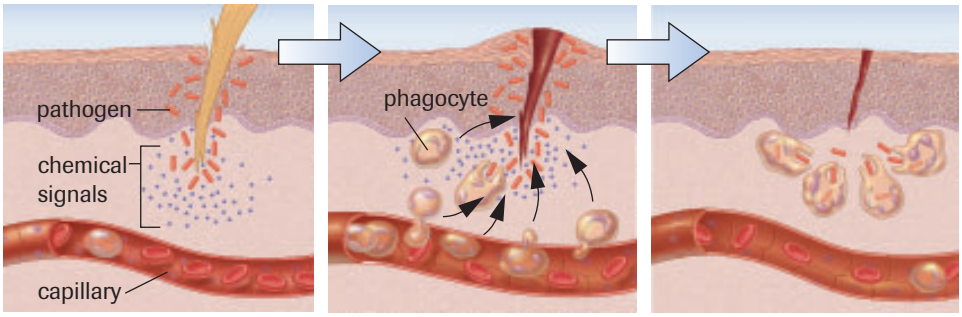
Figure 1
Cilia in the respiratory tract

phagocytosis the process by which a white blood cell engulfs and chemically destroys a microbe

macrophage a phagocytic white blood cells found in lymph nodes, bone marrow, and the spleen and liver

pus a thick liquid composed of protein fragments from digested leukocytes and microbes

inflammatory response localized nonspecific response triggered when tissue cells are injured by bacteria or physical injury, characterized by swelling, heat, redness, and pain



(a) At the first sign of injury, chemical signals are released by the foreign invader. Other chemicals—histamines and prostaglandins—are released by the cells of the body.

(b) Chemical signals cause the capillaries to dilate. Blood flow increases and the capillaries become more permeable. Other chemicals attract phagocytic cells and specialized white blood cells.

(c) Phagocytes engulf and digest the invaders and cellular debris, which promotes healing of the tissues.

Figure 2
Damage to tissue cells by bacteria or physical injury initiates a localized inflammatory response.

The body's nonspecific defence system responds to localized injuries, like a cut or puncture, but it can also respond with a system-wide defence to more severe damage or infection. Injured cells emit chemicals that stimulate the production of phagocytic white blood cells and increase their release into the bloodstream.

A fever is an example of the body's system-wide response to infection. When infectious organisms spread throughout your body, such as when you have a cold or flu, neutrophils and macrophages digest the invaders and release chemicals into your bloodstream. When these chemicals reach your hypothalamus, they reset the body's thermostat to a higher temperature—about 40 °C. A fever makes it difficult for harmful bacteria to survive; thus, the fever helps to prevent the proliferation of the infectious organisms. Reducing your fever by taking aspirin may actually prolong the infection. However, if your body temperature rises above 40 °C, it can be unsafe. For example, a fever of 41 °C may cause convulsions, especially in young children. Human cells cannot survive above 43 °C because proteins start to denature.

mini Investigation — Observing Phagocytosis

Protist models can be used to observe phagocytosis, the process by which macrophages engulf invaders (**Figure 3**).

Materials: prepared slide of amoeba, light microscope, medicine dropper, slide, cover slip, live amoeba culture, live yeast culture

- Obtain a prepared slide of amoeba that shows phagocytosis, and use a light microscope to look at it under high-power magnification.

(a) Draw what you see. Label the extension of false feet as "pseudopods" and indicate the food vacuole (if present).

- Using a medicine dropper, make a wet mount from a live amoeba culture. Observe the movement of the amoeba.
- Remove the cover slip from the slide and use a medicine dropper to add a drop of live yeast culture. Replace the cover slip and observe for phagocytosis.

(b) Describe the movement of the amoeba.
(c) Describe the process of phagocytosis.

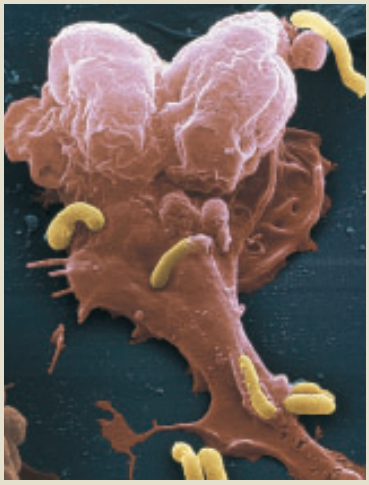


Figure 3
The macrophage has long, sticky extensions of cytoplasm that draw bacteria toward the macrophage. Once the bacteria come in contact with the macrophage, they are engulfed and destroyed.

The Immune Response (The Third Line of Defence)

Although some macrophages migrate throughout the body, others reside permanently in body tissues, such as the brain, lungs, kidneys, liver, and connective tissues. The fixed macrophages that reside in the spleen, lymph nodes, and other tissues of the lymphatic system trap and filter out microorganisms and foreign invaders that enter the blood. (Refer to **Figure 3**, Section 10.4, on page 338, for an illustration of the lymphatic system.)

The appearance of foreign organisms in the body activates antimicrobial plasma proteins, called **complement proteins**. There are about 20 known types of complement proteins. Under normal conditions, these proteins are present in the circulatory system in an inactive form. Marker proteins from invading microbes activate the complement proteins, which, in turn, serve as messengers. The proteins aggregate to initiate an attack on the cell membranes of fungal or bacterial cells. Some of the activated proteins trigger the formation of a protective coating around the invader, as shown in **Figure 4 (a)**. This coating seals the invading cell, immobilizing it. A second group punctures the cell membrane, as seen in **Figure 4 (b)**. Water enters the cell through the pore created by the protein, causing the cell to swell and burst. A third group of proteins attaches to the invader, as illustrated in **Figure 4 (c)**, making it more susceptible to phagocytosis by leukocytes.

complement protein a plasma protein that helps defend against invading microbes by tagging the microbe for phagocytosis, puncturing cell membranes, or triggering the formation of a mucous coating

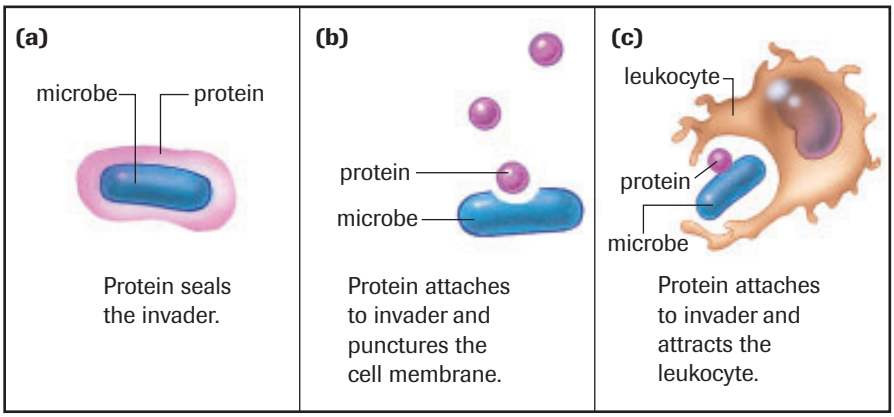


Figure 4
Complement proteins aid the immune response.

Also involved in the immune response are lymphocytes, a type of white blood cell that produces antibodies. An antibody is a protein molecule that protects the body from invaders. All cells have special markers located on their cell membranes. Normally, the immune system does not react to the body's own markers. However, intruding cells or foreign proteins activate the production of antibodies. The cell membrane of a bacterium and the outer coat of a virus contain many different antigens. The antigen (a term derived from antibody generator) may even be a toxin produced by moulds, bacteria, or algae. The toxin presents a danger to the cells of the body because it interferes with normal cell metabolism.

Two different types of lymphocytes are found in the immune system. The first is the **T cell**, which is produced in the bone marrow and stored in the thymus gland, from which the T cell receives its name. The T cell's mission is to seek out the intruder and signal the attack. Acting much like a sentry, one type of T cell identifies the invader by its antigen markers (**Figure 5**), which are located on the cell membrane. Once the antigen is identified, another T cell passes this information on to the antibody-producing **B cell**.

T cell a lymphocyte, manufactured in the bone marrow and processed by the thymus gland, that identifies and attacks foreign substances

B cell a lymphocyte, made and processed in the bone marrow, that produces antibodies

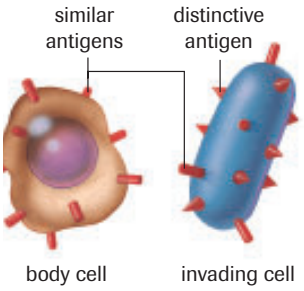


Figure 5
Sugar-protein complexes located on the cell membrane act as markers. T cells distinguish the markers on the body's cells from those of invading cells.

EXTENSION

Producing Monoclonal Antibodies

Have you ever wondered where synthetic antibodies come from? This Audio Clip provides a step-by-step description of the synthetic process used by industry to produce large quantities of identical antibodies.

www.science.nelson.com GO

B cells multiply and produce molecular weapons: the antibodies. Each B cell produces a single type of antibody, which is displayed along its cell membrane. Eventually, the B cells are released from the bone marrow and enter the circulatory system. Some B cells differentiate into super-antibody-producing cells called *plasma cells*. These plasma cells can produce as many as 2000 antibody molecules every second.

Antigen–Antibody Reactions

Antibodies are Y-shaped proteins engineered to target foreign invaders. Antibodies are specific; this means that an antibody produced against the influenza virus, for example, is not effective against HIV, the virus that causes acquired immunodeficiency syndrome (AIDS). The tails of these Y-shaped proteins are very similar regardless of the type of antibody. Variations exist only at the outer edge of each arm, the area in which the antibody combines with the antigen (**Figure 6**). Antigen markers found on the influenza virus are different from those found on HIV. Each antibody has a shape that is complementary to its specific antigen. Thus, the binding site of an antibody produced in response to the influenza virus will not complement HIV.

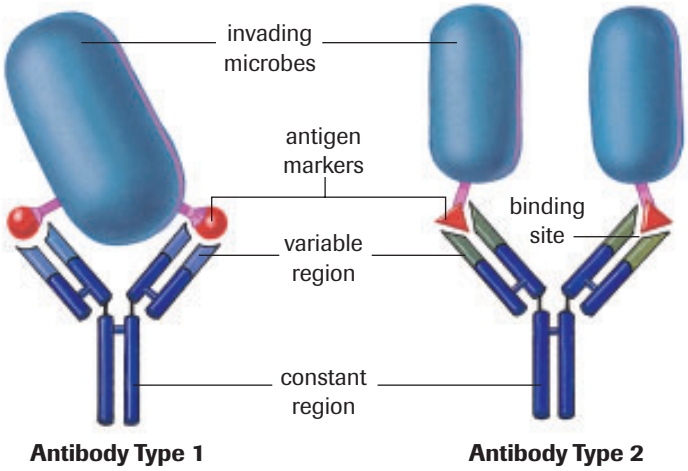


Figure 6
Each type of antibody will combine only with the appropriate antigen.

receptor site a port along a cell membrane into which hormones, nutrients, and other needed materials fit

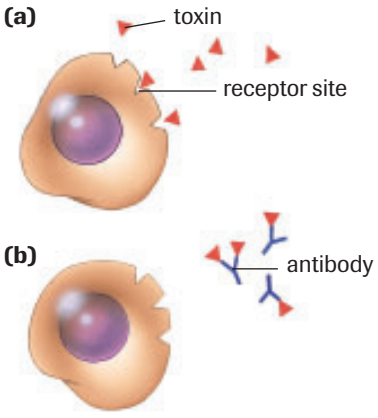


Figure 7
(a) Toxin binds to receptor.
(b) Antibody binds to toxin.

Many different antigen markers are located on the membrane of a virus or bacterium. Although different antibodies can attach to the invader, each antibody attaches only to its complementary marker. The attachment of antibodies to the antigens creates an antigen–antibody complex, which is larger and more conspicuous and, therefore, more easily engulfed and destroyed by the circulating macrophages.

How do antibodies prevent poisons, or toxins, from destroying cells? Specialized **receptor sites** are found on different cells, which may explain why some poisons affect the nervous system while others affect the digestive or circulatory system. The receptor site is designed to accommodate either a hormone or a specific nutrient. Unfortunately, the toxin has a shape similar to a hormone or nutrient that allows it to become attached to the receptor sites on cell membranes. Once attached, the poison is engulfed by the cell, which assumes that it is actually a needed substance. Antibodies interfere with the attachment of toxins to the cell membranes' receptor sites by binding to the toxins, as shown in **Figure 7**.

Viruses also use receptor sites as entry ports. The virus injects its hereditary material into the cell, but most often leaves the outer protein coat in the receptor site. Because of this outer coat, different viruses attach to different types of cells. For example, the outer

coat of the cold virus has a geometry that enables it to attach to lung cells. HIV attaches to the receptor sites of the T cell (**Figure 8**). Once attached, the virus is engulfed by a T cell, creating another problem for the immune system. Antibody production requires a blueprint of the invader, but the protein coat of the virus hides inside the very cells assigned as sentries for invading antigens. Does this provide a clue as to why the body experiences difficulty defeating HIV?

Antibodies attach themselves to invading viruses, thereby preventing the viruses from binding to receptor sites on cells. For some viruses, the antibody will cause the virus to change shape, so it cannot bind to a cell. Occasionally, the outer coat of an invader will change shape slightly because of mutations. The mutated viruses can still gain access to a receptor site but are not tied up by an antibody.

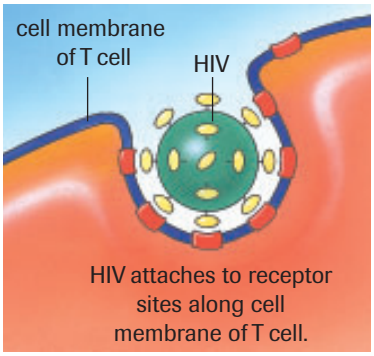


Figure 8
HIV has a shape that provides access to the T cell. The T cell engulfs HIV, unlike most other viruses.

Case Study

Bovine Spongiform Encephalopathy

Bovine spongiform encephalopathy (BSE) belongs to a larger group of transmissible spongiform encephalopathy (TSE) diseases that are characterized by the spongy deterioration of the brain. Transmissible means that the disease can pass from one animal to another. Eventually, BSE destroys the nervous system and causes death.

Spongiform encephalopathy is found in animals other than cattle. Scrapie affects sheep and goats. Chronic wasting disease (CWD) affects mule deer, white-tailed deer, and elk. Creutzfeldt-Jakob Disease (CJD) is a rare and fatal form of TSE that affects humans. Variant Creutzfeldt-Jakob disease (vCJD) has been diagnosed since 1996 and is thought to be linked to the consumption of meat products derived from BSE cattle.

What Causes the Disease?

The most widely accepted theory is that an agent, called a prion (**Figure 9**), infects the host and causes the conversion of normal proteins into abnormal proteins, which accumulate in the brain tissue and change its structure to a spongy form.

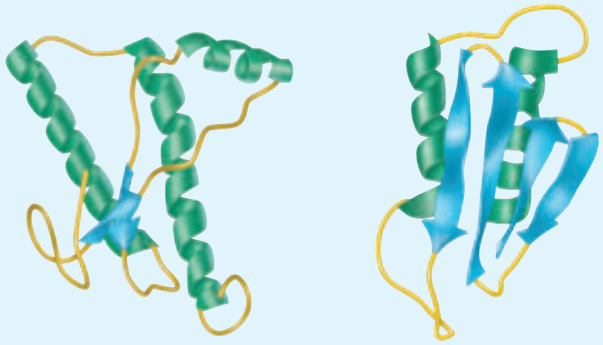


Figure 9
A normal prion (left) compared to the infectious form (right) that causes BSE. The structures of the proteins are shown using the ribbon model for ease of comparison.

Prions have caused the scientific community to examine disease in a new manner. Prions are proteins that are self-replicating, but, unlike other disease-causing agents, prions do not contain genetic material. Most prions are highly resistant to heat, freezing, and chemical sterilization.

The Origin of the Disease

Different and sometimes competing theories about the origin of this disease propose the possibility that BSE occurred at undetectable levels long before it was identified in British cattle in 1986. Many experts believe that BSE may have been caused by feeding ruminant (cattle, sheep, goats, deer, elk, bison) protein products to cattle. The prion could have been introduced to cattle from infected feed. One theory suggests that the protein may have come from another TSE, such as scrapie. Scrapie in sheep has been in existence for hundreds of years. When the protein from the sheep changed shape, it may have jumped species to the cow.

The recycling of proteins such as brain tissue and bone within cattle feed seems to be the problem. This practice dates back at least to the 1920s. It was originally seen as an inexpensive way to boost milk production and increase weight gain in cattle. The recycling of animal protein, known as rendering, is still regarded as an efficient way to utilize nutritious materials that would otherwise be wasted. Rendering serves the public interest by

- controlling the spread of pathogens that grow on waste tissues.
- reducing air pollution. Incinerating animal wastes as another means of disposal would reduce air quality.
- reducing wastes from packing plants. Approximately 50 % of every cow and about 30 % of every pig are not consumed by humans.

Understanding the Threat

Many scientists believe the disease began long before the first case of BSE was recorded in 1986 in England. A long incubation period (4 to 5 years) before the disease manifests itself indicates that it may have appeared in the 1970s.

In Canada, the first case of BSE was reported in 1993, in a beef cow imported from Britain in 1987. In 1997, feed-practice controls were put in place by the federal government of Canada. High-risk tissues such as cow brain and spinal cord could not be added to cattle feed. The second case was found in Alberta on May 20, 2003. The herd was immediately destroyed. Infected feed was identified as the most likely cause. The United States, along with other nations, closed the border to Canadian beef. In January 2005, two more Canadian cases of BSE were confirmed.

In March 1996, vCJD was diagnosed in people living in Britain and France. In August 2002, doctors confirmed that a Saskatchewan man died from vCJD, the human counterpart to BSE. The man was known to have spent time in Britain and may have acquired the disease there.

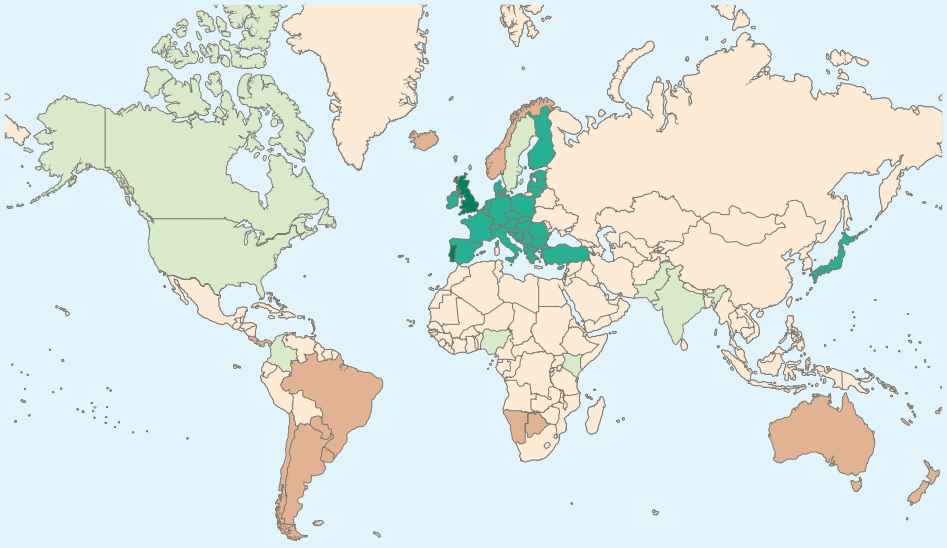
Evaluating Safety

- Canada had 13.5 million cows in 2005, with about 5.7 million (42 %) in Alberta.
- There had been four confirmed cases by January 2005, but one was from an imported cow. Only three cases were from cows native to Canada.
- To prevent prions from entering the food chain, rendering plants do not use sheep infected with scrapie, elk or deer infected with CWD, or high-risk cattle. Brain and spinal cord tissue are not used in feed.
- All ruminant products from countries that pose a risk of BSE are banned from Canada.
- All rendered proteins from cattle were banned from cattle feed in 1997.
- Feed practices are similar in the United States and Canada. Feed products are exported and imported between the two countries.
- BSE prions have never been found in dairy products.
- Random testing of beef cattle for BSE is routinely conducted. The testing frequency increased dramatically in 2003.

Case Study Questions

1. According to the map provided by the European Commission in 2002 (**Figure 10**), assess the risk presented for Canada.
2. According to the evidence presented, do cattle from Canada present higher levels of risk than those from the United States? Give your reasons.
3. According to the data provided, make a prediction about the country that might have been the original site of this disease. Give your reason.
4. Explain why it is difficult to provide a worldwide perspective on the spread of BSE.
5. How are prions unlike viruses and bacteria?
6. What would normally happen to a protein exposed to extreme heat?
7. Why would prion resistance to heat cause concern among humans?

Geographical BSE Risk



The geographical BSE risk (GBR) is a qualitative indicator of the likelihood of one or more cattle being infected with BSE, pre-clinically as well as clinically, at a given point in time.

no data: | Category 1: highly unlikely | Category 2: unlikely but not excluded | Category 3: likely but not confirmed or confirmed at a lower level | Category 4: confirmed, at a higher level

Source: European Commission, Scientific Steering Committee on the Geographical Risk of BSE (GBR), August 2002

Figure 10
BSE risk by country

8. Suggest a way of controlling the disease.
9. Explain why beef cattle under three years of age pose less threat.
10. Compare the BSE trends in and outside the UK using the graphs in **Figure 11**.
11. According to **Figure 11 (b)**, what was the worst year for BSE cases within the UK? What was the total number of cases?
12. Why would government officials want to know the age of infected cows?
13. Make two generalizations from the graph presented in **Figure 12**.
14. The decline in vCJD deaths from 2000 to 2001 (**Figure 12**) indicates fewer cases; however, it may not indicate that the disease is being eradicated. Why should caution be used in claiming that vCJD has been conquered?
15. Assess the risk of eating beef for humans.
16. What additional safety measures would you suggest?

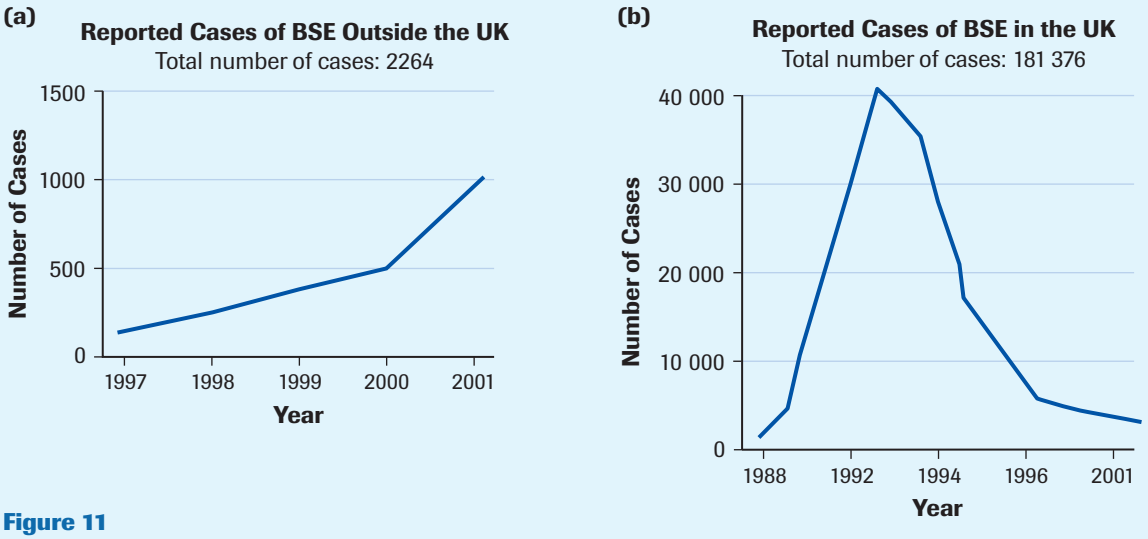


Figure 11
Reported cases of BSE

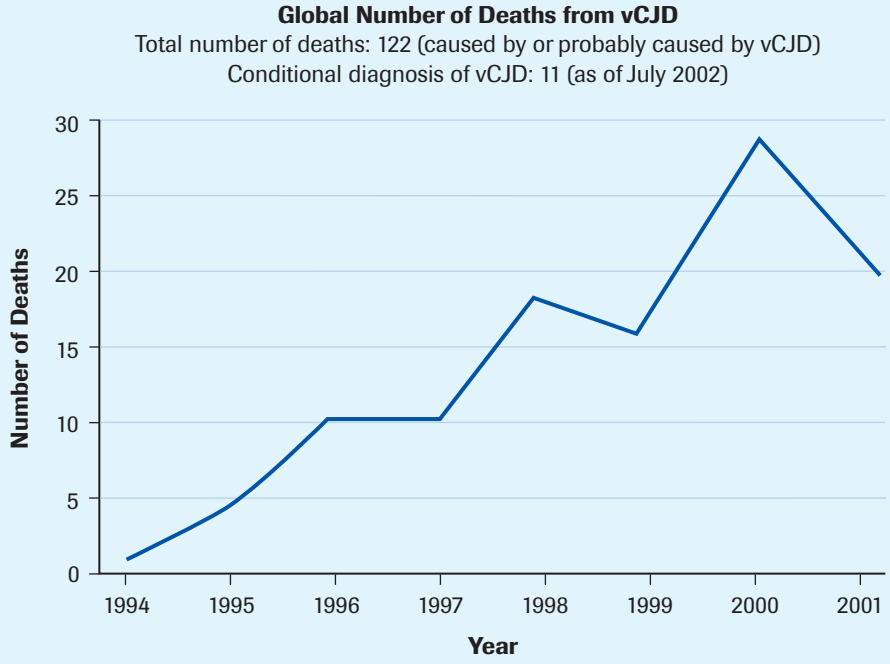


Figure 12
Global deaths from vCJD

Recognizing Harmful Antigens

Figure 13 illustrates how the body recognizes harmful antigens. The T cells roam the body in search of foreign invaders that pose a threat to survival. The macrophages attack the invaders and engulf them. The foreign antigen markers are not destroyed with the invader but are pushed to the cell membrane of the macrophage. Pressing the antigens into its cell membrane, the macrophage couples with T cells referred to as **helper T cells**. The T cells read the antigen's shape and release a chemical messenger called **lymphokine**. The lymphokine causes the B cells to divide into identical cells called clones. Later, a second message is sent from the helper T cells to the B cells, triggering the production of antibodies. Each B cell produces a specific type of antibody. By the time the B cells enter the circulatory system, many antibodies are attached to their cell membranes.

helper T cell a T cell with receptors that bind to fragments of antigens

lymphokine a protein produced by the T cells that acts as a chemical messenger between other T cells and B cells

killer T cell a T cell that destroys microbes, body cells infected with viruses, and mutated cells by puncturing cell membranes

The helper T cells activate an additional defender, the **killer T cells**. As the name suggests, these lymphocytes carry out search-and-destroy missions. Once activated, the killer T cells puncture the cell membrane of the intruder, which may be a fungus, protozoan parasite, or bacterium. Viruses, however, are much more insidious because they hide within the confines of the host cell. Here, the true value of the killer T cells is demonstrated. Once the viral coat is found attached to the cell's membrane, the T cell attacks the infected cell. By destroying the infected body cell, the killer T cell prevents the virus from reproducing.

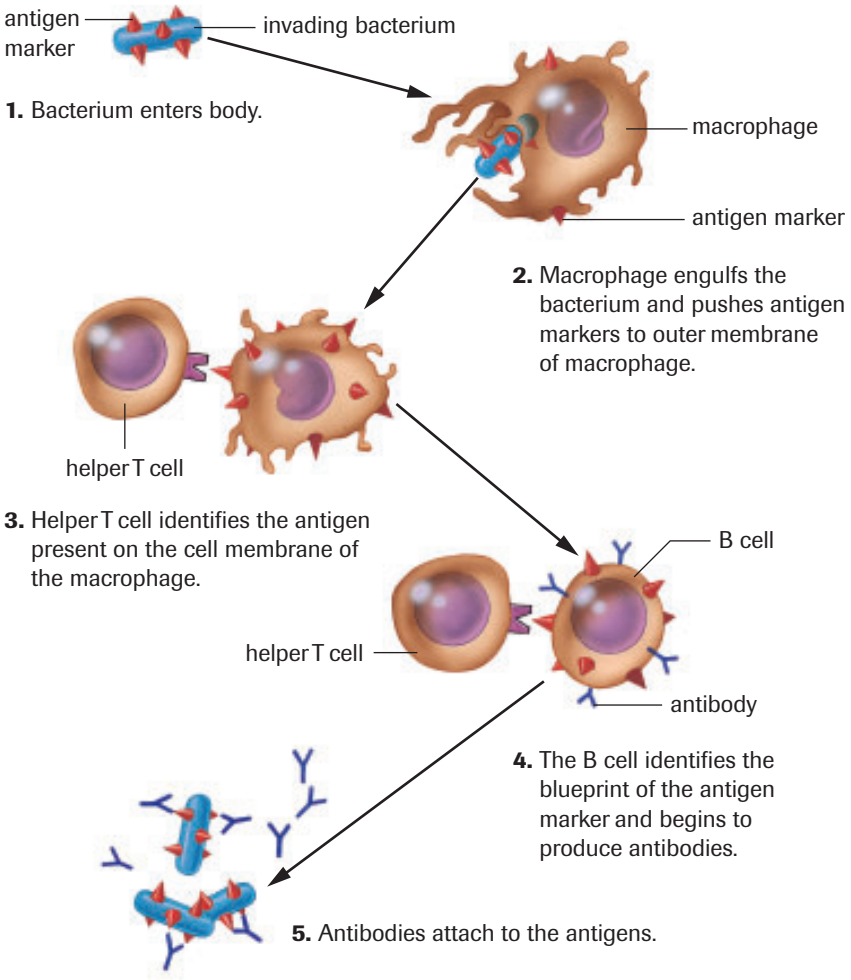


Figure 13
The immune system recognizes harmful antigens.

EXTENSION

Four Pathways to Achieve Immunity

How do you gain immunity to different diseases? This Audio Clip will discuss the four different ways to acquire immunity to specific diseases.

www.science.nelson.com GO

Killer T cells also destroy mutated cells (**Figure 14**). This is an extremely important process because some of the altered cells may be cancerous. Many experts believe that everyone develops cancerous cells, but, in most cases, the T cells eliminate them before a tumour forms. Killer T cells may also account for the body's rejection of transplanted organs. Antigen markers on the cell membranes of the donor will be different from those of the recipient. Once the foreign markers of the transplanted tissue are recognized, the recipient's killer T cells initiate an assault. Immunosuppressant drugs, such as cyclosporin, can slow the killer T cells. Unfortunately, individuals who receive these drugs become susceptible to bacterial infections. One of the leading causes of death for an organ transplant patient is pneumonia.

Once the battle against foreign invaders has been won, another T cell, the **suppressor T cell**, inhibits the immune system response. Communication between the helper T cells and the suppressor T cells ensures that the body maintains adequate numbers of antibodies to contain the invading antigen. Most of the B cells and T cells will die off within a few days after the battle, but a small contingent will remain long after to guard the site. Phagocytes survey the area, cleaning up the debris left from dead and injured cells.

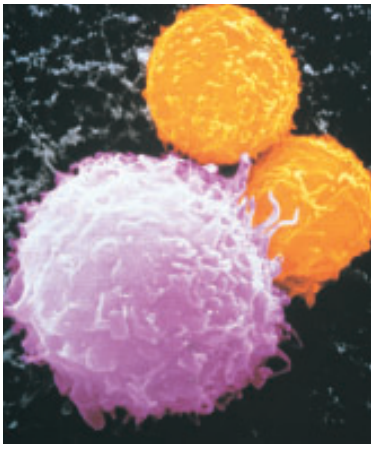


Figure 14
Killer T cells bind with a tumour cell.

suppressor T cell a T cell that turns off the immune system

The Immune System's Memory

The Aboriginal population of Hawaii was nearly annihilated by measles in the late 18th and early 19th centuries after British explorer James Cook and his sailors unwittingly introduced the disease when they arrived at the Hawaiian Islands. In North America, the Aboriginal population was decimated by epidemics of smallpox. Because neither group had been exposed to these viruses before, they had no antibodies to fight infection. At this time, Europeans and Asians, unlike the Aboriginal populations of Hawaii and North America, had long been exposed to many types of viruses and were better able to produce antibodies to fight them.

As mentioned earlier, the helper T cells must read a blueprint of the invader before B cells produce antibodies. This blueprint is stored even after the invader is destroyed so that subsequent infections can be stopped before the microbe gains a foothold. Immunity is based on maintaining an adequate number of antibodies. It is believed that a **memory B cell** is generated during the infection. Like helper T cells, the memory B cells hold an imprint of the antigen that characterizes the invader. Most T cells and B cells produced to fight the infection die within a few days; however, the memory B cells remain. During a subsequent infection, the memory B cells identify the invader and quickly mobilize antibody-producing B cells. Invading pathogens are defeated before they become established. As long as the memory B cell survives, the individual is immune.

EXTENSION

Immune Memory
Watch this brief simulation of how B cells help the body respond faster to antigens the body has encountered before.

www.science.nelson.com GO

memory B cell a B cell that retains information about the shape of an antigen

WWW WEB Activity

Simulation—Virtual Immunology Laboratory

How does your immune system respond to foreign invaders? How do antibodies know which antigen to attack? Can the formation of antibodies be used to diagnose disease? In this activity, you will use an ELISA (enzyme-linked immunosorbent assay) to detect either the antigen or antibody associated with a disease-causing agent. After you have finished the simulation, create a model to depict how the main components of the immune system function.

www.science.nelson.com GO

SUMMARY The Body's Lines of Defence

- Skin and mucous membranes provide physical barriers that prevent most infectious organisms from entering the body.
- Leukocytes (white blood cells), produced in the bone marrow, fight infection in a variety of ways. Phagocytosis of invading microbes is one of the main methods used by certain leukocytes to combat infection.
- Tissue damage due to physical injury initiates the inflammatory response, which is a nonspecific immune response resulting in swelling, redness, heat, and pain.
- Antibodies attach to foreign antigens, such as microbes and toxins. Each antibody is specific and can only bind its complementary antigen.

Table 1 Lymphocytes Involved in the Immune Response

Cell	Function
helper T cells	act as sentries to identify foreign invading substances
B cells	produce antibodies
killer T cells	puncture cell membranes of infected cells, thereby killing the cell
suppressor T cells	turn off the immune system
memory B cells	retain information about the shape of an antigen

Section 11.2 Questions

1. How does lysozyme protect the body against invading microbes?
2. Outline protective mechanisms provided by the respiratory tract.
3. How do monocytes protect against microbes?
4. Explain why swelling and pus at the site of an injury are signs that the immune system is functioning.
5. Define and contrast these terms: antigen, antibody; T cell lymphocytes, B cell lymphocytes; macrophages, lymphocytes.
6. Explain how B cell, helper T cell, and killer T cell lymphocytes provide immunity.
7. How do antibodies defeat antigens? Describe four contributions that antibodies make to the immune system.
8. How do memory B cells provide continuing immunity?
9. A patient displaying a high fever may be asked by the physician to have blood tests done. One of these tests would likely be a white blood cell count. Explain what an abnormal result might indicate.
10. A research group has begun testing on a potential cure for type 1 diabetes, an inherited disease caused by the destruction of the insulin-producing cells in the pancreas by one's own immune system. An immunosuppressant drug is administered twice daily to a test group of 150 people.
    (a) Why can the immunosuppressant drug prevent diabetes?
    (b) Researchers found that the drug wasn't effective once symptoms for diabetes were expressed in test subjects. What conclusions can you draw about this?
    (c) Explain why researchers are working on a test to identify antibodies that destroy insulin-producing cells.
    (d) List three important research questions that remain to be answered.

Malfunctions of the Immune System 11.3

Abnormal functioning of the immune system can cause two types of problems: immunodeficiency diseases and inappropriate attacks of the immune system against non-threatening agents. Immunodeficiency diseases may be caused by a foreign agent, such as HIV, which attacks T cells, or a hereditary condition, such as severe combined immunodeficiency (SCID). The gene mutation that causes SCID results in the inability to produce B cells and T cells. Cancer therapy or prolonged exposure to anti-inflammatory drugs, such as cortisol, can also reduce the effectiveness of the immune system.

Inappropriate or exaggerated immune responses can also create problems. A hypersensitivity to harmless agents (an allergy) or a response in which the immune system begins to attack normal cells in one's own body (an autoimmune disease) can destroy tissues and organs.

Allergies

Allergies occur when your immune system mistakes harmless antigens for harmful invaders. If you are allergic to peanuts, your immune system recognizes one of the proteins in the peanut as dangerous. Although the protein is quite safe, your body mobilizes the antibody strike force against it. Tissue swelling and mucus secretion and, sometimes, constricted air passages are part of the immune response. Dust, ragweed, strawberries, and leaf moulds do not pose any direct threat to life, but the immune response to these agents can sometimes be so severe that it becomes life threatening.

A severe allergic reaction is an anaphylactic reaction (**Figure 1**), which involves the respiratory and circulatory systems. It often is accompanied by swelling of different body parts, hives, and itching. When you ingest something, like food or medicine, to which you are allergic, cells that "believe" they are endangered release a chemical messenger, called *bradykinin*, which stimulates the release of another chemical, *histamine*. Histamine is produced by the circulating white blood cells known as basophils and by mast cells found in connective tissues. Histamine changes the cells of the capillaries, increasing

DID YOU KNOW?

Peanut Allergy

Peanut allergy is the most common cause of food anaphylaxis (anaphylactic shock from foods). Ingesting minute amounts can lead to a rapid reaction resulting in death within minutes. Because a reaction may recur even after an initial epinephrine injection, the affected person must be immediately hospitalized. Traces of peanut from a knife, plate, countertop, or even from kissing someone who has eaten peanuts can trigger a reaction. For those who are sensitive to peanuts, avoiding peanut products is crucial but also difficult. In Canada, annual peanut butter consumption is estimated to be about 3 kg per person. Many processed foods contain the ingredient "hydrolyzed vegetable protein," which may contain peanut protein.

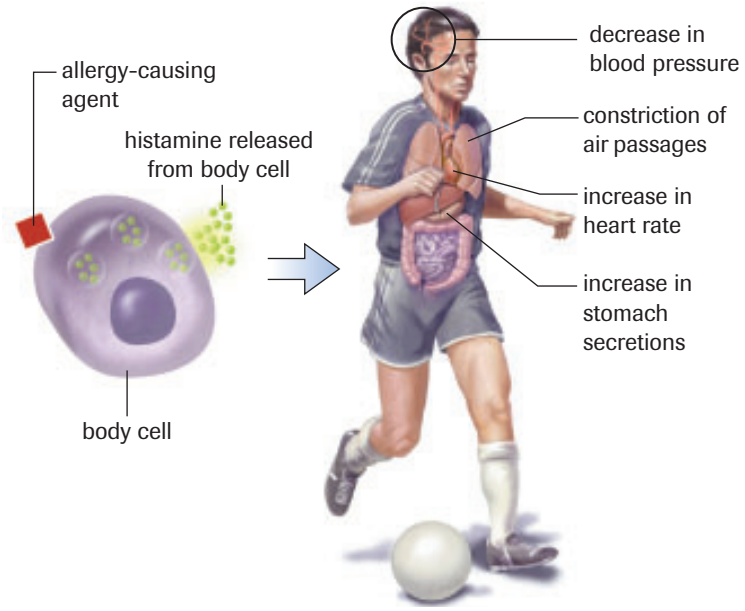


Figure 1
The body's response to an allergy-causing agent

permeability. The enlarged capillary causes the area to redden. Proteins and white blood cells leave the capillary in search of the foreign invader, but, in doing so, they alter the osmotic pressure. The proteins in the extracellular fluid create another osmotic force that opposes the osmotic force in the capillaries. Less water is absorbed into the capillaries, and tissues swell. These reactions can be brought on by drugs, vaccines, and some foods (peanuts, shellfish, eggs, berries, and milk) in individuals who are sensitive to these substances. Anaphylactic shock can occur very quickly. Weakness, sweating, and difficulty breathing are indicators of the condition. Nausea, diarrhea, and a drop in blood pressure may also occur. Medical precautions may range from carrying a kit with epinephrine to carrying antihistamines. People with severe food allergies should wear a medical alert bracelet or necklace and read all food labels carefully.

Autoimmune Diseases

The immune system can make mistakes. As you have already learned, allergies are caused when the immune system perceives harmless substances to be dangerous. The immune system can also go awry and launch an attack on the body's own cells. The renegade lymphocytes treat the body's cells as foreign and make antibodies to attach to their cell membranes. Many researchers believe that most people have mutated T cells and B cells that are capable of attacking the body; however, the renegade cells are usually held in check. The suppressor T cells play an important role in recognizing and intercepting the renegade T cells and B cells. One theory suggests that the suppressors secrete a substance that tells the macrophages to engulf the renegade cells.

The failure of the suppressor T cells to control the renegade cells can be seen in autoimmune diseases such as rheumatoid arthritis, in which an immune response is mounted against the connective tissues of the joints. Rheumatic fever, another autoimmune disorder, results from an exaggerated immune response that scars the heart muscle. Type 1 diabetes is caused by an immune reaction against the insulin-producing cells of the pancreas, and lupus is caused by the accumulation of antigen–antibody complexes that build up in the walls of blood vessels, joints, kidneys, and skin. Multiple sclerosis (MS) is an autoimmune disease in which T cells of the body initiate an attack on the myelin sheath of nerve cells. In the advanced stages of MS, paralysis results from the destruction of the insulation of the nerve cell provided by the myelin sheath.

Drugs or serious infections can weaken the suppressor T cells, leaving the body vulnerable to autoimmune diseases. We know that the number of suppressor T cells declines with age, increasing the incidence of rheumatoid arthritis and other autoimmune diseases. Some individuals are born with defective suppressor T cells. Although no single cure exists, immune-suppressing drugs have been developed that reduce the intensity of the attack by the renegade cells.

Organ Transplant Rejection

The main challenge with any tissue or organ transplant is the immune response of the recipient—that is, the immune system's ability to distinguish between "self" and "non-self." The donor organ is often identified as a foreign invader by distinctive protein markers on its cell membranes. The distinctive marker (known as major histocompatability complex, or MHC) is a protein fingerprint unique to each individual. The recipient makes antibodies designed to destroy the foreign invader.

Kidney transplants can be used as an example. Living donor kidneys account for about 15 % of all kidney transplants. Because humans are born with two kidneys, the donor is able to give one kidney without significant effects on quality of life. A single kidney can carry out the filtering and osmoregulatory functions of the body. To reduce rejections,

CAREER CONNECTION

Pathologist

Pathologists are medical doctors who diagnose diseases and advise other physicians and surgeons about the treatment of diseases such as cancer. Pathologists perform tests on human tissue and blood to determine the type and extent of disease. Forensic pathologists specialize in determining the cause of death in forensic investigations. Find out if this is a career direction for you.

www.science.nelson.com GO

DID YOU KNOW ?

Organ Donation in Canada

Canada's organ donation rate is among the lowest of all the developed countries—more than 3000 Canadians are waiting for an organ transplant. One organ donor can donate numerous organs and tissues including lungs, heart, liver, kidneys, pancreas, bowel, eye tissue, skin, heart valves, bone, tendons, veins, and ligaments. You can indicate your wish to become an organ donor on your health card. Discuss this decision with your family so your wishes are known.

attempts are made to match the MHC of the tissues of donors and recipients as closely as possible. For living donor transplants, physicians usually look to close relatives because the MHC is genetically controlled. The better the match, the greater the chances of long-term success.

Kidney transplants from recently deceased donors account for the vast majority of transplants. However, the need for organs far surpasses supply (**Figure 2**). Again, as with living donors, close matching is essential. Not every donor kidney is appropriate for a specific recipient. To help reduce rejection, even for close matches, immunosuppressant drugs can be given. However, a drug that minimizes the fight against foreign tissues will also reduce the immune system's ability to fight off invading viruses and bacteria. These drugs place patients at risk of infections.

Organ Transplants in Alberta

Alberta's Capital Health Regional Transplant Program, located at the University of Alberta Hospital and Stollery Children's Hospital in Edmonton, provides transplants for adults and children from Alberta, Saskatchewan, the Northwest Territories, and British Columbia (**Table 1**). Its survival rates are among the best in Canada, and it is the only program in the country that provides all types of organ and tissue transplants.

The HOPE (Human Organ Procurement and Exchange) Program is responsible for the coordination, recovery, and distribution of organs in Alberta. HOPE also promotes awareness of organ and tissue donation. The Comprehensive Tissue Centre is one of only two accredited tissue banks in Canada. Transplanted tissues include eyes (cornea and sclera), skin, heart valves, and bone.

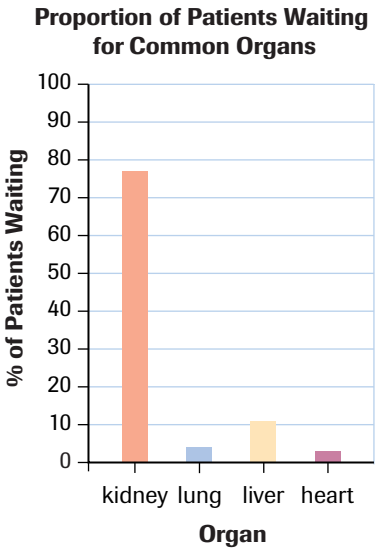


Figure 2
Percentage of all patients waiting for a transplant, by organ type. Kidney transplants are the second most common transplant in Canada (corneal transplants rank number one) and the most common organ transplant.

Stem Cell Research

The answer for replacing damaged tissues and organs may lie in stem cell research rather than transplantation. Stem cells can develop into a variety of different tissues such as epithelial, muscle, or nerve. Intestinal stem cells reline the gut; skin stem cells replace cells that are continuously sloughed off; and stem cells in the bone marrow give rise to a wide range of blood cells. Stem cells are **pluripotent cells**, meaning they can give rise to different types of body cells.

In 1998, James Thomson, a researcher at the University of Wisconsin, demonstrated that human stem cells could transform into a variety of cells, such as those that form the bone marrow, brain, muscle, skin, pancreas, liver, or practically any human tissue. If it were possible to regulate the development of human stem cells, the cells could replace destroyed islet cells that produce insulin, repair damaged cartilage, or repair cardiac tissue that has been destroyed by heart disease.

Dr. Freda Miller and colleagues at the Montreal Neurological Institute (MNI) have discovered multipotent stem cells in adult skin. These skin cells can be directed to become neurons or even muscle cells.

Table 1 Alberta's Capital Health Regional Transplant Program, 2004

Organ transplanted	Quantity
heart	28
heart/lung	1
lung	24
liver	71
kidney	84
kidney/pancreas	13
pancreas	1

pluripotent cell a cell that is capable of developing into a number of specialized cell, such as neuron or muscle cell

EXPLORE an issue

The Future of Stem Cell Research

The greatest challenge of organ transplants is to trick the recipient's immune system into accepting the new organ. Finding someone with a close tissue match to donate an organ can be extremely difficult. What if the person who needs a transplant could use his or her own stem cells to repair the damaged organ?

Statement

Governments should redirect some funding from organ transplant research to autologous (i.e., originating from the same individual) stem cell research.

1. Investigate this rapidly changing field of research. Search for information in newspapers, periodicals, CD-ROMs, and on the Internet.

www.science.nelson.com GO

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

2. Prepare a list of points and counterpoints. You might consider these questions:
   (i) Researchers are working on ways to use mature cells as a source for stem cells. How will this change the prospects for successful treatment?
   (ii) Companies have applied for patents on specific stem cells and techniques used to culture stem cells. These companies will own a medical procedure and collect huge royalties. Should this be allowed?
   (iii) Speculate why many people object to stem cell research.
   (iv) Why are governments regulating this field of research?
3. Decide whether you agree or disagree with the statement.
   (a) Prepare an outline.
   (b) Write your position paper.
   (c) Prepare to defend your position in class.

SUMMARY Malfunctions of the Immune System

- Abnormal functioning of the immune system can cause two types of problems: immunodeficiency diseases and inappropriate immune responses (allergic reactions and autoimmune diseases).
- Allergies occur when the immune system mistakes harmless antigens for harmful invaders.
- Autoimmune diseases occur when lymphocytes treat the body's cells as foreign.

Section 11.3 Questions

1. What are allergies?
2. Explain how an allergic reaction to peanuts can be life threatening.
3. Why is epinephrine administered as a treatment for a severe allergic reaction?
4. What causes autoimmune diseases?
5. What evidence suggests that suppressor T cells may be a significant factor in autoimmune diseases?
6. Why do donor organs have to be matched to the recipients?
7. Select an autoimmune disease and research the latest medical advance toward a cure. Search for information in newspapers, periodicals, CD-ROMs, and on the Internet.

www.science.nelson.com GO

8. Research the role of histamines in an allergic reaction.

INVESTIGATION 11.1

Diagnosing Disease by Examining Blood Cells

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

White blood cell counts can be used as clues in the diagnosis of disease. In this activity, you will examine prepared slides to identify different types of white blood cells and to determine how changes in blood cell counts are used to diagnose disease.

The slides have been prepared using Wright's stain, which allows you to clearly view cells and many types of microorganisms. Wright's and similar stains for blood and bone marrow smears are mixtures of acidic and basic dyes. According to the number of acid and basic groups present, cell components absorb the dyes from the mixture in various proportions.

Materials

prepared slide of human blood
light microscope
lens paper

Procedure

1. Before beginning the investigation, clean all microscope lenses with lens paper and rotate the nosepiece to the low-power objective. Place the slide of blood on the stage, and focus under low power. Locate an area in which individual blood cells can be seen.
2. Rotate the revolving nosepiece to the medium-power objective and focus. Red blood cells greatly outnumber white blood cells.

(a) Draw a single human red blood cell.

(b) Estimate the size of the human red blood cell. Show your calculation.

3. Scan the field of view for different white blood cells. Using the classification of leukocytes provided in **Table 1**, classify the leukocytes and record your results.
4. Repeat the procedure by scanning 10 different visual fields. Record the data in your table.

Analysis

(c) Explain why few blood tests provide a diagnosis of disease.

Table 1 Classification of Leukocytes

Type	Description	Normal proportion (%)	Observed number	Observed proportion (%)
Granulocyte	granular cytoplasm			
neutrophil	3-lobed nucleus, 10 µm (Wright's stain: purple nucleus, pink granules)	65		
eosinophil	2-lobed nucleus, 13 µm (Wright's stain: blue nucleus, red granules)	2–4		
basophil	2-lobed nucleus, 14 µm (Wright's stain: blue–black nucleus, blue–black granules)	0.5		
Agranulocyte	nongranular cytoplasm			
monocyte	U-shaped nucleus, 15 µm (Wright's stain: light bluish–purple nucleus, no granules)	4–7		
lymphocyte (small)	large nucleus, 7 µm (Wright's stain: dark bluish–purple nucleus, no granules)	2–3		
lymphocyte (large)	large nucleus, 10 µm (Wright's stain: dark bluish–purple nucleus, no granules)	20–25		

Synthesis

Blood tests are used to help diagnose disease. **Table 2** shows some changes in leukocyte counts and the conditions associated with those changes. Use **Table 2** to answer the following questions:

(d) Why would a physician not diagnose leukemia based on a single blood test?

(e) What information might a blood test provide about a patient being treated for the lung disease tuberculosis? Why would blood tests be taken even after the disease has been diagnosed?

(f) Leukemia can be caused by the uncontrolled division of cells from two different sites: the bone marrow or lymph nodes. Indicate how blood tests could be used to determine which site harbours the cancerous tumour.

(g) Do blood donors need to have their blood counts taken? Why or why not?

Table 2 Health Conditions Associated with Abnormal Leukocytes

Leukocyte change	Associated conditions
increased eosinophils	allergic condition, cholera, scarlet fever, granulocytic leukemia
increased neutrophils	toxic chemical, newborn acidosis, hemorrhage, rheumatic fever, severe burns, acidosis
decreased neutrophils	pernicious anemia, protozoan infection, malnutrition, aplastic anemia
increased monocytes	tuberculosis (active), monocytic leukemia, protozoan infection, mononucleosis
increased lymphocytes	tuberculosis (healing), lymphocytic leukemia, mumps

Chapter 11 SUMMARY

Outcomes

Knowledge

- describe the main components of blood and their role in transport, blood clotting, and in resisting the influence of pathogens, i.e., erythrocytes, leukocytes, platelets, plasma (11.1, 11.2)
- describe the ABO and Rh blood groups on the basis of antigens and antibodies (11.1)
- explain the sequence of the blood clotting process (11.1)
- describe and explain, in general terms, the function of the lymphatic system (11.2)
- list the main cellular and non-cellular components of the human defence system and describe their role, i.e., skin, macrophage, helper T cell, B cell, killer T cell, suppressor T cell, and memory B cell (11.2)

STS

- explain how Canadian society supports scientific research and technological development that help achieve a sustainable society, economy, and environment (11.2)
- explain that decisions regarding the application of scientific and technological developments involve a variety of perspectives (11.3)

Skills

- conduct investigations and gather and record data and information by: determining the morphology and abundance of cellular components in a prepared human blood slide (11.1) and; researching and designing a simulation or model of the functioning of the main components of the human immune system (11.2)
- analyze data and apply mathematical and conceptual models (11.2)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

11.1

plasma
erythrocyte
anemia
leukocyte
platelet
thrombus
embolus
antigen
antibody
agglutination

11.2

phagocytosis
macrophage
pus
inflammatory response
complement protein
T cell
B cell
receptor sites
helper T cell
lymphokine
killer T cell
suppressor T cell
memory B cell

11.3

pluripotent cell

MAKE a summary

1. Imagine a microbe entering your blood. Create a flow chart or diagram that shows how the immune system would respond to this potentially dangerous situation. Label the diagram with as many of the key terms as possible.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 11
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

CBC radioONE QUIRKS & QUARKS

The Path of Least Resistance: Alternatives to Antibiotics

More and more strains of bacteria are appearing that are resistant to antibiotics. Three researchers, Dr. Tania Watts (University of Toronto), Dr. Bob Hancock (University of British Columbia), and Dr. Gregor Reid (University of Western Ontario), discuss their research into alternatives to antibiotics.

www.science.nelson.com GO

EXTENSION

Pandemic Flu

This *NOVA* video investigates the question: Will the virus that causes bird flu develop the ability to move from person to person?

www.science.nelson.com GO

Chapter 11 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The introduction of a microbe into the bloodstream will result in the production of (1) _____ by (2) _____.
   A. (1) antigens, (2) erythrocytes
   B. (1) antibodies, (2) erythrocytes
   C. (1) antigens, (2) leukocytes
   D. (1) antibodies, (2) leukocytes

2. Identify two functions of proteins found in the plasma.
   A. acting as antigens and blood clotting
   B. acting as antibodies and maintaining osmotic balance
   C. carrying oxygen and clotting blood
   D. phagocytosis and acting as antibodies

3. The ability of blood to clot can be reduced by
   A. ruptured platelets
   B. low calcium concentration in the blood
   C. high levels of thrombin
   D. high levels of iron in red blood cells

4. Identify which of the following is not involved in the body's defence system.
   A. skin
   B. erythrocytes
   C. macrophages
   D. cilia

Use the following information to answer questions 5 and 6.

A kinesiologist measured the factors related to circulation shown in **Table 1** in four different subjects.

Table 1 Cardiovascular Measurements of Four Subjects

Measurement	Subject W (normal)	Subject X	Subject Y	Subject Z
cardiac output (L/min)	5.1	7.2	5.4	4.0
white blood cell count (per mm^3 of blood)	8000	7900	15 000	8200
O_2 content of arterial blood (mL/100 mL of blood)	19.5	10.2	19.0	17.5

5. Which subject is most likely suffering from a bacterial infection?
   A. Subject X: low levels of oxygen in the blood occur when someone has an infection
   B. Subject Y: higher leukocyte levels produce more antibodies
   C. Subject Z: lower cardiac output conserves energy
   D. Subject Y or Subject Z: both have higher cardiac output to deliver more nutrients to tissues

6. Which subject is most likely suffering from anemia?
   A. Subject X: low levels of oxygen occur in the blood when someone has an infection
   B. Subject X: low levels of oxygen occur with a deficiency of hemoglobin
   C. Subject Y: higher leukocyte levels produce more antibodies
   D. Subject Z: low cardiac output conserves energy

Use the information in **Figure 1** to answer questions 7 and 8.

Antigens and Antibodies of Four Blood Groups

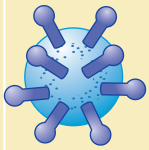
Group	1	2	3	4
antigens on red blood cells	A antigen 	B antigen 	A and B antigens 	no A or B antigens 
plasma antibodies			no anti-A or anti-B antibodies	

Figure 1

7. According to **Figure 1**, blood type A would be represented by
   A. group 1
   B. group 2
   C. group 3
   D. group 4

8. Blood group 3 has
   A. no antibodies because you do not produce antibodies against your own antigens.
   B. no antigens because you do not produce antigens against your own antibodies.
   C. no antibodies because you do not produce antigens against your own antibodies.
   D. no antigens because you do not produce antibodies against your own antibodies.

9. NR The following are steps involved in the immune response:

1. Suppressor T cells inhibit the immune system.
2. Antibodies attach to antigens on bacterial cells.
3. B cells produce antibodies.
4. Bacterial cells enter the body and are engulfed by macrophages.

Give the numbers of the steps in the order that they occur, from first to last. (Record all four digits of your answer.)

Part 2

10. (a) **Sketch** an antibody, showing how it attaches to specific antigens.
(b) Label the receptor sites on the cell membrane.
(c) Use the diagram to **explain why** an antibody produced in response to the mumps virus would have no effect against influenza.
(d) Use the diagram to **explain** how antibodies target antigens for phagocytosis.

11. **Explain why** the second time an organism invades the body, the person is not likely to get seriously ill.

12. **Distinguish** between T cell lymphocytes and B cell lymphocytes.

13. **How** do viruses use the receptor sites to gain access into the cell?

14. **Explain why** T cells have difficulty identifying antigens from HIV.

15. **Describe** the function of lymphokine.

16. **Describe** in your own words the function of each of the following:
(a) killer T cells
(b) helper T cells
(c) suppressor T cells
(d) memory B cells

17. **Explain why** the Hawaiian population was so severely affected by measles and the Aboriginal population of North America was so much more susceptible to smallpox than Europeans were.

18. **Define** pluripotent cells.

19. **Why** does the likelihood of autoimmune disease increase with age?

20. **Explain** how a food allergy can threaten life.

Use the following information to answer questions 21 to 23.

The data in **Table 2** were collected from three patients.

Table 2 Blood Cell Counts and Temperature of Three Patients

Patient	Red blood cell count (cells/μL)	White blood cell count (cells/μL)	Body temperature (°C)
normal	5.0×10^6	7 000	37.0
X	2.0×10^6	3 000	37.0
Y	2.5×10^6	10 000	36.5
Z	5.1×10^6	15 000	39.0

21. DE Lead poisoning is characterized by a destruction of bone marrow. Which patient would you suspect has lead poisoning? **Justify** your choice.

22. DE **Predict** which patient has a viral infection. Explain your answer.

23. DE Leukemia is a cancer characterized by the proliferation of white blood cells. Which patient would you suspect has leukemia? **Justify** your choice.

Use the following information to answer questions 24 and 25.

Before the work of Dr. Barry J. Marshall and Dr. Robert Warren of Perth, Australia, most doctors believed that stress was the cause of ulcers. In 1983, Marshall and Warren reported that *Helicobacter pylori*, a bacterium living in the stomach, is the most common cause of ulcers. Today, researchers around the world are turning to another bacterium, *Chlamydia pneumonia*, as the main culprit in triggering coronary heart disease.

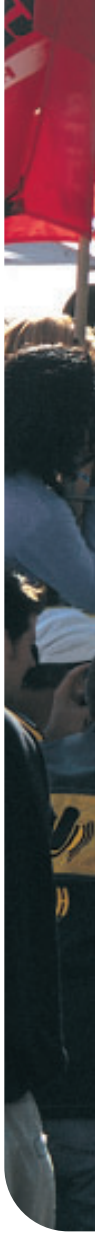
24. DE If coronary heart disease is caused by a bacterium, **how** might this affect the search for treatment?

25. DE **Explain why** physicians attempting to diagnose coronary heart disease may be monitoring antibodies.

chapter

12 Excretory System

In this chapter



In August 2000, Canadians Peter Reid and Lori Bowden won the Ironman Canada Triathlon men's and women's titles, completing the gruelling 226-km swim–cycle–run in 8 h, 29 min, and 49 s and 9 h, 17 min, and 23 s, respectively (**Figure 1**). The husband-and-wife team, dubbed "the world's fittest couple," went on to further victories: Peter once again won the Ironman Canada Triathlon in August 2001, and Lori won her third straight women's crown at the Australian Ironman competition in April 2001.

Imagine completing a 4-km swim and a 180-km bicycle ride only to have a 42-km marathon ahead of you. To meet the demands of this challenging competition, the body undergoes a series of adjustments to continue operating. One such adjustment is an increase in the rate of cellular respiration; another is a decrease in urine output.

The oxidation of glucose during cellular respiration generates waste energy in the form of heat. During severe strenuous exercise, body temperature can increase to more than 39 °C. To dissipate heat, sweat is produced.

The evaporation of sweat is a cooling process. The loss of water alters the volume of body fluids, which can cause a drop in blood pressure. The heart and circulatory system respond to changes in blood pressure, while the kidneys conserve water in an attempt to maintain fluid volume.

Water is not the only thing lost with sweating; many ions essential for nerve function and muscle contraction are carried to the skin with the perspiration. The kidneys are also responsible for maintaining the body's electrolyte balance.

STARTING points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. What dangers exist if your body is unable to regulate the fluid balance of your tissues?
2. What challenges would the body have to respond to if the kidneys failed to work?
3. Explain how the circulatory system and excretory system interact during exercise.

Career Connections:
Urologist; Emergency Medical Technician

Figure 1
Lori Bowden finished first in the women's Ironman Canada triathlon in 2000.

Exploration — Making a Model of a Filtering Excretory System

You can create a model of a filtering excretory system.

Materials: funnel, aquarium charcoal, 2 small beakers, food colouring, non-absorbent cotton, ring stand

- Place a small piece of non-absorbent cotton in a funnel. Fill the funnel with aquarium charcoal, and put a small beaker beneath the funnel. Fill a second beaker with about 25 mL of water, and add five drops of food colouring.
- Pour the coloured water through the funnel and collect it in the beaker beneath as shown in **Figure 2**.

(a) Compare the colour of the filtered water with the original coloured water.
(b) Predict what will happen if the water is filtered once again. Test your prediction.
(c) How would you improve the filter?

Figure 2
Model of a filtering excretory system

12.1 Waste Excretion and Internal Equilibrium

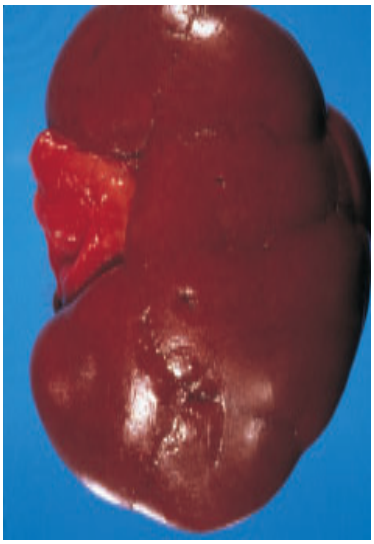


Figure 1
The human kidney is about the size of a fist and weighs approximately 0.5 kg.

The cells of the body obtain energy by converting complex organic compounds into simpler compounds. However, many of these simpler compounds can be harmful. To maintain life processes, the body must eliminate waste products. The lungs eliminate carbon dioxide, one of the products of cellular respiration. The liver transforms ingested toxins, such as alcohol and heavy metals, into soluble compounds that can be eliminated by the kidneys. The liver also transforms the hazardous products of protein metabolism into metabolites, which are then eliminated by the kidneys (**Figure 1**). In fact, the kidneys play a crucial role in removing waste, balancing blood pH, and maintaining water balance.

The average Canadian consumes more protein than is required to maintain tissues and promote cell growth. Excess protein is often converted into carbohydrates. Protein, unlike carbohydrates, contains nitrogen. The amino group (NH_2) that is characteristic of amino acids must be discarded by the body.

This process, referred to as **deamination**, occurs in the liver. The byproduct of deamination is ammonia, a water-soluble gas. However, ammonia is extremely toxic—a buildup of as little as 0.005 mg can kill humans. Fish are able to avoid ammonia buildup by continually releasing it through their gills. Land animals, however, do not have the ability to release small quantities of ammonia throughout the day—it must be stored. Once again, the liver is called into action. In the liver, two molecules of ammonia combine with another waste product, carbon dioxide, to form **urea**. Urea is 100 000 times less toxic than ammonia. The blood can dissolve 33 mg of urea per 100 mL of blood. A second waste product, **uric acid**, is formed by the breakdown of nucleic acids. **Table 1** summarizes the roles of various organs in the removal of metabolic waste.

The kidneys help maintain water balance. Although it is possible to survive for weeks without food, humans cannot survive for more than a few days without water. Humans deplete their water reserves faster than their food reserves. The average adult loses about 2 L of water every day through urine, perspiration, and exhaled air. Greater volumes are lost when physical activity increases. For the body to maintain water balance, humans must consume 2 L of fluids daily. A drop in fluid intake by as little as 1 % of your body mass will cause thirst, a decrease of 5 % will bring about extreme pain and collapse, while a decrease of 10 % will cause death.

deamination removal of an amino group from an organic compound

urea nitrogen waste formed from two molecules of ammonia and one molecule of carbon dioxide

uric acid a waste product formed from the breakdown of nucleic acids

EXTENSION

Water and Solute Balance

This animation discusses the processes that influence water and solute balance in mammals.

www.science.nelson.com GO

Table 1 Removal of Metabolic Waste

Waste product	Origin	Organ of excretion
ammonia	• deamination of amino acids by the liver	kidneys
urea	• deamination of amino acids by the liver • ammonia combined with carbon dioxide	kidneys; skin (small amounts)
uric acid	• product of the breakdown of nucleic acids, such as DNA	kidneys
carbon dioxide	• waste product of cellular respiration	lungs
bile pigments	• breakdown of red blood cell pigment hemoglobin	liver
lactic acid	• product of anaerobic respiration	liver

DID YOU KNOW ?

Uric Acid

Uric acid is found in the urine of only a few mammals: humans, higher apes, and Dalmatian dogs. The uric acid molecule has a structure similar to that of caffeine.

Anatomy of the Urinary System

Renal arteries branch from the abdominal aorta and carry blood to the kidneys. With a mass of about 0.5 kg each, the fist-shaped kidneys may hold as much as 25 % of the body's blood at any given time. **Figure 2** shows the position of the kidneys and other organs of the urinary system in the body. Wastes are filtered from the blood by the kidneys and conducted to the urinary bladder by **ureters**. A urinary sphincter muscle located at the base of the bladder acts as a valve, permitting the storage of urine. When approximately 200 mL of urine has been collected, the bladder stretches slightly and nerves send a signal to the brain. When the bladder fills to about 400 mL, more stretch receptors are activated and the message becomes more urgent. If a person continues to ignore the messages, the bladder continues to fill. After about 600 mL of urine has accumulated, voluntary control is lost. The sphincter relaxes, urine enters the **urethra**, and it is voided.

The cross section of the kidney in **Figure 2** reveals three structures. An outer layer of connective tissue, the **cortex**, encircles the kidney. An inner layer, the **medulla**, is found beneath the cortex. A hollow chamber, the **renal pelvis**, joins the kidney with the ureter.

ureter a tube that conducts urine from the kidney to the bladder

urethra the tube that carries urine from the bladder to the exterior of the body

cortex the outer layer of the kidney

medulla the area inside of the cortex

renal pelvis the hollow area where the kidney joins the ureter

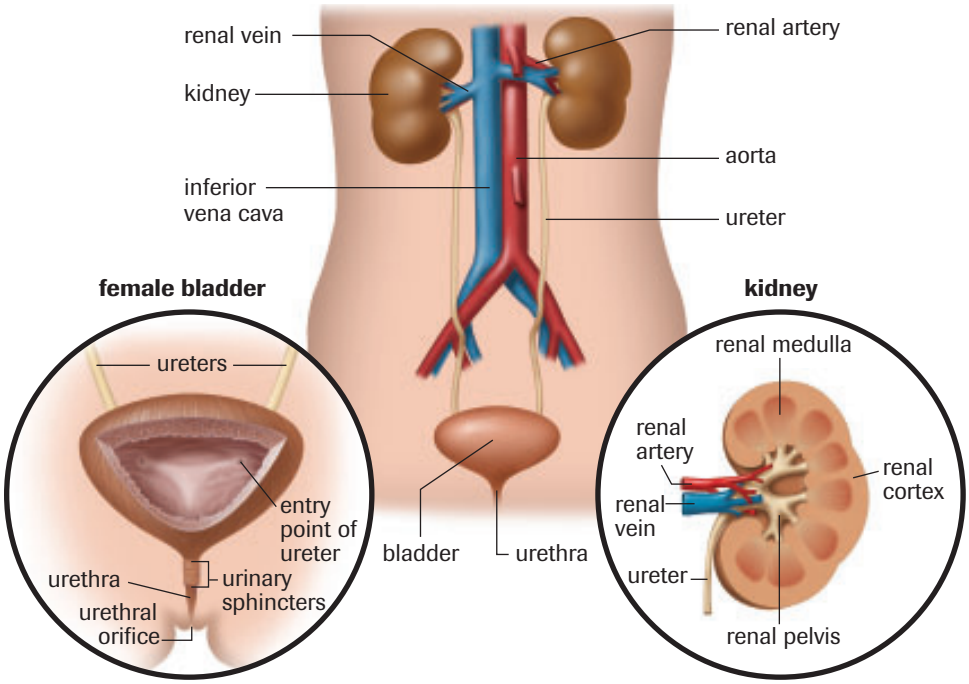


Figure 2
The human urinary system

Nephrons

Approximately one million slender tubules, called **nephrons**, are the functional units of the kidneys (**Figure 3**, next page). Small branches from the renal artery, the **afferent arterioles**, supply the nephrons with blood. The afferent arterioles branch into a capillary bed, called the **glomerulus**. Unlike other capillaries, the glomerulus does not transfer blood to a venule. Blood leaves the glomerulus by way of other arterioles, the **efferent arterioles**. Blood is carried from the efferent arterioles to a net of capillaries called **peritubular capillaries** that wrap around the kidney tubule. Blood leaves the nephron via a venule that joins the renal vein.

nephron a functional unit of the kidney

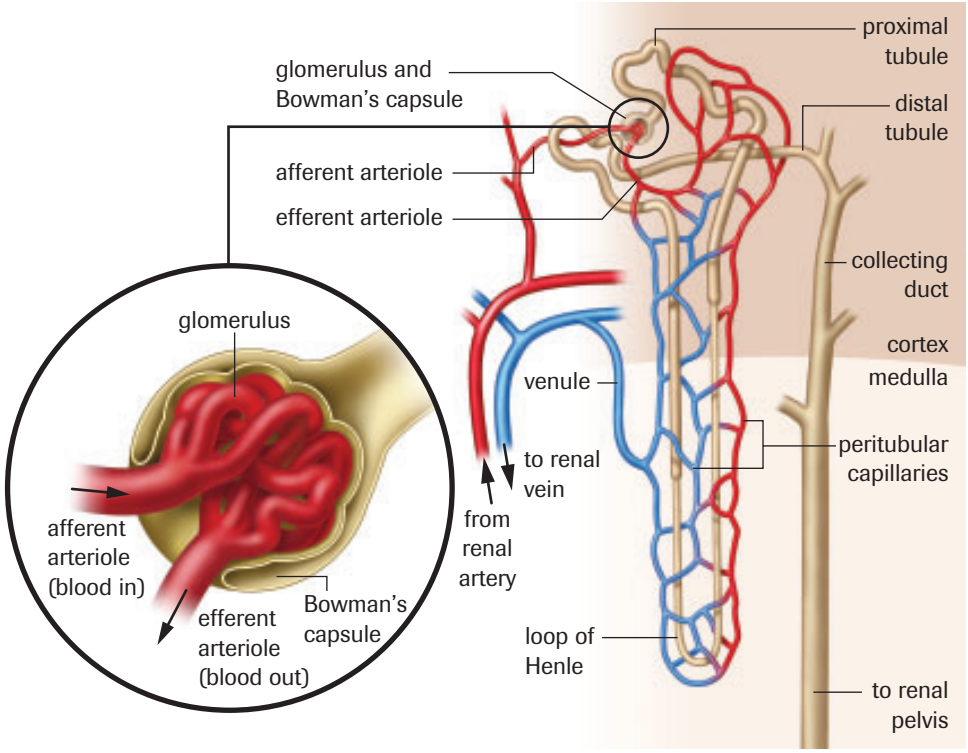
afferent arteriole a small branch of the renal artery that carries blood to the glomerulus

glomerulus the high-pressure capillary bed that is the site of filtration

efferent arteriole a small branch of the renal artery that carries blood away from the glomerulus to the peritubular capillaries

peritubular capillary a member of the network of small blood vessels that surround the tubule of the nephron

Figure 3
Diagram of a nephron showing the glomerulus and Bowman's capsule



Bowman's capsule the cuplike structure that surrounds the glomerulus

proximal tubule the section of the nephron joining the Bowman's capsule with the loop of Henle

loop of Henle the section of the tubule that carries filtrate from the proximal tubule to the distal tubule

distal tubule conducts urine from the loop of Henle to the collecting duct

collecting duct a tube that carries urine from nephrons to the renal pelvis

The glomerulus is surrounded by a funnel-like part of the nephron called the **Bowman's capsule**. The Bowman's capsule, the afferent arteriole, and the efferent arteriole are located in the cortex of the kidney. Fluid to be processed into urine enters the Bowman's capsule from the blood. The capsule tapers to a thin tubule, called the **proximal tubule**. Urine is carried from the proximal tubule to the **loop of Henle**, which descends into the medulla of the kidney. Urine moves through the **distal tubule**, the last segment of the nephron, into the **collecting ducts**. As the name suggests, the collecting ducts collect urine from many nephrons that, in turn, merge in the pelvis of the kidney.

Practice

1. Describe the two main functions of the kidneys.
2. What is deamination and why is it an important process?
3. How does the formation of urea prevent poisoning?

Formation of Urine

Urine formation depends on three functions. Filtration is accomplished by the movement of fluid from the blood into the Bowman's capsule. Reabsorption involves the transfer of essential solutes and water from the nephron back into the blood. Secretion involves the transport of materials from the blood into the nephron.

Filtration

Each nephron of the kidney has an independent blood supply. Blood moves through the afferent arteriole into the glomerulus, a high-pressure filter. Normally, pressure in a capillary bed is about 25 mmHg. The pressure in the glomerulus is about 65 mmHg.

EXTENSION

Structure of the Glomerulus
This animation provides a closer look at the structure of the glomerulus, and its role in urine formation (filtration).

www.science.nelson.com GO

Dissolved solutes pass through the walls of the glomerulus into the Bowman's capsule. Although materials move from areas of high pressure to areas of low pressure, not all materials enter the capsule. Scientists have extracted fluid from the glomerulus and Bowman's capsule using a thin glass tube called a micropipette. **Table 2** compares sample solutes extracted from the glomerulus and Bowman's capsule.

Plasma protein, blood cells, and platelets are too large to move through the walls of the glomerulus. Smaller molecules pass through the cell membranes and enter the nephron.

Table 2 Comparison of Solutes

Solute	Glomerulus	Bowman's capsule
water	yes	yes
sodium chloride	yes	yes
glucose	yes	yes
amino acids	yes	yes
hydrogen ions	yes	yes
urea	yes	yes
plasma proteins	yes	no
erythrocytes	yes	no
platelets	yes	no

Reabsorption

On average, about 600 mL of fluid flows through the kidneys every minute. Approximately 20 % of the fluid, or about 120 mL, is filtered into the nephrons. Imagine what would happen if none of the filtrate were reabsorbed back into the blood. You would form 120 mL of urine each minute. You would also have to consume at least 1 L of fluid every 10 min to maintain equilibrium. Much of your day would be concerned with regulating water balance. Fortunately, only 1 mL of urine is formed for every 120 mL of fluid filtered into the nephron. The remaining 119 mL of fluid and solutes is reabsorbed. Aldosterone is a hormone that increases the reabsorption of Na^+ ions and water by the kidneys, thereby helping to maintain body fluid levels.

Selective reabsorption occurs by both active and passive transport. Carrier molecules move Na^+ ions across the cell membranes of the cells that line the nephron. Negative ions, such as Cl^- and HCO_3^-, follow the positive Na^+ ions by charge attraction (**Figure 4** on next page). Numerous mitochondria supply the energy necessary for active transport. However, the energy supply is limited. Reabsorption occurs until the **threshold level** of a substance is reached. Excess NaCl remains in the nephron and is excreted with the urine.

Other molecules are actively transported from the proximal tubule. Glucose and amino acids attach to specific carrier molecules, which shuttle them out of the nephron and into the blood. However, the amount of solute that can be reabsorbed is limited. For example, excess glucose will not be shuttled out of the nephron by the carrier molecules. This means that individuals with high blood glucose and those who consume large amounts of simple sugars will excrete only some of the excess glucose.

The solutes that are actively transported out of the nephron create an osmotic gradient that draws water from the nephron. A second osmotic force, created by the proteins not filtered into the nephron, also helps reabsorption. The proteins remain in the bloodstream and draw water from the **interstitial fluid** into the blood. As water is reabsorbed from the nephron, the remaining solutes become more concentrated. Molecules such as urea and uric acid will diffuse from the nephron back into the blood, although less is reabsorbed than was originally filtered.

EXTENSION

Kidney Filtration and Exercise

This Audio Clip will explore the factors that contribute to lower levels of kidney filtration during exercise and relate these factors to the changes in blood chemistry during exercise.

www.science.nelson.com GO

CAREER CONNECTION

Urologist

Urology is a medical specialty that deals with the urinary system. What types of things do urologists do? Do they ever perform kidney transplants? Find out what training is needed to become a urologist.

www.science.nelson.com GO

threshold level the maximum amount of a substance that can be moved across the nephron

EXTENSION

Tubular Reabsorption

This animation illustrates how solutes and water are reabsorbed from the nephron back into the blood.

www.science.nelson.com GO

interstitial fluid the fluid that surrounds the body cells

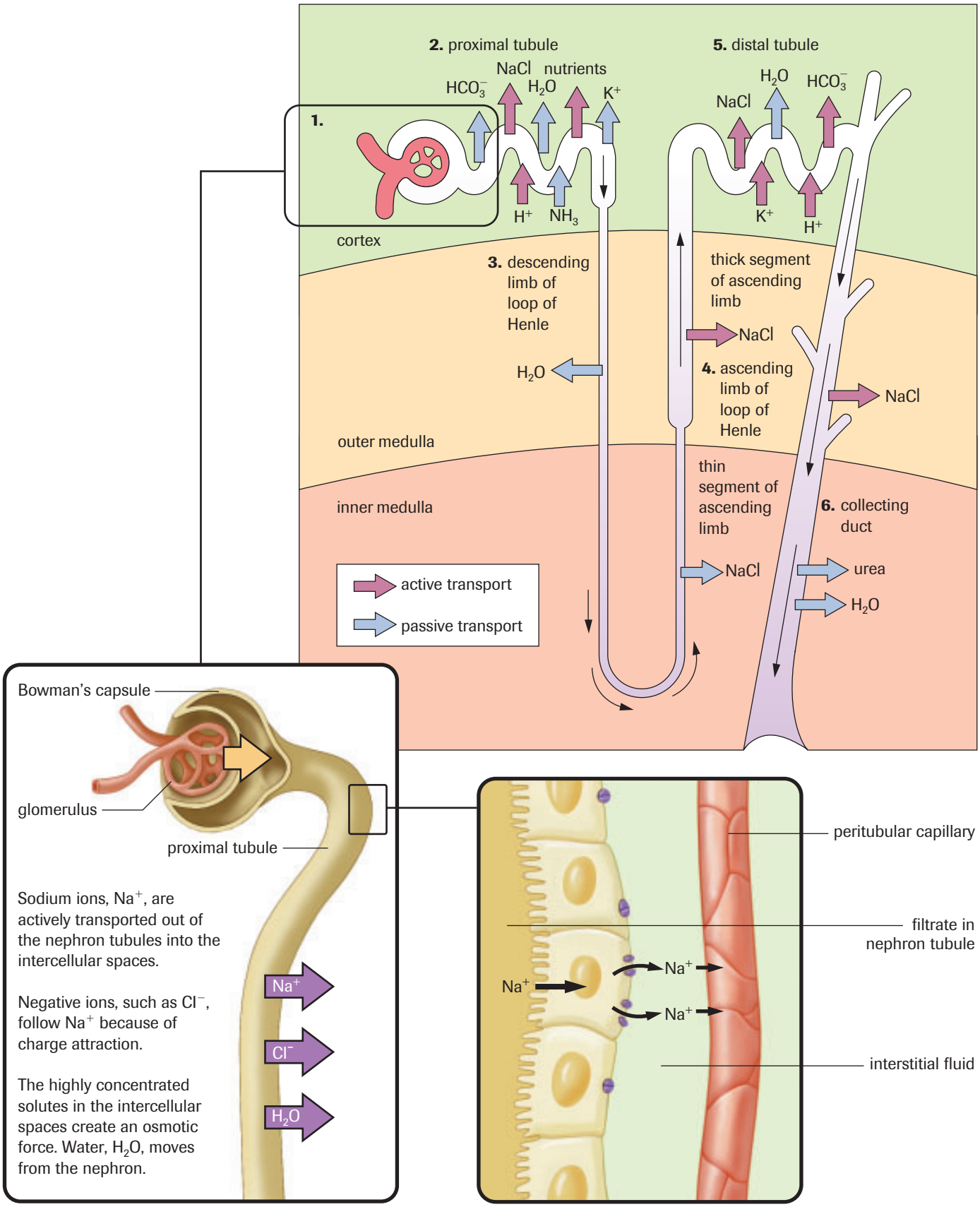


Figure 4
Overview of the steps in urine formation. The numbers in the diagram match the processes in **Table 3**, on the next page.

Secretion

Secretion is the movement of substances from the blood into the nephron. Ammonia, excess H^+ ions, and minerals such as K^+ ions are examples of substances secreted. Even drugs such as penicillin can be secreted. Cells loaded with mitochondria line the distal tubule. As in reabsorption, tubular secretion occurs by active transport, but, unlike in reabsorption, molecules are shuttled from the blood into the nephron. **Table 3** summarizes the events in urine formation.

Table 3 Urine Formation

Site	Description of process	Substances transported
1. glomerulus and Bowman's capsule	• Filtration of water and dissolved solutes occurs as blood is forced through walls of glomerulus into Bowman's capsule by fluid pressure in capillaries.	• sodium ions (Na^+), chloride ions (Cl^-), water (H_2O), hydrogen ions (H^+), glucose, amino acids, vitamins, minerals, urea, uric acid
2. proximal tubule	• Selective reabsorption of nutrients from filtrate back into blood occurs by active and passive transport. • Within proximal tubule, pH is controlled by secretion of hydrogen ions (H^+) and reabsorption of bicarbonate ions (HCO_3^-).	• bicarbonate ions (HCO_3^-), salt (NaCl), water (H_2O), potassium ions (K^+), hydrogen ions (H^+), ammonia (NH_3), glucose, amino acids, vitamins, urea
3. descending limb of loop of Henle	• The descending limb of loop of Henle is permeable to water, resulting in loss of water from the filtrate by osmosis. • Salt (NaCl) becomes concentrated in the filtrate as descending limb penetrates inner medulla of kidney.	• water (H_2O)
4. ascending limb of loop of Henle	• A thin segment of ascending limb of loop of Henle is permeable to salt, resulting in the diffusion of salt out of ascending limb. • Salt continues to pass from filtrate to interstitial fluid in the thick segment of ascending limb.	• salt (NaCl)
5. distal tubule	• Secretion of substances from blood into nephron occurs by active transport. Distal tubule helps regulate potassium (K^+) and salt (NaCl) concentration of body fluids. • As in the proximal tubule, pH is controlled by tubular secretion of hydrogen ions (H^+) and reabsorption of bicarbonate ions (HCO_3^-).	• salt (NaCl), potassium ions (K^+), water (H_2O), hydrogen ions (H^+), bicarbonate ions (HCO_3^-), uric acid, ammonia (NH_3)
6. collecting duct	• Urine formation	• water (H_2O), salt (NaCl), urea, uric acid, minerals

Practice

4. State the function of each part of the nephron: Bowman's capsule, proximal tubule, loop of Henle, distal tubule, and collecting duct.

5. Describe the three main processes that are involved in urine formation.

LAB EXERCISE 12.A

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	○ Evaluation
○ Hypothesis	○ Procedure	○ Synthesis
○ Prediction	○ Evidence	

Comparing Solutes in the Plasma, Nephron, and Urine

Micropipettes were used to draw fluid from the Bowman's capsule, the glomerulus, the loop of Henle, and the collecting duct. Solutes in the fluids were measured. The resulting data are displayed in **Table 4**.

Analysis

(a) Which of the solutes was not filtered into the nephron? Explain your answer.

(b) The test for glucose was not completed for the sample taken from the glomerulus. Predict whether glucose would be found in the glomerulus. Provide reasons for your prediction.

(c) Why do urea and ammonia levels increase after filtration occurs?

(d) Chloride ions, Cl^-, follow actively transported Na^+ ions from the nephron into the blood. Therefore, you would expect the Cl^- concentration to decrease as fluids are extracted along the nephron. What causes the discrepancy?

(e) Is it correct to say that veins carry blood with high concentrations of waste products and arteries carry blood with high concentrations of nutrients? Explain.

(f) Compare the blood found in a renal artery and a renal vein with respect to urea and glucose.

Table 4 Solute Concentrations in Various Parts of the Kidney

Solute	Bowman's capsule	Glomerulus	Loop of Henle	Collecting duct
protein	0	0.8	0	0
urea	0.05	0.05	1.50	2.00
glucose	0.10	no data	0	0
chloride ions	0.37	no data	no data	0.6
ammonia	0.0001	0.0001	0.0001	0.04
substance X	0	9.15	0	0

Quantities are in g/100 mL.

WWW WEB Activity

Simulation—Kidney Function

In this activity, you can follow the links to a number of computer-generated simulations of kidney function. Trace the pathway of fluid through the different parts of the kidney. You can also find other diagrams and descriptions of kidney function. Research and create a flow chart to show how the excretory system maintains water and ions in equilibrium.

www.science.nelson.com GO

INVESTIGATION 12.1 *Introduction*

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Do Sports Drinks Really Work?

Are sports drinks any better than water and sugar? How can you determine whether a sports drink is able to restore the electrolytes essential for the operation of nerves and muscles?

To perform this investigation, turn to page 393.

pH Balance

In addition to regulating body fluid volumes and maintaining the composition of salts in the blood, the kidneys maintain pH balance. Despite the variety of foods and fluids consumed with varying pH levels, the pH of the body remains relatively constant, between 7.3 and 7.5. In addition, during cellular respiration, cells produce carbon dioxide, which forms carbonic acid. Carbonic acid and other excess acids ionize to produce H^+ ions. The buildup of H^+ ions lowers pH.

An acid–base balance is maintained by buffer systems that absorb excess H^+ ions or ions that act as bases. Excess H^+ ions from metabolic processes are buffered by bicarbonate ions in the blood. Bicarbonate ions, HCO_3^-, eliminate the excess H^+ ions, preventing a change in pH. Carbonic acid, a weak acid, is produced. In turn, the carbonic acid breaks down to form carbon dioxide and water. The carbon dioxide is then transported to the lungs where much of it is exhaled. The following reaction shows one type of buffer system, called the bicarbonate–carbon dioxide buffer system (**Figure 5**):

$$HCO_3^- + H^+ \rightleftharpoons \underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons H_2O + CO_2$$

The buffer system of the blood removes excess H^+ ions; however, the buffer must be restored if the body is to be protected. The kidneys help restore the buffer by reversing the reaction. As shown in **Figure 5**, carbon dioxide is actively transported from the peritubular capillaries, which surround the nephron, into the cells that line the nephron. The carbon dioxide combines with water to initiate the reverse reaction, generating HCO_3^- and H^+ ions. The bicarbonate ions diffuse back into the blood, thereby restoring the buffer. The H^+ ions recombine with either phosphate ions or ammonia and are excreted with the filtrate from the nephron.

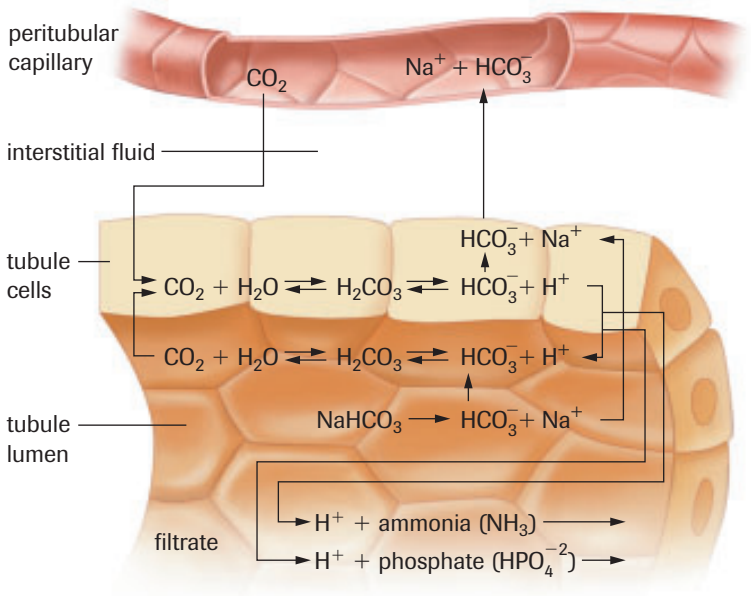


Figure 5
The bicarbonate–carbon dioxide buffer system maintains the pH balance.

CAREER CONNECTION

Emergency Medical Technician

Emergency medical technicians (EMTs), or paramedics, deliver pre-hospital emergency care. Their responsibilities include cardiopulmonary resuscitation, monitoring vital signs, starting intravenous lines, administering drugs, assisting in childbirth, and immobilizing patients. Discover more about the technical training programs EMTs receive.

www.science.nelson.com GO

SUMMARY Waste Excretion and Internal Equilibrium

- The kidneys filter waste from the blood and help maintain water balance.
- The liver helps to eliminate toxic nitrogen groups from the body by deamination.
- Nephrons are the functional units of the kidneys.
- Urine formation depends on three functions: filtration, reabsorption, and secretion.
- The glomerulus acts as a high-pressure filter.
- Selective reabsorption occurs by both active and passive transport.
- Secretion is the active transport of waste from the blood into the nephron.
- Kidneys help maintain pH by excreting excess H^+ ions and restoring HCO_3^- ions to the blood.

Table 5 Summary of Nephron Structure and Function

Structure	Function
afferent arteriole	carries blood to the glomerulus
glomerulus	a high-pressure capillary bed enclosed by the Bowman's capsule that is the site of filtration
efferent arteriole	carries blood away from the glomerulus
peritubular capillary bed	capillaries that network around the nephron
venule	carries filtered blood out of the nephron

Section 12.1 Questions

1. Why do you think it is beneficial to humans to have two kidneys rather than one? Explain your answer.
2. Explain the function of nephrons.
3. Use the diagram in **Figure 6** to identify the following:
   (a) the structure that filters blood
   (b) the structure that carries urine from the kidney
   (c) the structure that carries blood containing urea into the kidney
   (d) the structure that stores urine

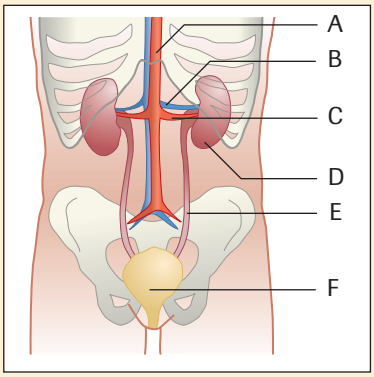


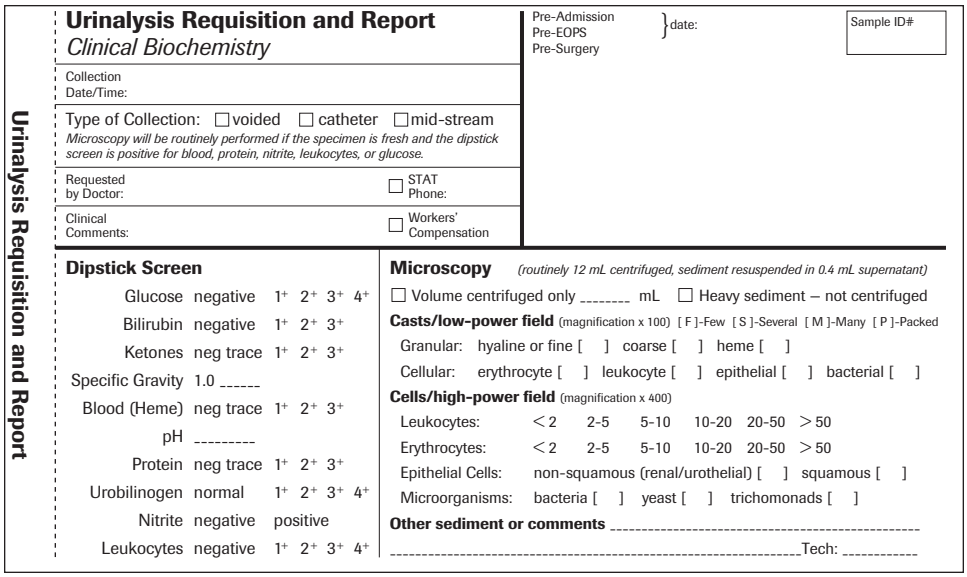
Figure 6

4. An adult under normal conditions will eliminate about 1.5 L of urine daily. Design an experiment that will test how urine output is affected by the consumption of a food containing caffeine (e.g., coffee, tea, chocolate, cola).
5. Explain why individuals who consume large amounts of sugars might do the following:
   (a) excrete large amounts of glucose in the urine
   (b) excrete large amounts of urine
6. Marine fish, such as herring and cod, live in a hypertonic environment. These fish lose water through their gills by osmosis. To replace the water, the fish drink seawater.
   (a) Explain why these fish must actively transport salt from their bodies.
   (b) Because these fish excrete salt through their gills, kidney function is affected. Explain the effect on the volume of urine excreted and the concentration of solutes in the urine.
7. Explain why the regulation of salt is important for people with renal hypertension.
8. What role do the kidneys serve in maintaining pH?
9. Using the HCO_3^- buffering system, explain what would happen if the kidneys failed to excrete H^+ ions.
10. Using the Internet and other resources, conduct research to explain how urine might be recycled on a space flight.

www.science.nelson.com GO

Kidney Dysfunction 12.2

Proper functioning of the kidneys is essential for the body to maintain equilibrium. The multifunctional kidneys are affected when other systems break down; conversely, kidney dysfunction affects other systems. Many kidney disorders can be detected by urinalysis (**Figure 1**).



Urinalysis Requisition and Report

Clinical Biochemistry

Collection Date/Time:

Type of Collection: ☐ voided ☐ catheter ☐ mid-stream

Microscopy will be routinely performed if the specimen is fresh and the dipstick screen is positive for blood, protein, nitrite, leukocytes, or glucose.

Requested by Doctor: ☐ STAT Phone:

Clinical Comments: ☐ Workers' Compensation

Pre-Admission
Pre-EOPS
Pre-Surgery
} date:

Sample ID#

Dipstick Screen

Glucose	negative	1+ 2+ 3+ 4+
Bilirubin	negative	1+ 2+ 3+
Ketones	neg trace	1+ 2+ 3+
Specific Gravity	1.0 ____	
Blood (Heme)	neg trace	1+ 2+ 3+
pH	----------	
Protein	neg trace	1+ 2+ 3+
Urobilinogen	normal	1+ 2+ 3+ 4+
Nitrite	negative	positive
Leukocytes	negative	1+ 2+ 3+ 4+

Microscopy *(routinely 12 mL centrifuged, sediment resuspended in 0.4 mL supernatant)*

☐ Volume centrifuged only _____ mL ☐ Heavy sediment – not centrifuged

Casts/low-power field (magnification x 100) [F]-Few [S]-Several [M]-Many [P]-Packed

Granular: hyaline or fine [ ] coarse [ ] heme [ ]

Cellular: erythrocyte [ ] leukocyte [ ] epithelial [ ] bacterial [ ]

Cells/high-power field (magnification x 400)

Leukocytes:	< 2	2-5	5-10	10-20	20-50	> 50
Erythrocytes:	< 2	2-5	5-10	10-20	20-50	> 50

Epithelial Cells: non-squamous (renal/urothelial) [ ] squamous [ ]

Microorganisms: bacteria [ ] yeast [ ] trichomonads [ ]

Other sediment or comments _____

_____Tech: _____

Figure 1
Many kidney problems can be diagnosed by analyzing a urine sample.

Diabetes Mellitus

Diabetes mellitus is caused by inadequate secretion of insulin from islet cells in the pancreas. Without insulin, blood glucose levels tend to rise. Some people with diabetes mellitus need insulin injections to regulate their blood glucose levels. The cells of the proximal tubule are supplied with enough ATP to reabsorb 0.1 % blood glucose, but in diabetes mellitus much higher blood glucose concentrations are found. The excess glucose remains in the nephron and is excreted in the urine. This excess glucose provides an osmotic pressure that opposes the osmotic pressure created by other solutes that have been actively transported out of the nephron. Water remains in the nephron and is lost with the urine. Individuals with untreated diabetes mellitus void large volumes of urine, which explains why they are often thirsty. The water lost with the excreted sugar must be replenished.

Another form of diabetes, diabetes insipidus, results from a defect in a different hormone—antidiuretic hormone (ADH), which regulates water reabsorption in the nephron. A person with this form of diabetes produces large volumes of dilute urine.

EXTENSION

Osmoregulation in the Collecting Duct

This Audio Clip examines how antidiuretic hormone (ADH) impacts the cells of the collecting duct in the kidney and influences the amount of water that is re-absorbed from the filtrate.

www.science.nelson.com GO

Nephritis

Nephritis is not a single disease but a broad description of many diseases characterized by inflammation of the nephrons. One type of nephritis affects the tiny blood vessels of the glomerulus. It is believed that toxins produced by invading microbes destroy the tiny blood vessels, altering the permeability of the nephron. Proteins and other large molecules are able to pass into the nephron. Because no mechanism is designed to reabsorb protein, the proteins remain in the nephron and create an osmotic pressure that draws water into the nephron. The movement of water into the nephron increases the output of urine. Nephritis can lead to irreversible kidney damage and kidney failure.

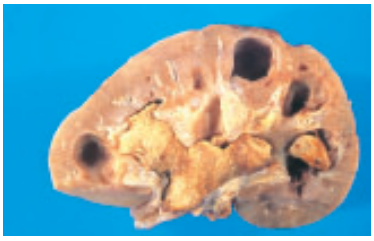


Figure 2
This kidney contains several large stones. Most stones consist mainly of calcium oxalate, calcium phosphate, or both.

Kidney Stones

Kidney stones (**Figure 2**) are caused by the precipitation of mineral solutes from the blood. The sharp-sided stones can lodge in the renal pelvis, or they may move down the ureter into the bladder and be passed out of the body with the urine. Delicate tissues are torn as the stone moves toward the bladder, causing excruciating pain. Larger stones may even lodge in the ureter, which requires medical attention.

Blasting Kidney Stones

The traditional treatment for unpassable kidney stones has been surgical removal followed by a period of convalescence. A technique developed by German urologist Dr. Christian Chaussy, called extracorporeal shock-wave lithotripsy (ESWL), has greatly improved prospects for kidney stone patients with stones less than 2 cm in size.

The nonsurgical technique uses high-energy shock waves to break the kidney stones into small fragments. The shock waves pass through soft tissue and strike the stone. After a few days, tiny granules from the stone can be voided through the excretory system.

Not all stones can be eliminated by shock-wave treatment. The size of the stone, its location in the urinary tract, and its composition all determine whether ESWL is an appropriate treatment. In most cases, this technique can be performed on an outpatient basis, and recovery time is greatly reduced from that of surgical removal.

INVESTIGATION 12.2 ***Introduction***

Diagnosis of Kidney Disorders

How is urinalysis used to detect various kidney disorders? In this investigation, you will test simulated urine for kidney disease.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 394.

Dialysis Technology

For people whose kidneys cannot effectively process bodily wastes, a dialysis machine can restore the proper solute balance. Dialysis is defined as the exchange of substances across a semipermeable membrane. Like a kidney that is functioning normally, a dialysis machine operates on the principles of diffusion and blood pressure. However, unlike a kidney, a dialysis machine cannot perform active transport.

There are two types of dialysis: hemodialysis and peritoneal dialysis (**Figure 3**, next page). In hemodialysis, the machine is connected to the patient's circulatory system by a vein. Blood is pumped through a series of dialysis tubes that are submerged in a bath of various solutes. Glucose and a mixture of salts set up concentration gradients. For example, HCO_3^- ions will move from the bath into the blood if it is too acidic. Because the dialysis fluids have no urea, this solute always moves from the blood into the dialysis fluid. Urea will move from the blood into the dialysis fluid until equal concentrations are established. By continually flushing expended dialysis solution and replacing it, the process continually removes urea and other waste solutes. During hemodialysis, the body also receives the hormones the kidneys are unable to produce.

An alternative is peritoneal dialysis, sometimes referred to as continuous ambulatory peritoneal dialysis (CAPD). With this method, 2 L of dialysis fluid is pumped into the abdominal cavity, and the membranes of the cavity selectively filter wastes from the blood. Urea and other wastes diffuse from the plasma into the peritoneum and into the dialysis fluid. Wastes accumulate in the dialysis fluid, which can be drained off and

DID YOU KNOW?

Earliest Treatment of Kidney Stones

Operations to remove kidney stones were performed in the time of Hippocrates, the Greek physician considered to be the father of medicine (c. 460–377 B.C.E.).

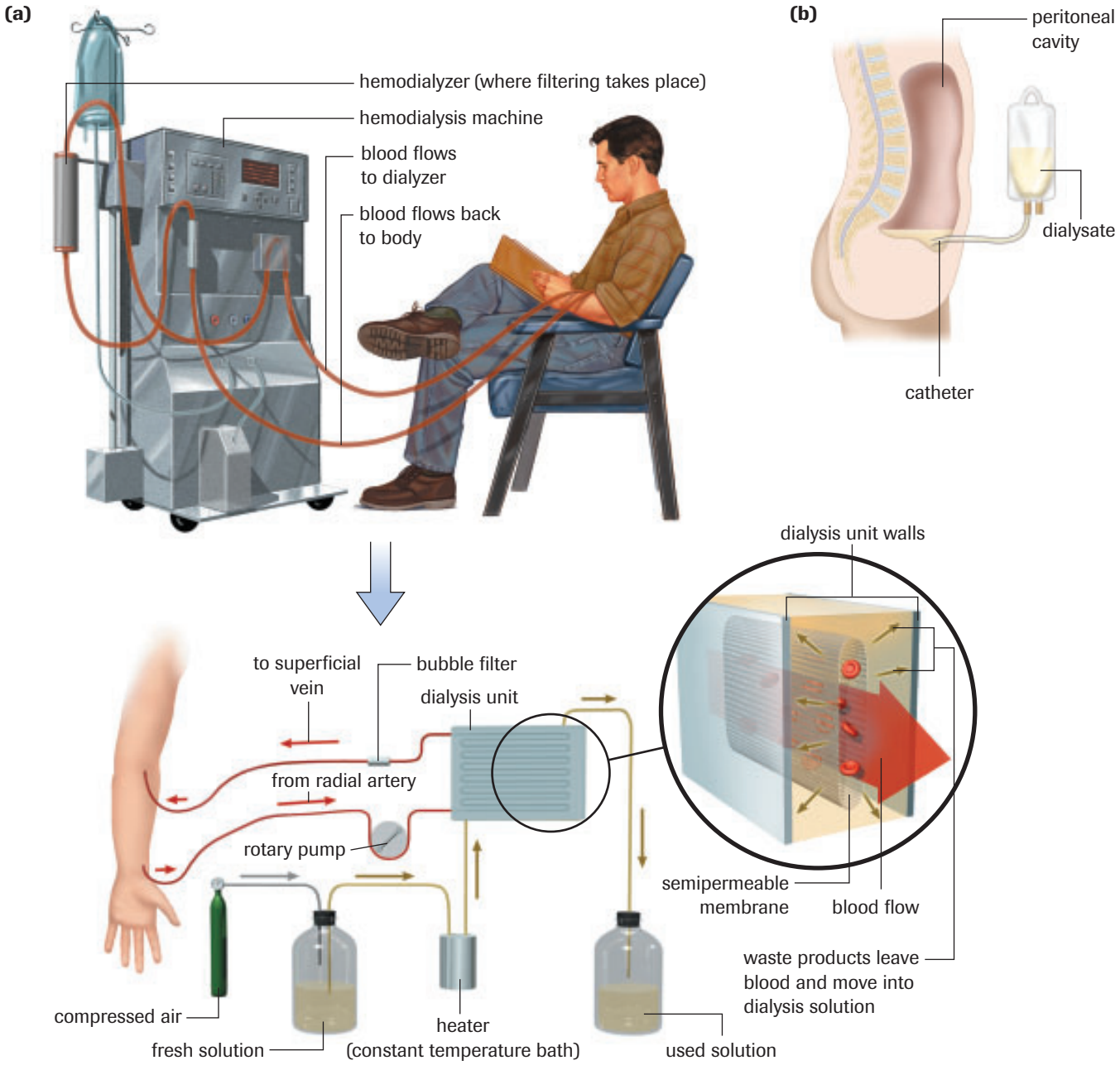


Figure 3

(a) In hemodialysis, a unit called a dialyzer mimics the action of the nephron. For hemodialysis treatments, a person must first have a minor surgical procedure to create an access, a shunt, for the needles and tubing needed to connect the circulatory system to the dialysis machine. Most people need three weekly dialysis sessions of about four hours each.

(b) Peritoneal dialysis is done through the peritoneal membrane, which is the lining of the abdominal cavity. In a minor surgical procedure, a catheter (a thin tube) is first inserted. A solution called the dialysate is then fed into the abdominal cavity through the catheter. The dialysate remains in this cavity for two to six hours. Then, the dialysate fluid is drained from the abdomen via the catheter. Once the fluid is drained, new fluid is placed to begin the process anew.

EXTENSION

Kidney Dialysis

This animation explains in more detail how hemodialysis and peritoneal dialysis work to restore proper solute balance in place of functioning kidneys.

www.science.nelson.com GO

replaced several times a day. As dialysis occurs, the patient may continue with non-strenuous activities. Peritoneal dialysis allows for greater independence because patients can perform the procedure in their own home.

Although dialysis technology can remove toxic wastes from the body and maintain electrolyte balance, it is unable to accomplish other tasks of the kidneys. Dialysis equipment is not able to produce hormones, such as erythropoietin and renin, nor is it able to activate vitamin D.

A new and promising technique involves the transplant of kidney cells from a pig into a dialysis machine. The living cells not only produce renal hormones but seem to be much better at regulating electrolytes and pH.

Kidney Transplants

According to the Kidney Foundation of Canada, a patient diagnosed with end-stage renal disease (kidney failure) in the 1960s had little chance of surviving. By the 1970s, renal dialysis had changed life expectancy dramatically, but the patient had to spend up to 36 hours each week in treatment. By the 1980s, hemodialysis had reduced treatments to 12 hours a week.

Although dialysis machines are effective, nothing can surpass the workings of a real kidney. Today, kidney transplants are 85 % successful and the preferred treatment for many patients (**Figure 4**). A transplanted kidney produces hormones and responds to the homeostatic adjustments of other body systems. The main disadvantage with any transplant is the immune response of the recipient. The donor kidney is often identified as a foreign invader, and the recipient's immune system springs into action in an attempt to destroy it. (See "Recognizing Harmful Antigens," Section 11.2, page 364.)

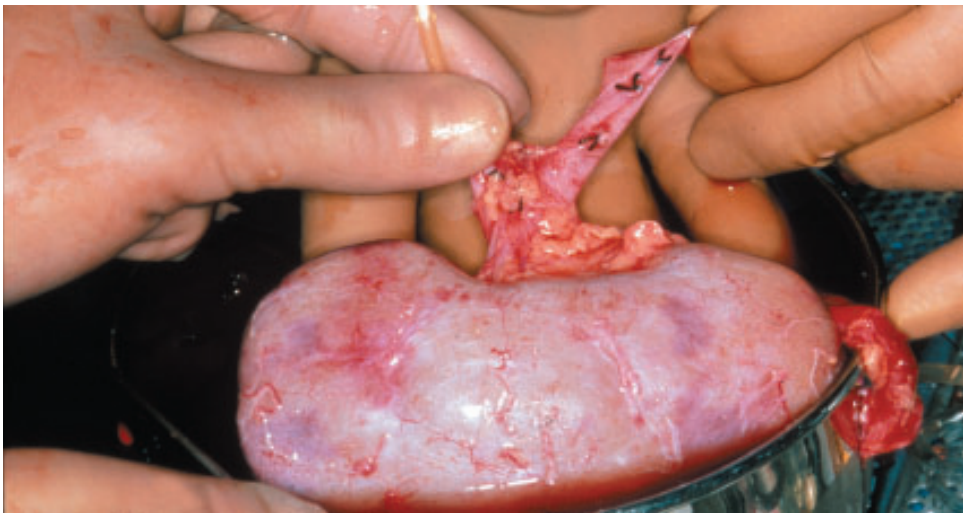


Figure 4
A human kidney being prepared for transplant

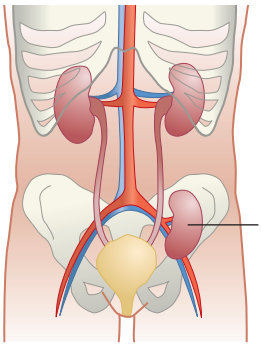


Figure 5
Location of new kidney

A kidney transplant involves placing a new kidney and ureter in the lower abdomen near the groin, where they are surgically attached to the blood vessels and bladder (**Figure 5**). The operation usually takes two to four hours. The old kidneys are not usually removed unless they are very large or chronically infected. After surgery, a catheter is inserted into the bladder for several days to drain the urine produced by the new kidney. Sometimes dialysis is required after the transplant until the new kidney can fully function. Immunosuppresive drugs are given after the transplant to help prevent rejection of the new organ.

EXPLORE an issue

Issue Checklist

○ Issue	○ Design	● Analysis
● Resolution	● Evidence	● Evaluation

Xenotransplants

A survey of Canadians in the year 2000 found that

- 94 % agreed that organ donation was a positive outcome of a person's death;
- 81 % indicated a willingness to donate organs; and
- 65 % reported having had a discussion about organ donation with loved ones.

In spite of public education, the organ donation rate in Canada is less than 40 %. The shortage of organs has spurred scientists to explore new and creative solutions for the many patients awaiting new organs. Xenotransplants are transplants from one species to another (*xeno* means strange or foreign). Xenotransplants from animals to humans have been attempted for several decades, but scientists have yet to successfully solve the problem of organ rejection. Improvements in immunosuppressive drugs have extended the boundaries of possibility and could relieve the wait for thousands of patients.

A second advance, the placement of human genes into animals by genetic engineering, has made xenotransplantation even more viable. Transgenic animals are animals that have genes from other species inserted into their DNA. Because transgenic animals possess not only their own genes but also those of humans, the chances of rejection are reduced. The immune system of the recipient will recognize the human marker on cell membranes as being related to their own tissues.

Although primates were once used as the primary source for xenotransplants, pigs have become the most common animal (**Figure 6**). The organs of the pig resemble those of humans in both size and structure. In addition, pigs are easier and less expensive to breed. Baboons, the early primate of choice, were found to harbour many viruses that can easily be transferred to humans.

As of 2003, xenotransplants were not allowed in Canada. One of the fears is the introduction of new viruses into humans. Microbes that might be harmless in their natural animal host could be deadly in a human. Could xenotransplants cause an outbreak of a deadly disease?

Figure 6
Pigs have become the animal of choice for xenotransplants.

Statement
The government should allow xenotransplants in Canada.

(a) In your group, research the issue. Search for information in newspapers, periodicals, CD-ROMs, and the Internet.

www.science.nelson.com GO

(b) Discuss the issue with class members and others in preparation for the debate.

(c) Write a list of points and counterpoints that your group considered.

(d) Decide whether your group agrees or disagrees with the statement.

(e) Prepare to defend your group's position in a class discussion.

(f) What responsibilities do governments have to ensure that all groups have a voice in the debate?

SUMMARY Kidney Dysfunction

- Proper functioning of the kidneys is essential for maintaining equilibrium.
- Many kidney diseases can be detected by urinalysis.
- A number of kidney diseases affect proper kidney function, including diabetes mellitus, diabetes insipidus, nephritis, and kidney stones.
- Dialysis and transplants are the most common treatments for kidney disease.

Section 12.2 Questions

1. What are kidney stones?
2. Explain why people with diabetes become dehydrated.
3. Why isn't there a cure for nephritis?
4. Sketch a diagram of a kidney dialysis machine and explain how it works.
5. Identify advantages of peritoneal dialysis over hemodialysis.
6. Complete **Table 1** in your notebook.

Table 1 Types of Kidney Dysfunction

Kidney dysfunction	Cause	Problem created	Recommended treatment
diabetes mellitus	lack of insulin production	glucose in urine will cause dehydration	
diabetes insipidus			ADH provided by injection
nephritis			
kidney stones			

7. What is the most difficult challenge to overcome in achieving successful kidney transplants? Provide a reason.
8. Tests were performed on patients A, B, C, and D. Results from the tests are provided in **Table 2**. The results obtained for patient A are considered normal.

Table 2 Test Results for Four Patients

Patient	Blood pressure (mmHg)	Cardiac output (L/min)	Glucose in urine (g/100 mL)	Urine output (mL/24 h)
A	120/70	5.0	0.00	1500
B	130/80	5.5	0.00	1700
C	115/70	4.5	0.06	1950
D	90/55	3.0	0.00	500

   (a) Which patient could have a circulatory problem?
   (b) Explain how a circulatory problem could affect urine output.
   (c) Explain why the urine output of patient C is elevated.
9. Alcohol is a diuretic, a substance that increases the production of urine. Alcohol suppresses the production and release of ADH. Should people who are prone to developing kidney stones consume alcohol? Explain.
10. In some countries, kidneys are sold for transplant. Do you believe that this practice is acceptable? Explain your answer.

INVESTIGATION 12.1

Do Sports Drinks Really Work?

Sweating helps to cool the body while exercising. Drinking water during and after exercising helps to restore water balance, but does not, according to many sports drinks advertisers, enable the body to continue operating at peak athletic performance. Sugar and electrolyte levels must be restored. Sugars provide the fuel for cellular respiration. Electrolytes, such as K^+ and Ca^{2+}, are essential for nerve and muscle function.

Nerve and muscle function can be measured by monitoring changes in reaction time. In this investigation, you will design ways to test the effects of a sports drink on reaction time.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	○ Synthesis
● Prediction	● Evidence	

Purpose

To determine the effect of sports drinks on reaction time

Hypothesis/Prediction

(a) Predict what effects, if any, that sports drinks will have on reaction time. Record your prediction, and describe the criteria you used in making your prediction.

Design

(b) Design a controlled experiment to test your hypothesis. Include the following in your design:

- descriptions of the manipulated, responding, and controlled variables
- a step-by-step description of the procedure, including the steps for measuring reaction time (one possibility for measuring reaction time is given below)
- a list of safety precautions
- a table to record observations

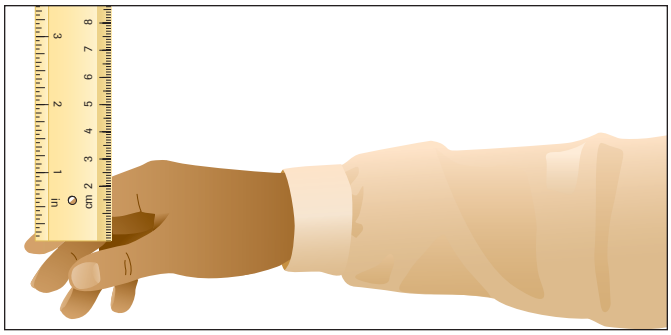


Figure 1
Starting position of ruler

Procedure

1. Submit your procedure, safety precautions, data table, and list of materials and apparatus to your teacher for approval. The procedure for measuring reaction time is given below. For the rest of the procedure, use your own approved design.

Measuring Reaction Time

2. Ask your subject to place his or her forearm flat on the surface of a desk. The subject's entire hand should be extended over the edge of the desk.
3. Ask the subject to place his or her index finger and thumb approximately 2 cm apart. Hold a 30-cm ruler vertically between the thumb and forefinger of the subject. The lower end of the ruler should be even with the top of the thumb and forefinger (**Figure 1**).
4. Indicate when ready, and release the ruler within the next 30 s. Measure the distance the ruler falls before being caught between the subject's thumb and forefinger. Repeat twice more and calculate the average. Repeat the procedure for the left hand. Record your data in a table.

Analysis

(c) Explain how the sports drink affected reaction time.

(d) Explain how the data confirmed or disproved your prediction.

Evaluation

(e) Describe any problems you encountered while carrying out the procedure.

(f) Describe how you could improve your current design.

(g) Reaction time is affected by other factors, such as anticipation. If you were to repeat this experiment, what new factors would you investigate? Write a brief description of the new procedure.

INVESTIGATION 12.2

Diagnosis of Kidney Disorders

The identification of proteins and sugars in urine samples can reveal kidney disease. This investigation will involve the use of simulated urine samples to test for indications of disease.

Biuret reagent can be used to identify proteins. It reacts with the peptide bonds joining amino acids together, producing colour changes from blue, indicating no protein, to pink or purple.

Benedict's solution can be used to identify reducing sugars. In this investigation, it will be used to detect glucose in the urine. **Table 1** summarizes the quantitative results obtained when reducing sugars, such as glucose, react with Benedict's solution.

Table 1 Reducing Sugar and Benedict's Solution Reactions

Colour of Benedict's solution	Approximate % of sugar
blue	negative
light green	0.5–1.0
green to yellow	1.0–1.5
orange	1.5–2.0
red to red–brown	> 2.0

Purpose

To determine which of the samples have characteristics that indicate kidney disease

Materials

safety goggles
laboratory apron
4 urine samples (simulated), labelled W, X, Y, and Z in dropper bottles
4 small test tubes
wax pencil
distilled water in wash bottle
Benedict's solution (in small dropper bottle)
test-tube clamp
hot water bath
test-tube brush
Biuret reagent (in small dropper bottle)
hydronium pH paper

Safety goggles and a laboratory apron must be worn for the entire laboratory. Handle hot objects and their contents carefully to avoid burns.

Benedict's solution is toxic and corrosive. Biuret reagent is toxic. Avoid skin and eye contact. Wash all splashes off your skin and clothing thoroughly. If you get any chemical in your eye, rinse your eye for at least 15 min and inform your teacher.

Report Checklist

- ○ Purpose
- ● Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ○ Materials
- ○ Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

Procedure

1. Label four test tubes W, X, Y, and Z. Place 20 drops of urine sample W in test tube W. Repeat the procedure for samples X, Y, and Z in their respective test tubes.
2. Add 10 drops of Benedict's solution to each test tube and, using a test-tube clamp, place the test tubes in a hot water bath (approximately 80 °C).
3. Observe for 6 min. Record any colour changes in a table. Use **Table 1** to identify the values for each sample. Record the values in the table.
4. Wash each of the test tubes and dry them before beginning the protein test.
5. Use your four labelled test tubes. Place 20 drops of each urine sample in its respective test tube. Add 20 drops of Biuret reagent to each of the test tubes, then tap the test tubes with your fingers to mix the contents. Record your results in a table.
6. Use hydronium paper to determine the pH of each sample. A chart is usually located on the pH paper dispenser. Record your results in the table.
7. Clean up your work space. Dispose of all chemicals as directed by your teacher.
8. Wash your hands thoroughly.

Analysis

(a) Which sample indicates diabetes mellitus? Provide your reasons.

(b) Which sample indicates diabetes insipidus? Give reasons for your response.

(c) Which sample indicates nephritis? Provide reasons for your answer.

(d) Which sample indicates a tremendous loss of body water while exercising? Provide your reasons.

Synthesis

(e) What are recommended treatments for diabetes mellitus and diabetes insipidus?

(f) Why is nephritis difficult to treat?

Chapter 12 SUMMARY

Outcomes

Knowledge

- identify the principal structures of the excretory system, i.e., kidneys, ureters, urinary bladder, and urethra (12.1)
- explain the structure and function of the nephron, including the glomerulus, Bowman's capsule, tubules, loop of Henle, collecting duct, afferent and efferent arterioles, and capillary net, and explain their functions in maintaining plasma compositions, i.e., water, pH, and ions (12.1)
- describe the function of the kidney in excreting metabolic wastes and expelling them into the environment (12.1)
- identify the role of antidiuretic hormone (ADH) and aldosterone in water reabsorption and excretion (12.1, 12.2)

STS

- explain that the goal of science is knowledge about the natural world (12.2)
- identify the role of antidiuretic hormone (ADH) and aldosterone in water reabsorption and excretion (12.1, 12.2)

Skills

- ask questions and plan investigations (12.1, 12.2)
- conduct investigations and gather and record data and information by researching and creating a flow chart to describe how humans maintain homeostasis with respect to water and ions (12.1)
- analyze data and apply mathematical and conceptual models by: observing the principal features of a mammalian excretory system and identifying structures from drawings obtained from various print and electronic sources (12.1); collecting and interpreting data in analysis of simulated urine, identifying limitations of data, comparing to theoretical values, and producing a generalization (12.1, 12.2); and making analogies between kidney function and renal and peritoneal dialysis (12.2)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

12.1

deamination
urea
uric acid
ureter
urethra
cortex
medulla
renal pelvis
nephron
afferent arteriole
glomerulus
efferent arteriole
peritubular capillary
Bowman's capsule
proximal tubule
loop of Henle
distal tubule
collecting duct
threshold level
interstitial fluid

MAKE a summary

1. Create a flow chart or diagram that shows how the excretory system maintains an internal equilibrium through the exchange of matter and energy with the environment. Label the diagram with as many of the key terms as possible. Check other flow diagrams and use appropriate designs to make your sketch clear.
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To www.science.nelson.com GO

The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 12
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

CBC radioONE QUIRKS & QUARKS

Pig Cell Transplants

Dr. David White discusses the controversy of a new technique of transplanting insulin-producing islet cells into diabetics. The procedure would allow diabetics to cut down, or even stop their daily shots. The controversy stems from the fact that the islet cells come from seven-day-old piglets.

www.science.nelson.com GO

UNIT 20 D PERFORMANCE TASK

Determining Fitness Level

In this Performance Task, you will design and carry out a fitness test. This test will indirectly indicate the amount of oxygen being delivered to your tissues.

www.science.nelson.com GO

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The site of filtration in the kidney occurs between the
   A. renal artery and renal vein
   B. glomerulus and Bowman's capsule
   C. distal tubule and collecting duct
   D. renal artery and glomerulus

2. The normal sequence of processes in the formation of urine is
   A. reabsorption, secretion, filtration
   B. secretion, reabsorption, filtration
   C. filtration, reabsorption, secretion
   D. active transport, reabsorption, filtration

3. Identify the area in **Figure 1** in which the reabsorption of glucose takes place.
   A. W
   B. Y
   C. X
   D. Z

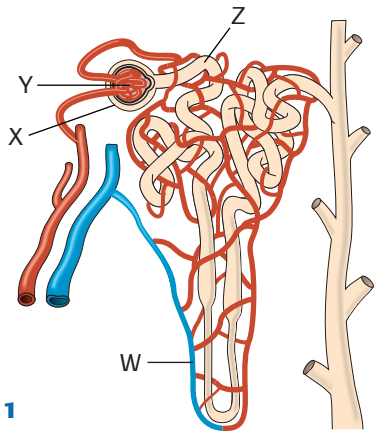


Figure 1

4. The following are structures of the excretory system:
   NR
   1. ascending limb of the loop of Henle
   2. ureter
   3. renal pelvis
   4. Bowman's capsule

   List the numbers of the structures in the order in which urine passes through them. (Record all four digits of your answer.)

Part 2

5. **Sketch** a labelled diagram that shows the following parts of the excretory system: kidney, renal artery, renal vein, ureter, bladder, and urethra. **Describe** the function of each organ.

6. **Figure 2** is a diagram of a nephron. Write a unified
   DE response that addresses the following aspects of this structure:
   - **Identify** which letters indicate the afferent and efferent arterioles.
   - **Explain** how an increase in blood pressure in B would affect the functioning of the kidney.
   - **Explain** why proteins and blood cells are found in B but not in D.
   - **Identify** the area of the nephron where you would expect to find the greatest concentration of glucose.
   - **Identify** the area(s) in which Na^+ ions are actively transported.
   - **Identify** the area of secretion.
   - **Identify** the area(s) of the nephron where you would expect to find urea?
   - In which area of the nephron would you expect to find cells with a great number of mitochondria? **Justify** your answer.

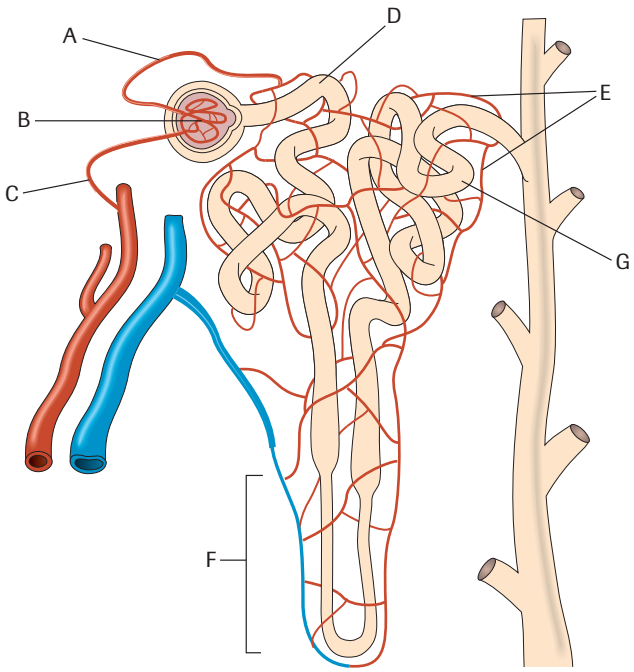


Figure 2

7. The following processes occur in the formation and excretion of urine once the blood has entered the kidney. List these subsequent processes in the order in which they occur.
   (a) urine is stored in the bladder
   (b) blood enters the afferent arteriole
   (c) fluids pass from the glomerulus into the Bowman's capsule
   (d) urine is excreted by the urethra
   (e) Na^+ ions, glucose, and amino acids are actively transported from the nephron
   (f) urine passes from the kidneys into the ureters

Use the following information to answer questions 8 to 10.

A micropipette was used to extract fluids from various structures within the kidney. The data in **Table 1** show an analysis of the fluids.

Table 1 Concentration of Substances in Kidney Fluids

Substance found in fluid	Blood plasma from afferent arteriole	Glomerular filtrate from Bowman's capsule	Urine
protein	7.00	0.00	0.00
urea 0.04	0.04	2.00	
glucose	0.10	0.10	0.00
sodium ions	0.32	0.32	0.35
chloride ions	0.38	0.38	0.60

Quantities are in g/100 mL.

8. DE According to the data provided, which substance is not filtered from the blood into the Bowman's capsule? **Justify** your answer.

9. DE Which substance provides evidence of secretion? **Justify** your response.

10. DE Which substance provides evidence of reabsorption? **Justify** your answer.

11. A pH analysis reveals that the urine of humans fluctuates between acidic and basic depending on the diet. **How** does the kidney help to maintain a constant blood pH?

12. A drug causes dilation of the afferent arteriole and constriction of the efferent arteriole. **Describe how** the drug will affect urine production.

13. **Why** do the walls of the proximal tubule contain so many mitochondria?

14. Athletes now undergo random urine testing for drugs. From your knowledge of excretion, **describe** the pathway of substances such as drugs through the urinary system, from the time they enter the glomerulus until they are excreted in the urine.

15. A drug that inhibits the formation of ATP by the cells of the proximal tubule is introduced into the nephron. **How** will the drug affect urine formation? Provide a complete physiological explanation.

16. A blood clot lodges in the renal artery and restricts blood flow to the kidney. **Explain why** this condition leads to high blood pressure.

17. For every 100 mL of salt water consumed, 150 mL of body water is lost. The solute concentration found in seawater is greater than that found in the blood. **Explain** in physiological terms **why** this loss of body water occurs. (*Hint:* Consider the threshold level for salt reabsorption by the cells of the nephron.)

18. **Predict** how a drop in blood pressure would affect urine output. **Justify** your prediction.

19. **Outline** in a chart the advantages and disadvantages of the following:
   (a) hemodialysis
   (b) peritoneal dialysis
   (c) kidney transplants by living donors and cadaver donors

Use the following information to answer questions 20 and 21.

Figure 3 outlines a dialysis procedure.

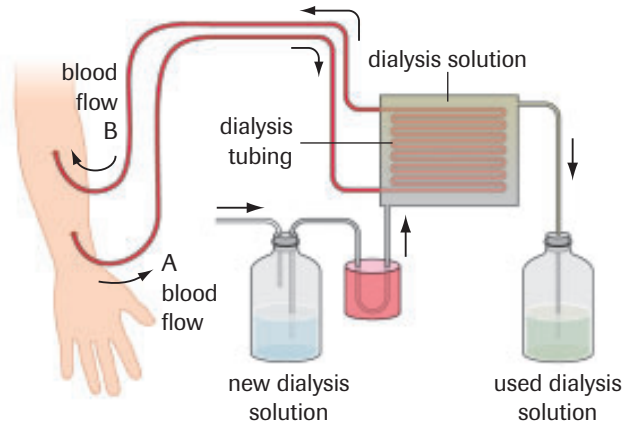


Figure 3

20. DE **Describe** what happens to the concentration of urea in the blood in **Figure 3**, as blood moves through blood vessel A, through the dialysis tubing, and into blood vessel B.

21. DE For effective dialysis to occur in **Figure 3**, will wastes move by active transport or by diffusion? **Identify** which fluid must contain the lower concentration of wastes: the blood or the dialysis solution.

Extension

22. **Design** an efficient kidney for an animal living in a desert.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

www.science.nelson.com GO

DO NOT WRITE IN THIS TEXTBOOK.

Part 1

Use the following information to answer questions 1 and 2.

In a study, a volunteer fasted for 12 hours, and was then given 300 g of food. Blood samples were taken before she ate, then once an hour for 9 h. The concentrations of fatty acids, glucose, and amino acids in the blood were determined. **Figure 1** is a graph of this data.

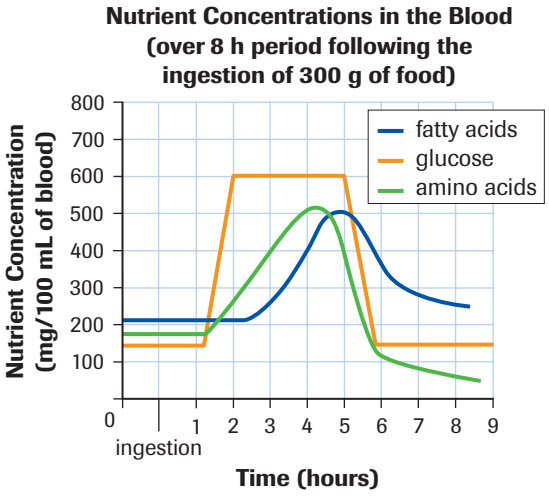


Figure 1

1. According to the data in **Figure 1**, the most difficult food to chemically break down and use for energy is
   A. fat
   B. protein
   C. carbohydrate
   D. amino acids

2. Identify how long after ingestion the maximum concentration of amino acids and fats in the blood occurred.
   A. amino acids, 1h; fats, 3h
   B. amino acids, 2h; fats, 4h
   C. amino acids, 4h; fats, 5h
   D. amino acids, 5h; fats, 8h

3. Identify the reason why the backwash of bile salts into the stomach can lead to stomach ulcers.
   A. Bile salts are very acidic and corrosive to cells. Cells that line the stomach are destroyed by acids.
   B. Bile salts can emulsify the mucosal layer, which is composed of proteins and lipids. Unprotected cells are digested.
   C. Bile salts convert pepsinogen into pepsin, which begins digesting proteins in the cells of the stomach's lining.
   D. Bile salts can digest the mucosal layer, which is composed of proteins and vitamins. Unprotected cells are digested.

4. Correctly complete the following statement: A heart attack will result from lack of nutrients and oxygen to the heart muscle, due to a blockage by atherosclerosis of the
   A. pulmonary arteries
   B. coronary arteries
   C. pulmonary veins
   D. coronary veins

5. Identify which of the following respiratory volumes cannot be measured directly using a respirometer.
   A. tidal volume
   B. expiratory reserve volume
   C. inspiratory reserve volume
   D. vital capacity

6. Identify which of the following is not involved in the immune system's second line of defence.
   A. helper T cells
   B. chemotaxis
   C. phagocytosis
   D. pseudopods

7. Identify the process by which gases move from the alveoli into the capillaries.
   A. active transport
   B. osmosis
   C. filtration
   D. diffusion

8. Correctly complete the following statement: Complete separation of the pulmonary and systemic circulation systems is necessary to provide
   A. increased cardiac output
   B. more efficient operation of the lungs
   C. more efficient oxygenation of the blood
   D. increased ventricular contractions

9. Identify the statement that correctly describes how breathing rate is regulated.
   A. The heart controls the breathing rate by monitoring oxygen levels.
   B. The heart controls the breathing rate by monitoring carbon dioxide levels.
   C. The brain controls the breathing rate by monitoring oxygen levels.
   D. The brain controls the breathing rate by monitoring carbon dioxide levels.

Use the following information to answer questions 10 and 11.

Fluid samples were taken from different parts of the nephron (samples W, X, and Y). The concentration of urea, glucose, and protein in each sample was then determined, and recorded in **Table 1**.

Table 1 Composition of Fluid Samples from Nephron

Component	Sample W (g/100 mL)	Sample X (g/100 mL)	Sample Y (g/100 mL)
urea	0.03	0.03	2.00
glucose	0.10	0.10	0.00
protein	0.007	7.00	0.00

10. Identify the part of the nephron from which sample X was likely taken.

A. The glomerulus: there is a higher protein concentration because very few proteins pass through the glomerulus.
B. The distal tubule: there is a lower concentration of urea because most of the water is absorbed in the distal tubule.
C. The collecting duct: there is a lower concentration of urea because water is not reabsorbed.
D. The proximal tubule: glucose is found in the proximal tubule because the glomerulus is permeable to glucose.

11. Identify the parts of the nephron from which samples W and Y were taken.

A. Sample W is from the distal tubule; sample Y is from the collecting duct.
B. Sample W is from the loop of Henle; sample Y is from Bowman's capsule.
C. Sample W is from the loop of Henle; sample Y is from the distal tubule.
D. Sample W is from Bowman's capsule; sample Y is from the collecting duct.

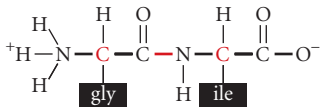
12. During muscle contraction

A. the sarcomeres lengthen, and actin and myosin fibres shorten
B. the sarcomeres shorten, and actin and myosin fibres lengthen
C. the sarcomeres lengthen, but actin and myosin fibres do not change in length
D. the sarcomeres shorten, but actin and myosin fibres do not change in length

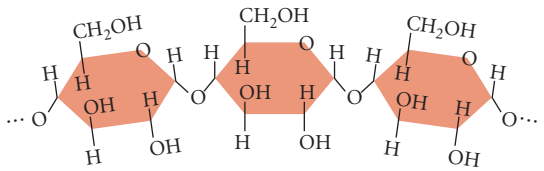
Use the following information to answer questions 13 and 14.

These four numbered structures are examples of different classes of nutrients used by the human body.

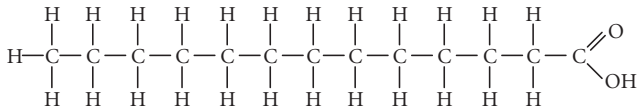
1



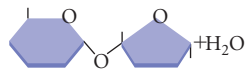
2



3



4



13. NR Match the number of each of the structures with its description. Use each number only once. (Record all four digits of your answer.)

_____ _____ _____ _____

disaccharide fat dipeptide polysaccharide

14. NR Match the number of each of the structures with its enzyme below. Use each number only once. (Record all four digits of your answer.)

_____ _____ _____ _____

sucrase amylase lipase protease

Part 2

15. **Identify** the blood vessel that is being referred to in each of the following statements:

(a) This blood vessel is the site of diffusion of oxygen and nutrients.
(b) This blood vessel has the highest blood pressure.

16. **Figure 2** (next page) shows the components of the human respiratory system. **Identify** the structure by number and name that is described in each of the following statements:

(a) This muscular structure relaxes during exhalation, causing the volume of the chest cavity to decrease.
(b) This structure conducts air into the left lung.
(c) This structure prevents food from entering the trachea.
(d) Inhalation and exhalation are indicated by pressure changes within these structures.

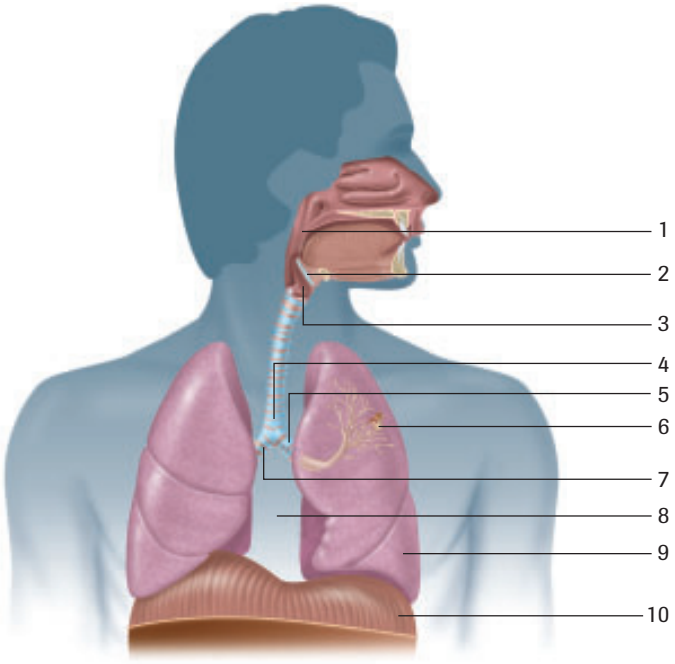


Figure 2

Use the following information to answer questions 17 and 18.

Amylase digestion of starch is tested by the experiment shown in **Figure 3**. Each of the flasks is filled with 100 mL of 4 % starch suspension. A 1 % amylase solution is added to flask 1. The amylase solution is boiled for 2 min then added to flask 3.

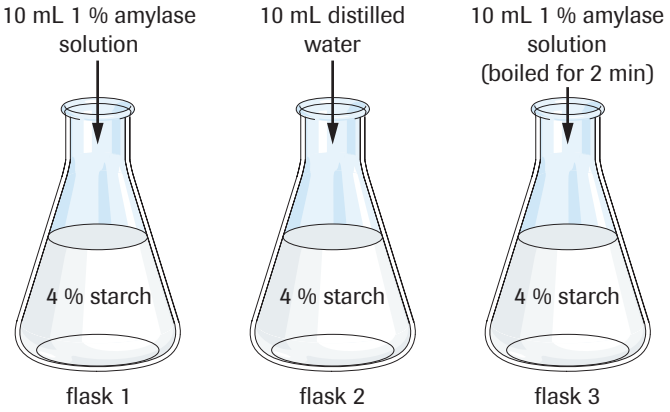


Figure 3

17. **Identify** the control in this experiment.
DE

18. Iodine was added to the flasks after 10 min. **Predict** in
DE which flask(s) the blue–black colour, indicating the presence of starch, would likely be observed. **Explain why**.

19. The money spent on cancer treatment continues to
DE escalate every year. One politician has suggested that medical problems caused by inappropriate lifestyle choices should be given a lower priority for treatment. Write a unified response that addresses the following aspects of life style and health.

- **Identify** two diseases that could be reduced by changing lifestyles.
- **Evaluate** the politician's statement. Should money be used first to treat people who have not contributed to their own health problem? **Justify** your answer.

Use the following information to answer questions 20 to 23.

Pancreatin is a commercially prepared mixture of the components of the pancreas, including trypsin and lipase. An experiment was conducted to determine the effect of pancreatin and bile on the digestion of egg yolk. Egg yolk contains lipids and proteins. The scientist placed 10 g of egg yolk in each of four test tubes and incubated them at 37 °C for 24 h. As shown in **Table 2**, the pH of the solution was recorded at the beginning of the experiment and after 24 h. The degree of digestion is indicated by plus signs (+).

Table 2 Experimental Data for the Digestion of Egg Yolk

Test tube	Initial pH	Pancreatin	Bile	pH after 24 h	Amount of digestion
1	9	no	no	9	none
2	9	✓	no	7	+++
3	9	no	✓	9	+
4	9	✓	✓	6	++++

20. **Identify** which test tube acted as a control. **Describe** what
DE the control indicates.

21. **Explain why** the pH of the solution changes after 24 h in
DE test tubes 2 and 4.

22. **Explain why** test tube 4 shows a greater amount of
DE digestion than test tube 2.

23. **Interpret** the results of test tube 3.
DE

Use the following information to answer questions 24 to 27.

Hemoglobin and myoglobin are two proteins that carry oxygen. Myoglobin, found in muscle cells, has the ability to combine with one molecule of oxygen. Hemoglobin, found in red blood cells, has the ability to combine with four oxygen molecules. **Figure 4**, on the next page, shows the ability of hemoglobin and myoglobin to combine with oxygen at varying partial pressures.

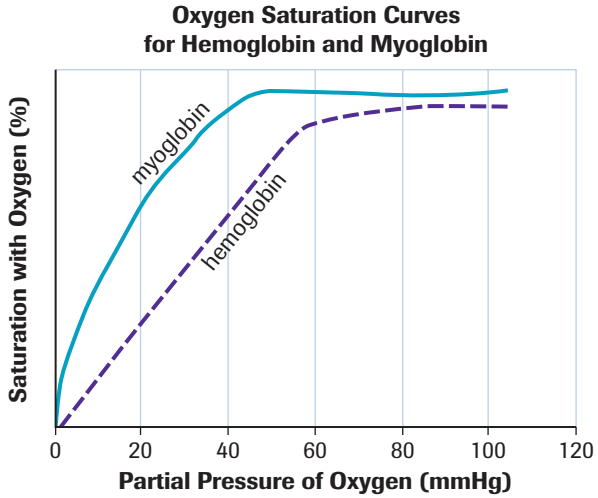


Figure 4

24. **Identify** the protein that accepts oxygen more readily.
DE

25. **Identify** the partial pressure at which hemoglobin becomes saturated.
DE

26. **Identify** the partial pressure at which myoglobin becomes saturated.
DE

27. **Describe** the adaptation for exercise by comparing the saturation curves for hemoglobin and myoglobin.
DE

---

28. **List** all types of T and B lymphocytes and explain the role of each in the immune response.

29. A glass of milk contains lactose, proteins, butterfat (mostly triglycerides), vitamins, and minerals. **Describe** what happens to each component in your digestive tract.

30. Often, holiday meals are larger than regular meals and have a higher fat content. After eating a holiday meal, you may feel uncomfortably full for longer than normal. Based on what you have learned about digestion, **describe** in biochemical terms the cause of the discomfort.

31. In some forms of heart failure, the left side of the heart is the weaker and fails to perform properly, while the right side continues to pump blood into the lungs with near normal vigour. Write a unified response addressing the following aspects of this form of heart failure:
DE
- **Explain why** fluid flows from the lung capillaries into the alveoli and bronchioles of the lungs, resulting in a condition called pulmonary edema.
- **Describe** the effect of pulmonary edema on the normal functioning of the lungs.
- **Describe** a possible technological solution for this condition.

32. Prolonged starvation reduces the amount of protein in the blood. One consequence of this is an increased amount of tissue fluid, which tends to gather in the abdomen and lower limbs. Write a unified response addressing the following aspects of this increase in tissue fluid:
DE
- **How** is this related to capillary fluid exchange?
- Indicate a possible reason **why** scientists have been unable to solve the problem.

33. **Define** muscle tetanus.

Use the following information to answer questions 34 to 37.

Lung cancer is the leading cause of cancer death in both men and women in Canada. It is also a disease that can be prevented. Controllable environmental factors seem to stimulate cancer-causing genes over a period of time to become active, causing cells to develop into lung cancer. Interpret the information presented in **Figure 5**.

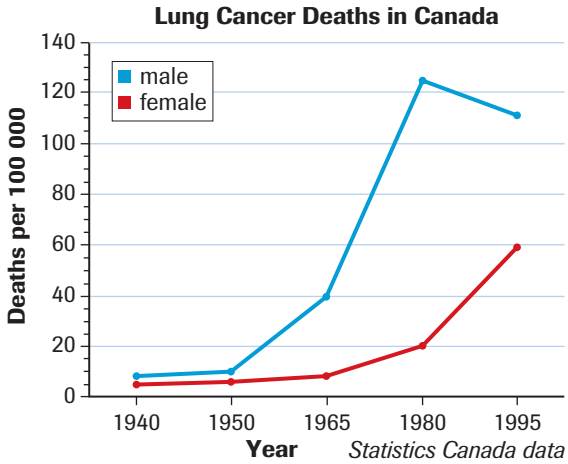


Figure 5

34. In the early 1920s, shortly after the First World War, smoking became fashionable for men. **Hypothesize** why lung cancer rates did not increase until the 1950s.
DE

35. Suggest a reason **why** no comparable increase occurred in lung cancer in women during the same period. **Justify** your answer.
DE

36. **Predict** trends in lung cancer over the next 10 to 20 years.
DE

37. **Compare** the trends between males and females between 1980 and 1995.
DE

---

38. About 80 % of runners land on the outer part of their foot and roll inward. This action helps absorb the shock, but for people whose foot bends more than 10 degrees, the action can lead to problems. Conduct research on running shoes that correct for pronation, or excessive foot roll. **How** have running shoe manufacturers attempted to prevent injuries?

www.science.nelson.com GO

39. Review the focusing questions on page 236. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.