

Respiration, Circulation, and Excretion

What You'll Learn

- You will identify the functions of the respiratory system and explain the mechanics of breathing.
- You will describe the structure and function of the different types of blood cells and trace the pathway of blood circulation through the body.
- You will describe the structure and function of the urinary system.

Why It's Important

With a knowledge of how your circulatory, respiratory, and urinary systems function, you will understand how your cells receive, deliver, and remove materials to maintain your body's homeostasis.

Understanding the Photo

Coordination of the respiratory and circulatory systems allows blood to deliver much needed oxygen and nutrients to the hard-working cells of this climber.



Biology Online

Visit ca.bdol.glencoe.com to

- study the entire chapter online
- access Web Links for more information and activities on respiration, circulation, and excretion
- review content with the Interactive Tutor and self-check quizzes

Section 37.1

SECTION PREVIEW

Objectives

Identify the structures involved in external respiration.

Contrast external and cellular respiration.

Explain the mechanics of breathing.

Review Vocabulary

diaphragm: sheet of muscles beneath the lungs that separates the chest cavity from the abdominal cavity (p. 843)

New Vocabulary

trachea
alveoli

The Respiratory System

California Standards Standard 9a Students know how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide.

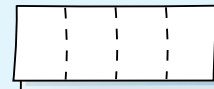
FOLDABLES™ Study Organizer

Systems Make the following Foldable to help you organize information about the respiratory, circulatory, and urinary systems.

STEP 1 Fold one piece of paper lengthwise into thirds.



STEP 2 Fold the paper widthwise into fourths.



STEP 3 Unfold, lay the paper lengthwise, and draw lines along the folds.



STEP 4 Label your table as shown.

	Organs	Function
Respiratory system		
Circulatory system		
Urinary system		

Make a Table As you read Chapter 37, complete the table by describing the organs and functions of the respiratory, circulatory, and urinary systems.

Physical Science Connection

Elements, compounds, and mixtures in everyday life

The atmosphere is a mixture of gases, liquids, and solids. The gases include nitrogen, oxygen, water vapor, argon, and carbon dioxide. Smoke and wind-blown dust particles are some of the solids found in air, and liquid water droplets are seen as clouds.

Passageways and Lungs

Your respiratory system is made of a pair of lungs and a series of passageways, each one extending deeper into your body. These passageways include the nasal passages, the throat, the windpipe, and the bronchi. When you hear the term respiratory system, you probably think of breathing. However, breathing is just one of the functions that the respiratory system carries out. Respiration, the process of gas exchange, is another important function performed by the respiratory system. Respiration includes all of the mechanisms involved in getting oxygen to the cells of your body and getting rid of carbon dioxide. Recall that cellular respiration also involves the formation of ATP within the cells.

The path air takes

The first step in the process of respiration involves taking air into your body through your nose or mouth. Air flows into the pharynx, or throat, passes the epiglottis, and moves through the larynx. It then travels down the windpipe, or **trachea** (TRAY kee uh), a tubelike passageway that leads to two tubes, or bronchi (BRAHN ki) (singular, bronchus), which lead into the lungs. When you swallow food, the epiglottis covers the entrance to the trachea, which prevents food from getting into the air passages.

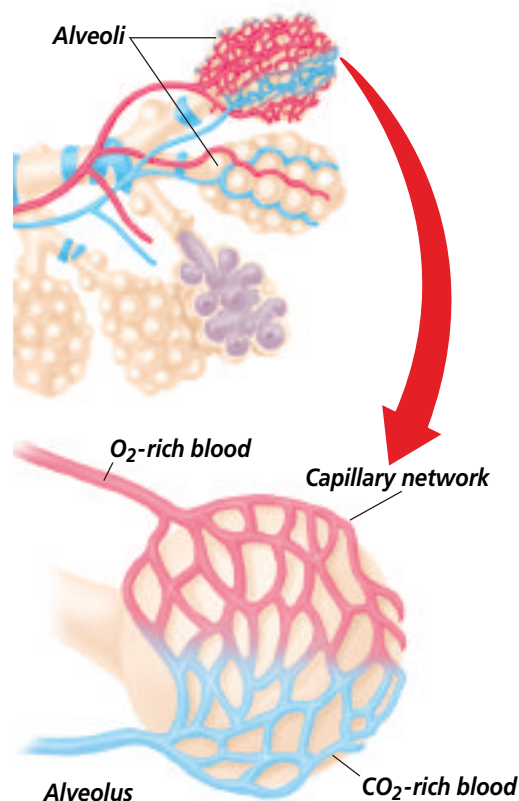
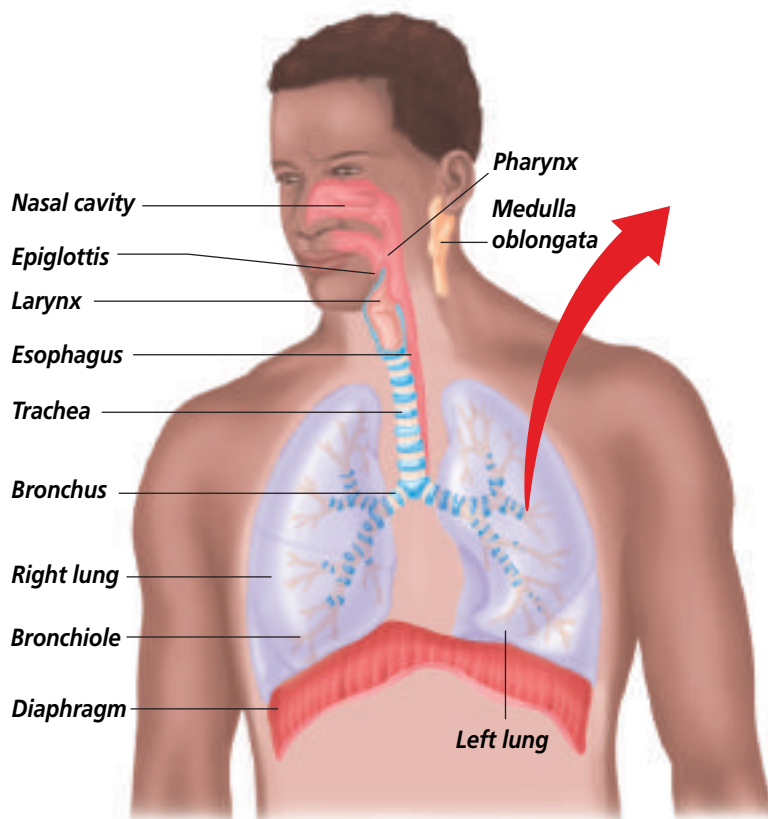


Figure 37.1

As air passes through the respiratory system, it travels through narrower and narrower passageways until it reaches the alveoli.

Explain Interpret the functions of the respiratory system.

Cleaning dirty air

The air you breathe is far from clean. An individual living in an urban area breathes in millions of particles of foreign matter each day. To prevent most of this material from reaching the lungs, the nasal cavity, trachea, and bronchi are lined with ciliated cells that secrete mucus. The cilia constantly beat upward in the direction of your throat, where foreign material can be swallowed or expelled by coughing or sneezing. Follow the passage of air through the respiratory system in *Figure 37.1*.

Alveoli: The place of gas exchange

Like the branches of a tree, each bronchus branches into bronchioles, which in turn branch into numerous microscopic tubules that eventually open into thousands of thin-walled sacs called alveoli. **Alveoli** (al VEE uh li) are the sacs of the lungs where oxygen and carbon dioxide are exchanged by

diffusion between the air and blood. The clusters of alveoli are surrounded by networks of tiny blood vessels, or capillaries. Blood in these vessels has come from the cells of the body and contains wastes from cellular respiration. Diffusion of gases takes place easily because the wall of each alveolus, and the walls of each capillary, are only one cell thick. External respiration involves the exchange of oxygen or carbon dioxide between the air in the alveoli and the blood that circulates through the walls of the alveoli, and is shown in the inset portion of *Figure 37.1*.

Blood transport of gases

Once oxygen from the air diffuses into the blood vessels surrounding the alveoli, it is pumped by the heart to the body cells, where it is used for cellular respiration. In an earlier chapter, you learned that cellular respiration is the process by which cells use oxygen to break down glucose and release energy in the form of ATP. Carbon dioxide is

Word Origin

alveoli from the Latin word *alveolus*, meaning "cavity" or "hollow"; The alveoli are small air sacs of the lung.

a waste product of this process. The carbon dioxide diffuses into the blood, which carries it back to the lungs.

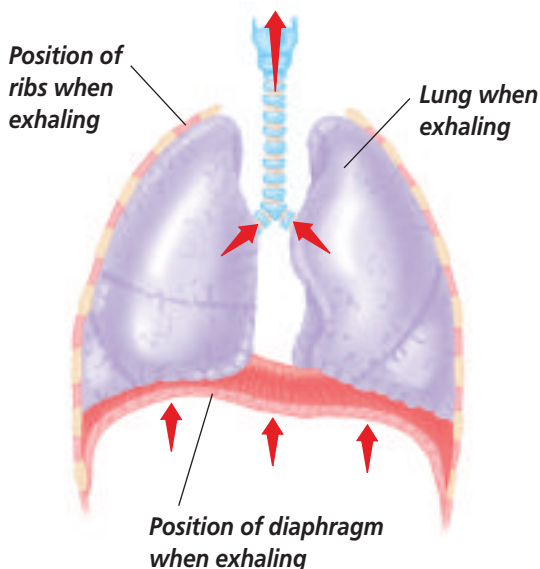
As a result, the blood that comes to the alveoli from the body's cells is high in carbon dioxide and low in oxygen. Carbon dioxide from the body diffuses from the blood into the air spaces in the alveoli. During exhalation, this carbon dioxide is removed from your body. At the same time, oxygen diffuses from the air in the alveoli into the blood, making the blood rich in oxygen. Use the *Problem-Solving Lab* on this page to find out more about how the composition of air changes as it passes through the lungs.

The Mechanics of Breathing

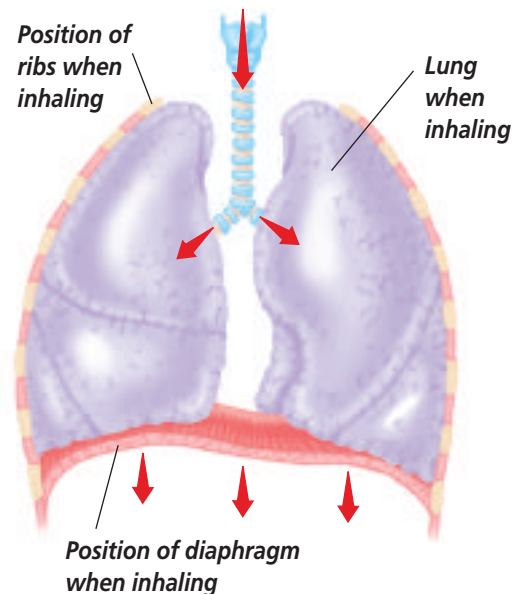
The action of your diaphragm and the muscles between your ribs enable you to breathe in and breathe out. *Figure 37.2* shows how air is drawn in or forced out of the lungs as a result of the diaphragm's position.

Figure 37.2

The diaphragm is located beneath the lungs. Explain **How does the contraction of the diaphragm affect air pressure in the lungs?**



A When relaxed, your diaphragm is positioned in a dome shape beneath your lungs, decreasing the volume of the chest cavity and forcing air out of the lungs.



B When contracting, the diaphragm flattens, enlarging the chest cavity and drawing air into the lungs.

Problem-Solving Lab 37.1

Interpret Data

How do inhaled and exhaled air compare? Air is composed of a number of different gases. As a result of cellular respiration, the percentages of some of the gases in air are altered by the time air is exhaled from the body.

Solve the Problem

Study the table below. It compares the relative percentages of gases in inhaled and exhaled air.

Comparison of Gases in Inhaled and Exhaled Air		
Gas	Inhaled Air	Exhaled Air
Nitrogen	78.00%	78.00%
Oxygen	21.00%	16.54%
Carbon dioxide	0.03%	4.49%
Other gases	0.97%	0.97%

Thinking Critically

- Interpret Data** What information about cellular respiration is conveyed by the data in the table?
- Sequence** Trace the pathway that a molecule of nitrogen follows when entering and leaving the lungs. (Note: Normally, nitrogen does enter the blood stream.)
- Explain** Why are carbon dioxide levels higher in air that is exhaled?

Registered Nurse

If you want a fast-paced, hands-on career that puts your “people skills” to work, consider becoming a registered nurse.

Skills for the Job

Nurses give care, support, and advice as they help their patients get well or stay well. They may work in hospitals, doctors’ offices, schools, nursing homes, rehabilitation centers, or public health agencies. Registered nurses (RNs) must complete a two-year associate degree program, a two- or three-year diploma program, or a four-year bachelor’s degree. To become licensed, they must also pass a national test.



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When you inhale, the muscles between your ribs contract and your rib cage rises. At the same time, the diaphragm muscle contracts, becomes flattened, and moves lower in the chest cavity. These actions increase the space in the chest cavity, which creates a slight vacuum. Air rushes into your lungs because the air pressure outside your body is greater than the air pressure inside your lungs.


When you exhale, the muscles associated with the ribs relax, and your ribs drop down in the chest cavity. Your

diaphragm relaxes, returning to its resting position. The relaxation of these muscles decreases the volume of the chest cavity and forces most of the air out of the alveoli.

The alveoli in healthy lungs are elastic, they stretch as you inhale and return to their original size as you exhale. The alveoli still contain a small amount of air after you exhale. Measure your breathing rate in the *BioLab* at the end of this chapter.

Control of Respiration

Breathing is usually an involuntary process. It is partially controlled by an internal feedback mechanism that involves signals being sent to the medulla oblongata about the chemistry of your blood. The medulla oblongata helps maintain homeostasis. It responds to higher levels of carbon dioxide in your blood by sending nerve signals to the rib muscles and diaphragm. The nerve signals cause these muscles to contract, and you inhale. When breathing becomes more rapid, as during exercise, a more rapid exchange of gases between air and blood occurs.

 **Reading Check** Describe the relationship between an internal feedback mechanism and the rate of respiration.

Section Assessment

Understanding Main Ideas

1. Describe the path an oxygen molecule takes as it travels from your nose to a body cell. List each structure of the respiratory system through which it passes.
2. Describe how air in the respiratory tract is cleaned before it reaches the lungs.
3. Contrast external respiration and cellular respiration.
4. Explain the process by which gases are exchanged in the lungs.

Thinking Critically

5. During a temper tantrum, four-year-old Jamal tries to hold his breath. His parents are afraid that he will be harmed by this behavior. How will Jamal be affected by holding his breath?

SKILL REVIEW

6. **Sequence** What is the sequence of muscle actions that takes place during inhalation and exhalation? For more help, refer to *Sequence* in the **Skill Handbook**.



Section 37.2

SECTION PREVIEW

Objectives

Distinguish among the various components of blood and among blood groups.

Trace the route blood takes through the body and heart.

Explain how heart rate is controlled.

Review Vocabulary

tissue: groups of cells that work together to perform a specific function (p. 210)

New Vocabulary

plasma
red blood cell
hemoglobin
white blood cell
platelet
antigen
antibody
artery
capillary
vein
atrium
ventricle
vena cava
aorta
pulse
blood pressure

The Circulatory System

California Standards Standard 9a Students know how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide.

Vital Functions

Using Prior Knowledge You know that when you scrape your knee that blood will flow from the wound. What can you do to stop the bleeding? Applying direct pressure to the wound limits bleeding until the blood can clot. Forming clots is one function of the blood. Blood also carries oxygen from your lungs and nutrients from your digestive system to your cells, then hauls away cellular wastes. Together, your blood, your heart, and a network of blood vessels make up your circulatory system.

Infer If the blood could not carry out its functions, how would this affect other cells in the body?



A blood clot is composed of a network of fibers in which blood cells are trapped.

Your Blood: Fluid Transport

Your blood is a tissue composed of fluid, cells, and fragments of cells. **Table 37.1** summarizes information about the components of human blood. The fluid portion of blood is called **plasma**. Plasma is straw colored and makes up about 55 percent of the total volume of blood. Blood cells—both red and white—and cell fragments are suspended in plasma.

Table 37.1 Blood Components

Components	Characteristics
Red blood cells	Transport oxygen and some carbon dioxide; lack a nucleus; contain hemoglobin
White blood cells	Large; several different types; all contain nuclei; defend the body against disease
Platelets	Cell fragments needed for blood clotting
Plasma	Liquid; contains proteins; transports red and white blood cells, platelets, nutrients, enzymes, hormones, gases, and inorganic salts

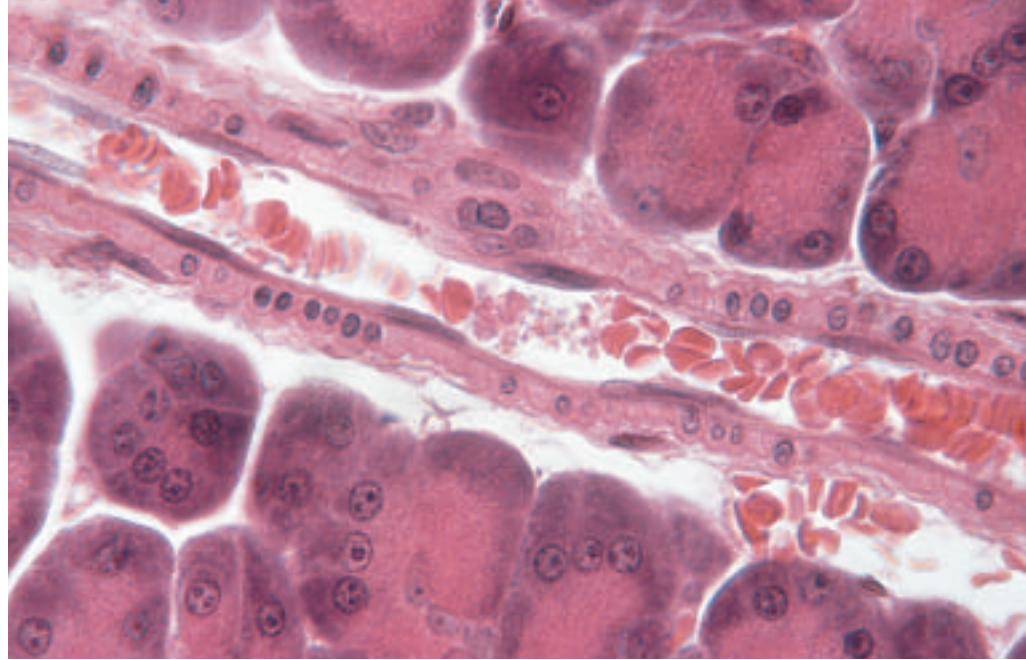
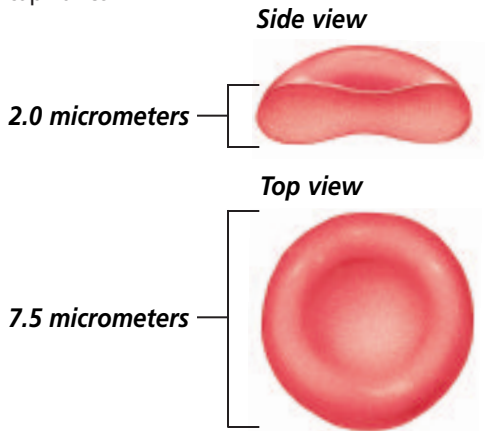
Red blood cells: Oxygen carriers

The round, disk-shaped cells in blood are red blood cells. **Red blood cells** carry oxygen to body cells. They make up 44 percent of the total volume of your blood, and are produced in the red bone marrow of your ribs, humerus, femur, sternum, and other long bones.

Red blood cells in humans have nuclei only during an early stage in each cell's development. The nucleus is lost before the cell enters the bloodstream.

Figure 37.3

Red blood cells are disk-shaped cells that carry oxygen to tissue cells through thin-walled capillaries.



LM Magnification: 200×

Red blood cells remain active in the bloodstream for about 120 days, then they break down and are removed as waste. Old red blood cells are destroyed in your spleen, an organ of the lymphatic system, and in your liver.

Oxygen in the blood

How is oxygen carried by the blood? Red blood cells like those shown in *Figure 37.3* are equipped with an iron-containing protein molecule called **hemoglobin** (HEE muh gloh bun). Oxygen becomes loosely bound to the hemoglobin in blood cells that have entered the lungs.

These oxygenated blood cells carry oxygen from the lungs to the body's cells. As blood passes through body tissues with low oxygen concentrations, oxygen is released from the hemoglobin and diffuses into the tissues.

Carbon dioxide in the blood

Hemoglobin carries some carbon dioxide as well as oxygen. You have already learned that, once biological work has been done in a cell, wastes in the form of carbon dioxide diffuse into the blood and are carried in the bloodstream to the lungs. About 70 percent of this carbon dioxide combines with water in the blood plasma to form bicarbonate. The remaining 30 percent travels back to the lungs dissolved in the plasma or attached to hemoglobin molecules that have already released their oxygen into the tissues.

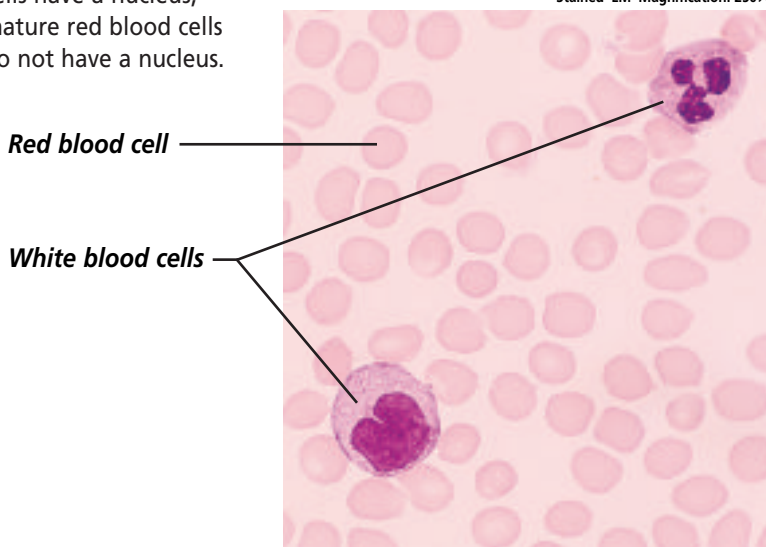
White blood cells: Infection fighters

White blood cells, shown in *Figure 37.4*, play a major role in protecting your body from foreign substances and from microscopic organisms that cause disease. They make up only one percent of the total volume of your blood.

Figure 37.4

Compared with red blood cells, white blood cells are larger in size and far fewer in number. White blood cells have a nucleus; mature red blood cells do not have a nucleus.

Stained LM Magnification: 250×



Blood clotting

Think about what happens when you cut yourself. If the cut is slight, you usually bleed for a short while, until the blood clots. That's because, in addition to red and white blood cells, your blood also contains small cell fragments called **platelets**, which help blood clot after an injury, as shown in *Figure 37.5*. Platelets help link together a sticky network of protein fibers called fibrin, which forms a web over the wound that traps escaping blood cells. Eventually, a dry, leathery scab forms. Platelets are produced from cells in bone marrow and have a short life span. They are removed from the blood by the spleen and liver after only about one week.

ABO Blood Groups

If a person is injured so severely that a massive amount of blood is lost, a transfusion of blood from a second person may be necessary. Whenever blood is transfused from one person to another, it is important to know to which blood group each person belongs. You have already learned about the four human blood groups—A, B, AB, and O. You inherited the characteristics of one of these blood groups from your parents. Sometimes, the term *blood type* is used to describe the blood group to which a person belongs. If your blood falls into group O, for example, you are said to have type O blood.

Blood surface antigens determine blood group

Differences in blood groups are due to the presence or absence of proteins, called antigens, on the membranes of red blood cells. **Antigens** are substances that stimulate an immune response in the body. As you'll learn in a later chapter, an immune response

defends the body against foreign proteins. The letters A and B stand for the types of blood surface antigens found on human red blood cells.

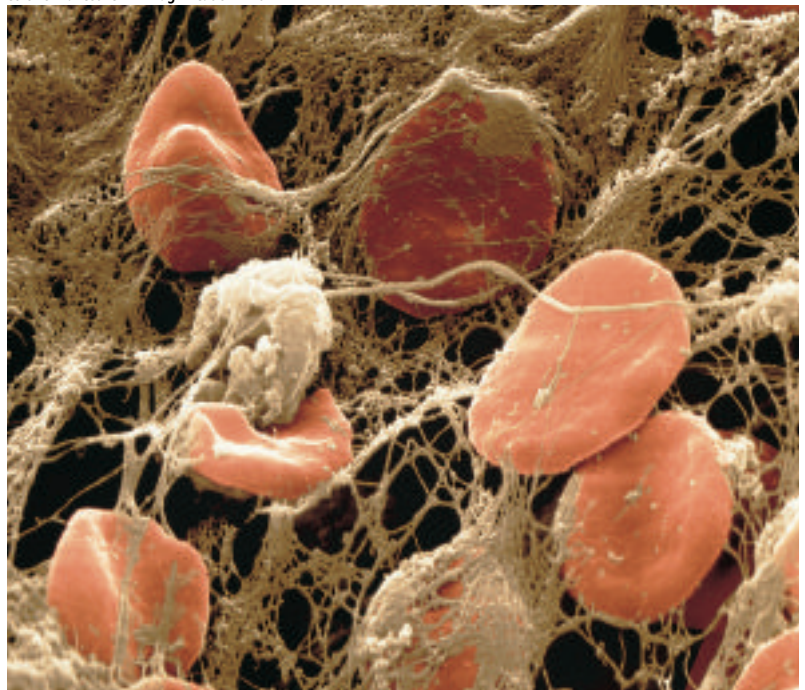
Blood plasma contains proteins, called **antibodies** (AN tih bahd eez), that are shaped to correspond with the different blood surface antigens. The antibody in the blood plasma reacts with its matching antigen on red blood cells if they are brought into contact with one another. This reaction results in clumped blood cells that can no longer function. Each blood group contains antibodies for the blood surface antigens found only in the other blood groups—not for antigens found on its own red blood cells.

For example, if you have type A blood, you have the A antigen on your red blood cells and the anti-B antibody in your plasma. If you had anti-A antibodies, they would react with your own type A red blood cells. What would happen if you had type A blood and anti-A was added to it by way of a transfusion of type B blood?

Figure 37.5

The whitish, globular structures shown adhering to red blood cells are platelets. **Describe** *What is the function of platelets?*

Color-enhanced SEM Magnification: 120X



An antigen-antibody reaction would occur, resulting in clumped blood cells like those shown in **Figure 37.6B**. Clumped blood cells cannot carry oxygen or nutrients to body cells. Similarly, if you have type B blood, you have the B antigen on your red blood cells and the anti-A antibody in your blood plasma. **Figure 37.6C** illustrates the antigens and antibodies present in each blood group.

Rh factor

Another characteristic of red blood cells involves the presence or absence of an antigen called Rh, or Rhesus factor. Rh factor is an inherited

characteristic. People are Rh positive (Rh⁺) if they have the Rh antigen factor on their red blood cells. They are Rh negative (Rh⁻) if they don't.

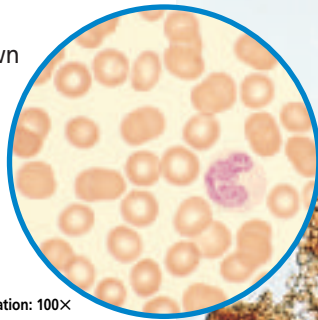
Rh factor can cause complications in some pregnancies. The problem begins when an Rh⁻ mother becomes pregnant with an Rh⁺ baby. At birth, the Rh⁺ baby's blood mixes with the Rh⁻ blood of the mother, as **Figure 37.7A** illustrates. Upon exposure to the baby's Rh⁺ antigen factor, the mother will make anti-Rh⁺ antibodies like those shown in **Figure 37.7B**. If the mother becomes pregnant again, these antibodies can cross the placenta. If the new fetus is Rh⁺, the anti-Rh⁺

Figure 37.6

Blood contains both antigens and antibodies.

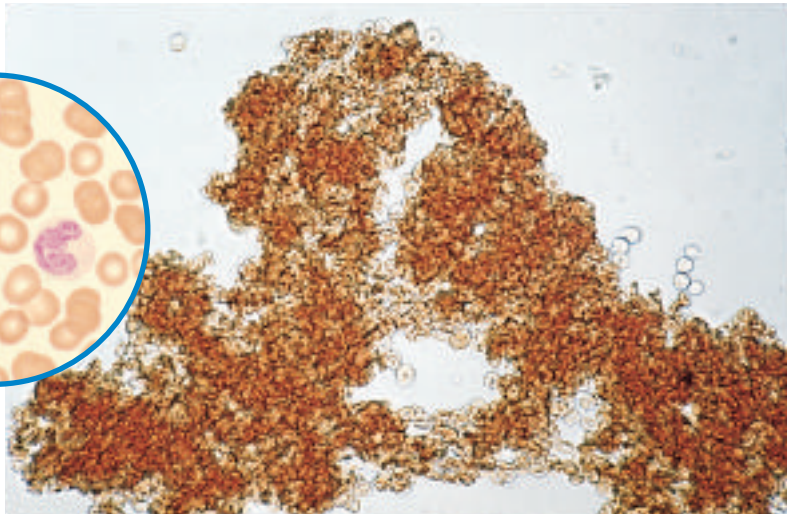
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A Normal blood is shown here. The plasma in your blood contains antibodies that do not react with the antigens on your own red blood cells.



Stained LM Magnification: 100×

B The clumped blood illustrates an antibody-antigen reaction that could occur with an incorrect transfusion.



C The four types of blood groups have different antigens and antibodies.

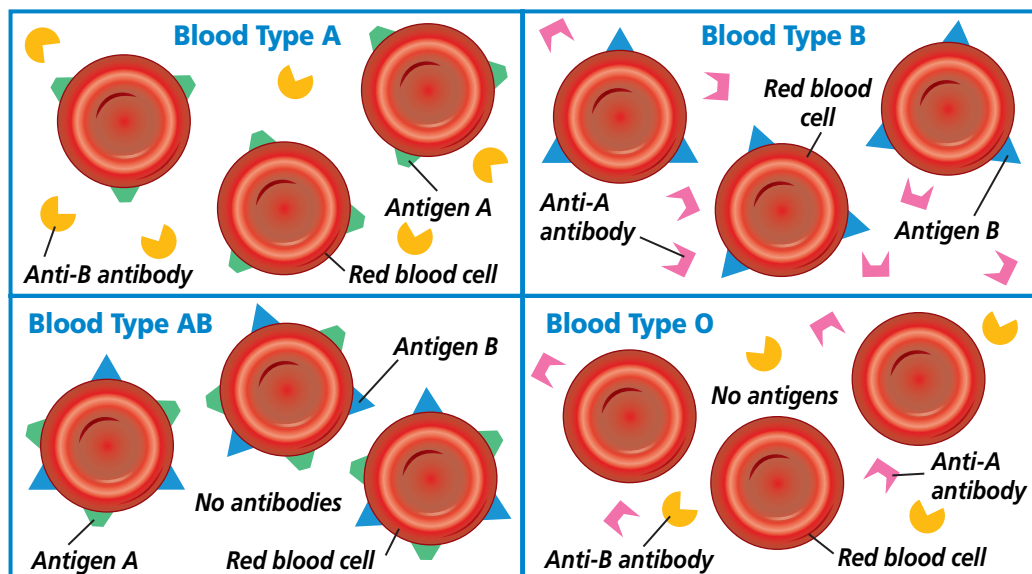
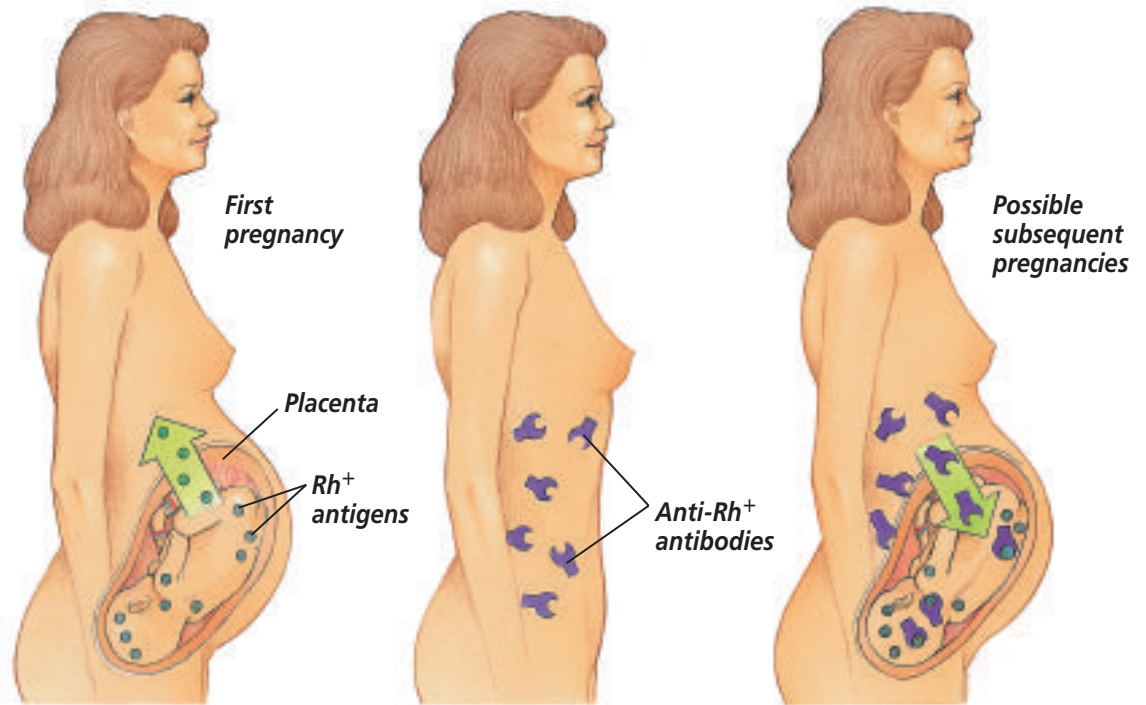


Figure 37.7
If a baby inherits Rh⁺ blood from the father and the mother is Rh⁻, problems can develop if the blood cells of mother and baby mix during birth.



A Mother is exposed to Rh antigens at the birth of her Rh⁺ baby.

B Mother makes anti-Rh⁺ antibodies.

C During the mother's next pregnancy, Rh antibodies can cross the placenta and endanger the fetus.

antibodies from the mother will destroy red blood cells in the fetus, as shown in **Figure 37.7C**.

Prevention of this problem is possible. When the Rh⁺ fetus is 28 weeks old, and again shortly after the Rh⁺ baby is born, the Rh⁻ mother is given a substance that prevents the production of Rh antibodies in her blood. As a result, the next fetus will not be in danger.

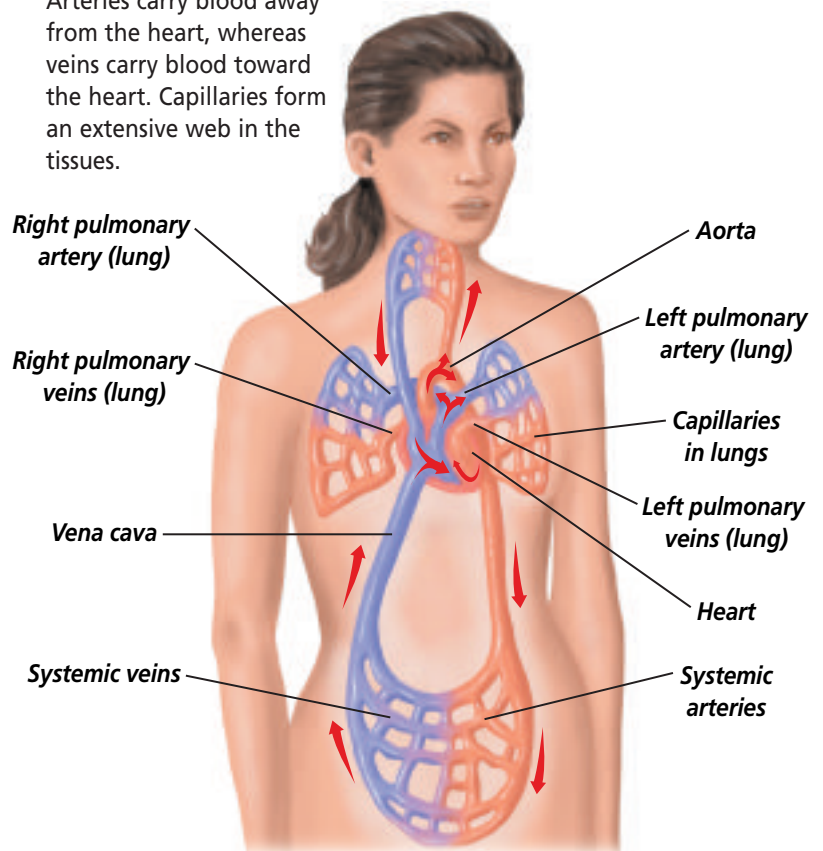
Your Blood Vessels: Pathways of Circulation

Because blood is fluid, it must be channeled through blood vessels like those shown in **Figure 37.8**. The three main types of blood vessels are arteries, capillaries, and veins. Each is different in structure and function.

Arteries are large, thick-walled, muscular, elastic blood vessels that carry blood away from the heart.

Figure 37.8

Arteries carry blood away from the heart, whereas veins carry blood toward the heart. Capillaries form an extensive web in the tissues.



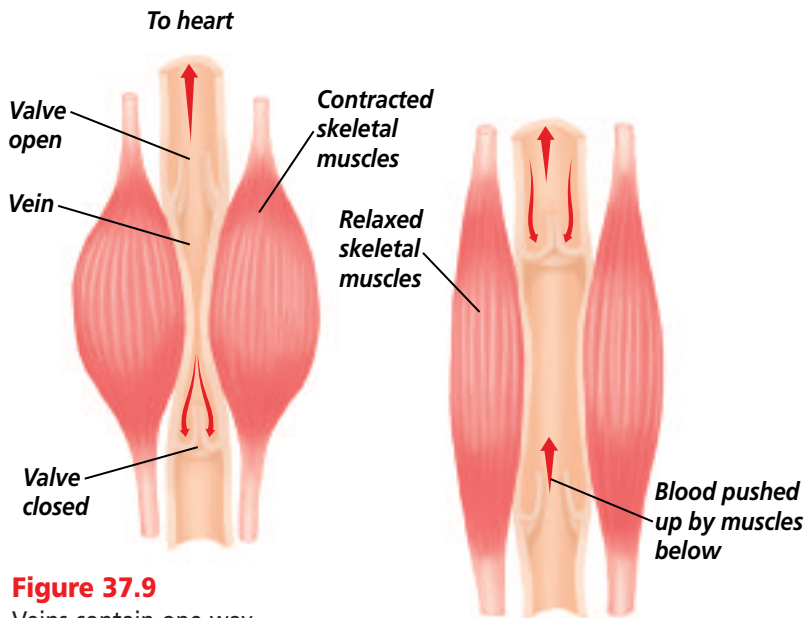


Figure 37.9

Veins contain one-way valves that work in conjunction with skeletal muscles.

that carry blood from the tissues back toward the heart. Blood in veins is not under pressure as great as that in the arteries. In some veins, especially those in your arms and legs, blood travels uphill against gravity. These veins are equipped with valves that prevent blood from flowing backward. **Figure 37.9** shows how these valves function. When your skeletal muscles contract, the top valves open, and blood is forced toward the heart. When the skeletal muscles relax, the top valves close to prevent blood from flowing backward, away from the heart.

 **Reading Check** Explain why some veins have valves.

The blood that they carry is under great pressure. As the heart contracts, it pushes blood through the arteries. Each artery's elastic walls expand slightly. As the heart relaxes, the artery shrinks a bit, which also helps push the blood forward. As a result, blood surges through the arteries in pulses that correspond with the rhythm of the heartbeat.

After the arteries branch off from the heart, they divide into smaller arteries that, in turn, divide into even smaller vessels called arterioles. Arterioles (ar TEER ee ohlz) enter tissues, where they branch into the smallest blood vessels, the capillaries. **Capillaries** (KA puh ler eez) are microscopic blood vessels with walls that are only one cell thick. These vessels are so tiny that red blood cells must move through them in single file. Capillaries form a dense network that reaches virtually every cell in the body. Thin capillary walls enable nutrients and gases to diffuse easily between blood cells and surrounding tissue cells.

As blood leaves the tissues, the capillaries join to form slightly larger vessels called venules. The venules merge to form **veins**, the large blood vessels

Your Heart: The Vital Pump

The thousands of blood vessels in your body would be of little use if there were not a way to move blood through them. The main function of the heart is to keep blood moving constantly throughout the body. Well adapted for its job, the heart is a large organ made of cardiac muscle cells that are rich in energy-producing mitochondria.

All mammalian hearts, including yours, have four chambers. The two upper chambers of the heart are the **atria**. The two lower chambers are the **ventricles**. The walls of each atrium are thinner and less muscular than those of each ventricle. As you will see, the ventricles perform more work than the atria, a factor that helps explain the thickness of their muscles. Each atrium pumps blood into the corresponding ventricle. The left ventricle pumps blood to the entire body, so its muscles are thicker than those of the right ventricle, which pumps blood to the lungs. As a result, your heart is somewhat lopsided.

Word Origin

vena cava from the Latin words *vena*, meaning "vein," and *cava*, meaning "empty"; Each vena cava empties blood into the heart.

Blood's path through the heart

Blood enters the heart through the atria and leaves it through the ventricles. Both atria fill up with blood at the same time. The right atrium receives oxygen-poor blood from the head and body through two large veins called the **venae cavae** (vee nee • KAY vee) (singular, vena cava). The left atrium receives oxygen-rich blood from the lungs through four pulmonary veins. These veins are the only veins that carry blood rich in oxygen. After they have filled with blood, the two atria then contract, pushing the blood down into the two ventricles.

After the ventricles have filled with blood, they contract simultaneously. When the right ventricle contracts, it pushes the oxygen-poor blood from the right ventricle out of the heart and toward the lungs through the pulmonary arteries. These arteries are the only arteries that carry blood poor in oxygen. At the same time, the left ventricle forcefully pushes oxygen-rich blood from the left ventricle out of the heart through the **aorta** to the arteries of the body. The aorta is the largest blood vessel in the body. See **Figure 37.10** on the next page to learn how a drop of blood moves through the heart.

Heartbeat regulation

Each time the heart beats, a surge of blood flows from the left ventricle into the aorta and then into the arteries. Because the radial artery in the arm and carotid arteries near the jaw are fairly close to the surface of the body, the surge of blood can be felt as it moves through them. This surge of blood through an artery is called a **pulse**. Find out more about how the pulse is used to measure heart rate by conducting the *MiniLab* on this page.

MiniLab 37.1

Experiment

Checking Your Pulse The heart speeds up when the blood volume reaching your right atrium increases. It also speeds up when you exercise. The number of heartbeats per minute is your heart rate, which can be measured by taking your pulse.



Procedure

- 1 Copy the data table.
- 2 Have a classmate take your resting pulse for 60 seconds while you are sitting at your lab table or desk. Use the photo above as a guide to finding your radial pulse.
- 3 Record your pulse in the table.
- 4 Repeat steps 2 and 3 four more times, then calculate your average resting pulse rate. Switch roles and take your classmate's resting pulse.
- 5 Exercise by walking in place for one minute.
- 6 Have your classmate take your pulse for 60 seconds immediately after exercising. Record the value in the data table.
- 7 Repeat steps 5 and 6 four more times, then calculate your average pulse after exercise. Switch roles again with your classmate.

Data Table

Heart Rate (beats per minute)		
Trial	Resting	After Exercise
1		
2		
3		
4		
5		
Total		
Average		

Analysis

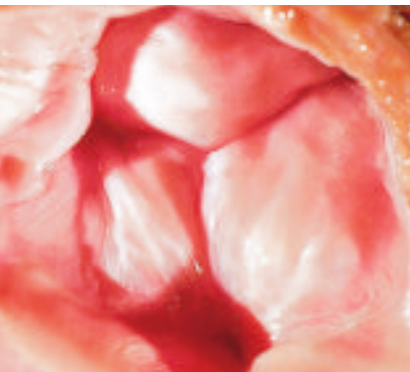
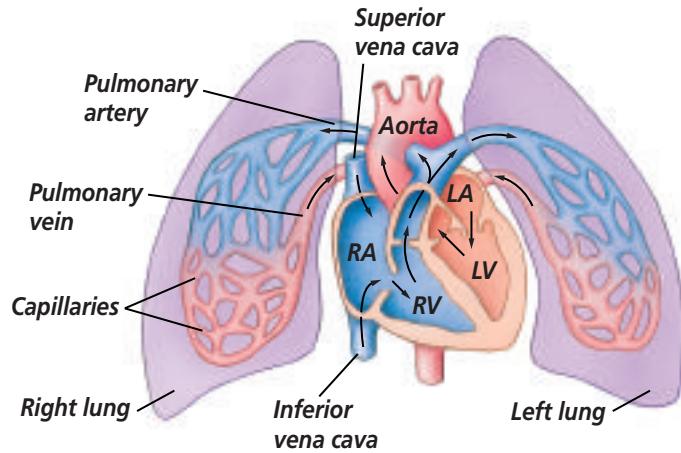
1. **Explain** Why is your pulse a means of indirectly measuring heart rate?
2. **Describe** Use values from your data table to describe the changes that occur to your heart rate when exercising.
3. **Use Numbers** Suppose the amount of blood pumped by your left ventricle each time it contracts is 70 mL. Calculate your cardiac output (70 mL \times heart rate per minute) while at rest and just after exercise.

Your Heart

Figure 37.10

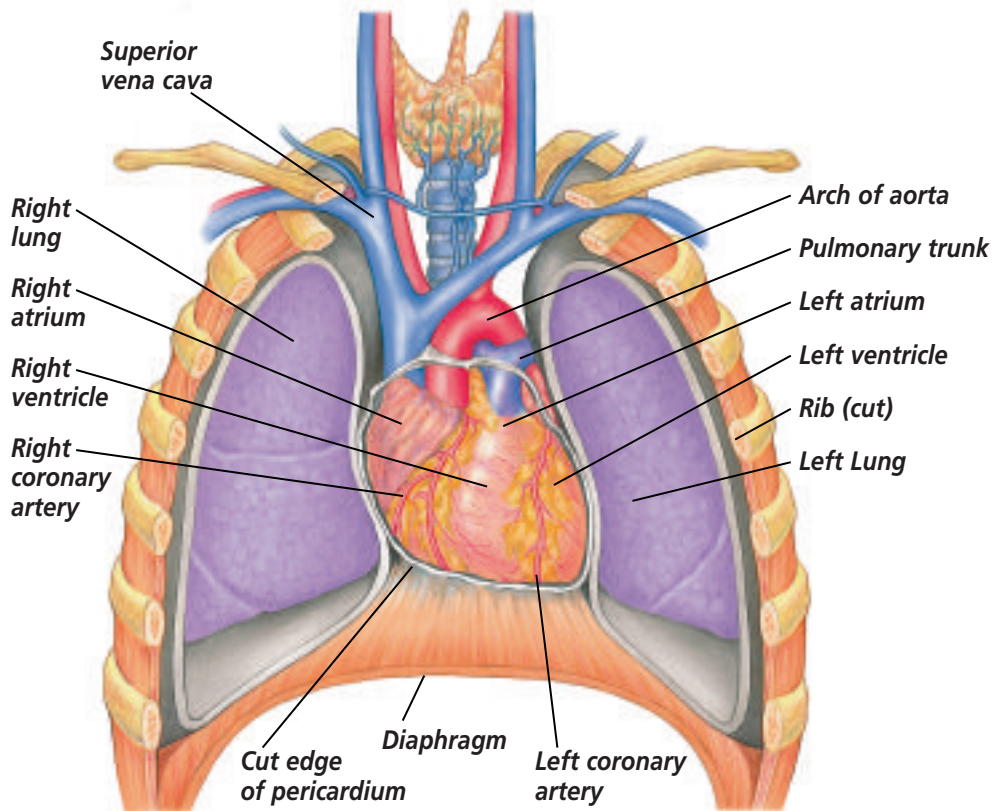
Your heart is about 12 cm by 8 cm—roughly the size of your fist. It lies in your chest cavity, just behind the breastbone and between the lungs, and is essentially a large muscle completely under involuntary control. **Critical Thinking** *The cells in heart tissue receive oxygen and nutrients from a group of blood vessels located on the wall of the heart. How would the function of the heart be affected if bloodflow in these vessels was reduced?*

A The passage of blood If you were to trace the path of a drop of blood through the heart, you could begin with blood coming back from the body through a vena cava. The drop travels first into the right atrium, then into the right ventricle, and then through a pulmonary artery to one of the lungs. In the lungs, the blood drops off its carbon dioxide and picks up oxygen. Then it moves through a pulmonary vein to the left atrium, into the left ventricle, and finally out to the body through the aorta, eventually returning once more to the heart.



B Heart valves

Between the atria and ventricles are one-way valves that keep blood from flowing back into the atria. Sets of valves also lie between the ventricles and the arteries that leave the heart.



C Pericardium The heart is enclosed in a protective membrane called the pericardium.

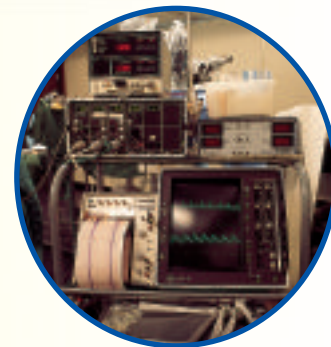
Problem-Solving Lab 37.2

The heart rate is set by the pacemaker, a bundle of nerve cells located at the top of the right atrium. This pacemaker generates an electrical impulse that spreads over both atria. The impulse signals the two atria to contract at almost the same time. The impulse also triggers a second set of cells at the base of the right atrium to send the same electrical impulse over the ventricles, causing them to contract. These electrical signals can be measured and recorded by a machine called an electrocardiograph. This recording, shown in **Figure 37.11**, is called an electrocardiogram (ECG).

The ECG is an important tool used in diagnosing abnormal heart rhythms or patterns. Each peak or valley in the ECG tracing represents a particular electrical activity that takes place during a heartbeat. You can learn how ECG tracings are analyzed by carrying out the *Problem-Solving Lab* on this page.

Analyze Information

How are electrocardiograms analyzed? The electrical signals that regulate the pattern of heart muscle contraction and relaxation can be measured and recorded on an electrocardiograph.



Electrocardiograph

Solve the Problem

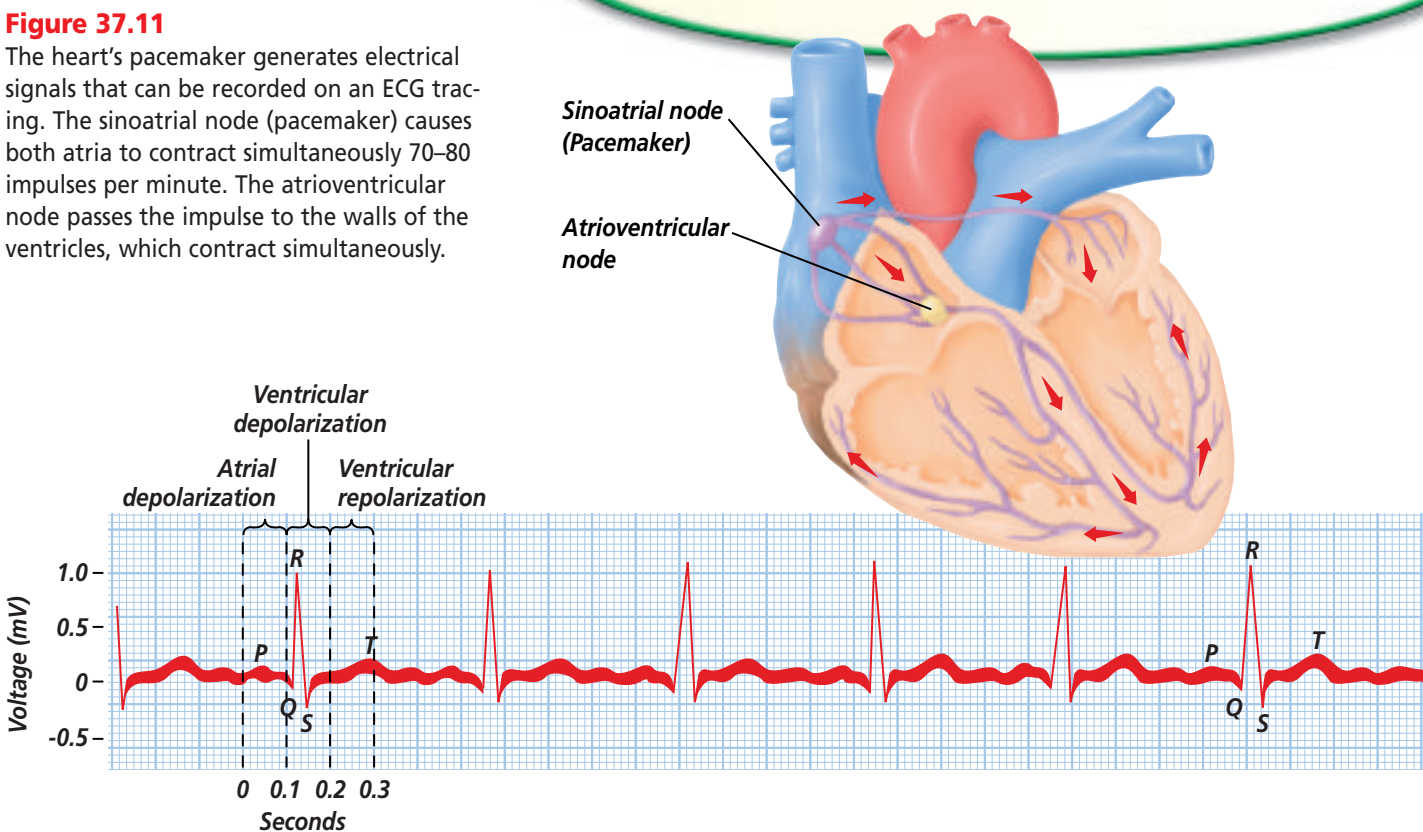
The electrocardiogram (ECG) in **Figure 37.11** is a tracing from a normal heart. The red, inked line is marked with letters that can be used to identify electrical impulses that occur during the heartbeat, such as P–Q and QRS. Segment P–Q represents the electrical charge that causes the atria to contract. Segment Q–T records the electrical charge that causes the ventricles to contract and repolarize. The blue, vertical lines of the graph paper represent units of time. The distance between heavy graph lines is equal to 0.1 seconds. The distance between light lines is equal to 0.02 seconds.

Thinking Critically

- Analyze** How long does it take for the electrical signal to travel through the atria? Through the ventricle?
- Infer** How would a physician interpret an ECG if the distances between T and P were much closer?

Figure 37.11

The heart's pacemaker generates electrical signals that can be recorded on an ECG tracing. The sinoatrial node (pacemaker) causes both atria to contract simultaneously 70–80 impulses per minute. The atrioventricular node passes the impulse to the walls of the ventricles, which contract simultaneously.



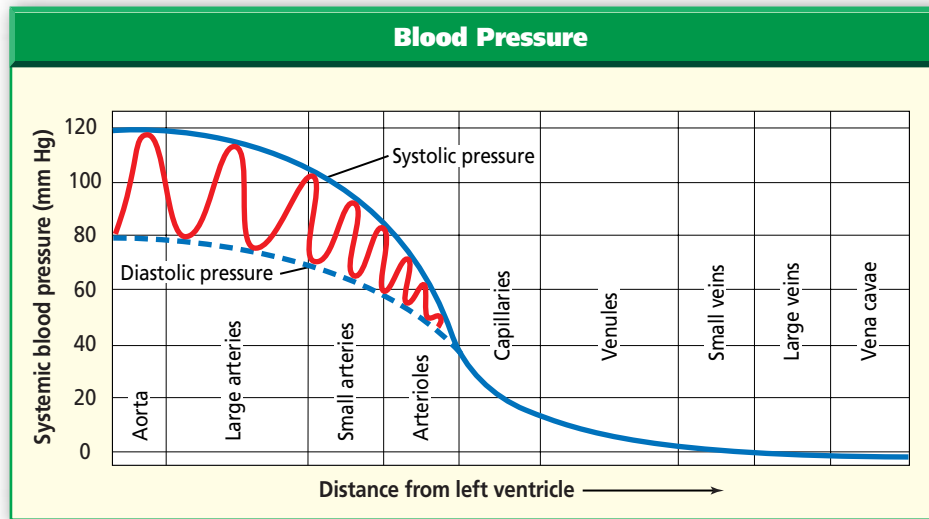
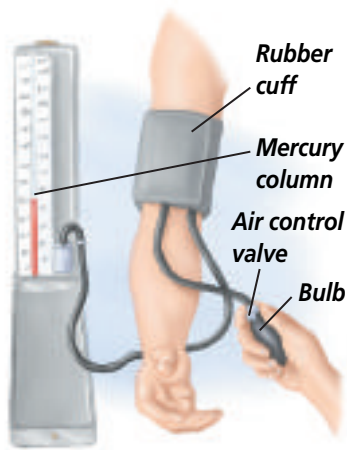


Figure 37.12

Blood pressure rises and falls with each heart beat. Pressure is exerted on all vessels throughout the body. However, blood vessels near the left ventricle are subjected to higher pressure than vessels that are farther away. Blood pressure usually is measured in the artery of the upper arm.

Blood pressure

A pulse beat represents the pressure that blood exerts as it pushes against the walls of an artery. **Blood pressure** is the force that the blood exerts on the blood vessels. As *Figure 37.12* shows, blood pressure rises and falls as the heart contracts and then relaxes.

Blood pressure rises sharply when the ventricles contract, pushing blood through the arteries. The high pressure is called systolic pressure. Blood pressure then drops dramatically as the ventricles relax. The lowest pressure occurs just before the ventricles contract again and is called diastolic pressure.

Control of the heart

Whereas the pacemaker controls the heartbeat, a portion of the brain called the medulla oblongata regulates the rate of the pacemaker, speeding or slowing its nerve impulses. If the heart beats too fast, sensory cells in arteries near the heart become stretched. Via the nervous system, these cells send a signal to the medulla oblongata, which in turn sends signals that slow the pacemaker. If the heart slows down too much, blood pressure in the arteries drops, signalling the medulla oblongata to speed up the pacemaker and increase the heart rate.

Section Assessment

Understanding Main Ideas

1. Summarize the distinguishing features and functions of each of the four components of blood: plasma, platelets, and red and white blood cells.
2. Compare and contrast an artery and a vein.
3. Outline the path taken by a red blood cell as it passes from the left atrium to the right ventricle of the heart.
4. Identify and interpret the functions of the circulatory system.

Thinking Critically

5. The level of carbon dioxide in the blood affects breathing rate. How would you expect high levels of carbon dioxide to affect the heart rate?

SKILL REVIEW

6. **Get the Big Picture** Compare how the nervous, respiratory, and circulatory systems interrelate to provide life support to body cells. How would homeostasis be affected if one of these systems could not function? For more help, refer to *Get the Big Picture* in the **Skill Handbook**.



Section 37.3

SECTION PREVIEW

Objectives

Describe the structures and functions of the urinary system.

Explain the kidneys' role in maintaining homeostasis.

Review Vocabulary

amino acids: basic building blocks of proteins (p. 161)

New Vocabulary

kidney
ureter
urinary bladder
nephron
urine
urethra

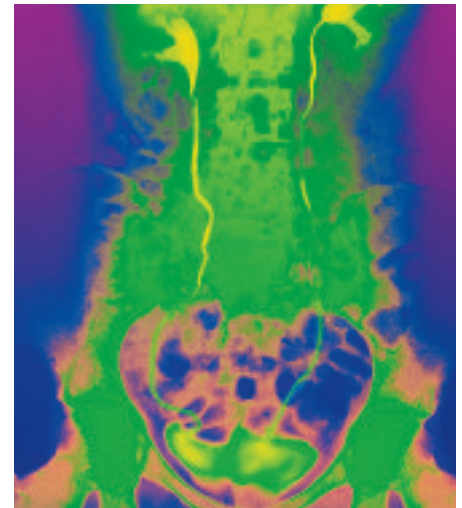
The Urinary System

California Standards Standard 9g* Students know the homeostatic role of the kidneys in the removal of nitrogenous wastes and the role of the liver in blood detoxification and glucose balance.

Waste Removal

Using an Analogy Sorting your CDs is a process similar to how the kidneys filter the blood. Some CDs you know you want to keep. Those are never even removed from the rack. Of the remaining CDs, some you will end up keeping, while others you may give away or sell. When blood enters the kidney, proteins and blood cells remain in the blood. Other substances, such as water and ions, are removed from the blood by a filter but may be reabsorbed later. Waste material is not reabsorbed and is excreted in the urine.

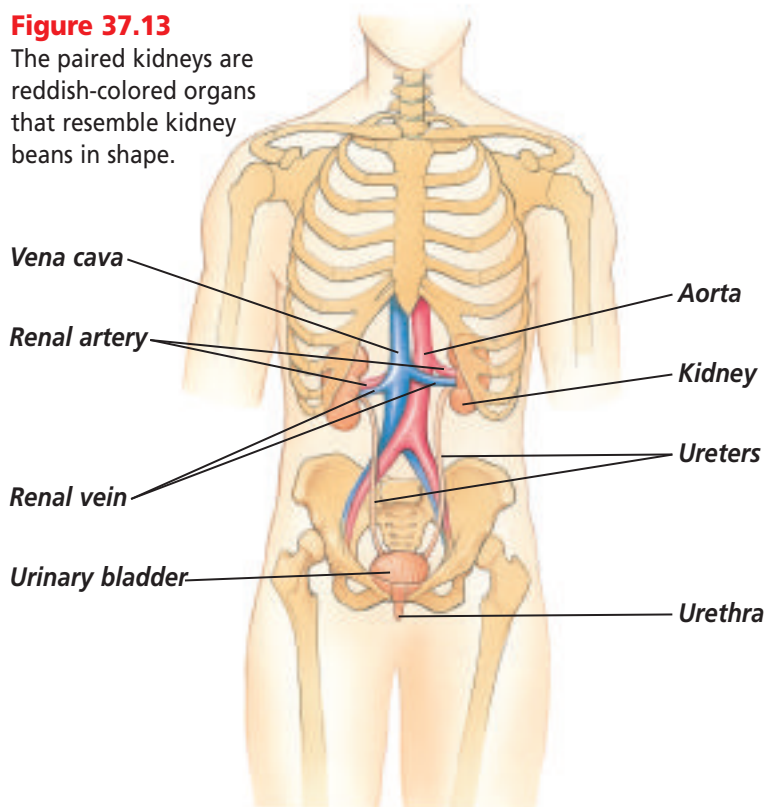
Explain Why is it important that waste material be excreted from the body?



Left and right ureters lead to the urinary bladder, as seen in a colorized X ray of the human urinary system.

Figure 37.13

The paired kidneys are reddish-colored organs that resemble kidney beans in shape.



Kidneys: Structure and Function

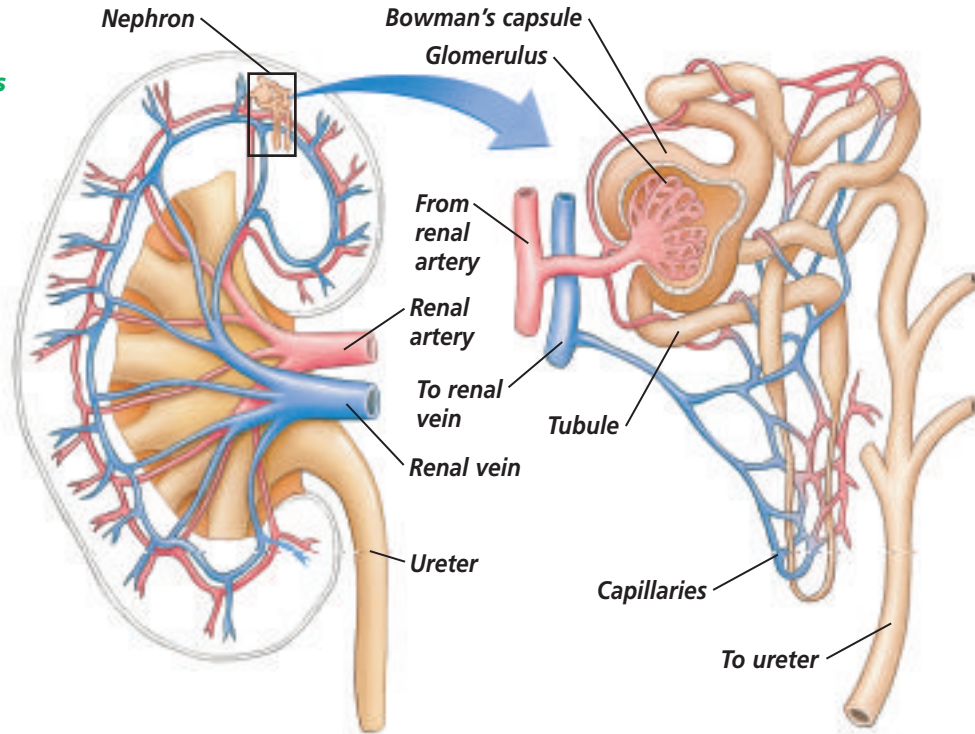
The urinary system is made up of two kidneys, a pair of ureters, the urinary bladder, and the urethra, which you can see in *Figure 37.13*. The **kidneys** filter the blood to remove wastes from it, thus maintaining the homeostasis of body fluids. Your kidneys are located just above the waist, behind the stomach. One kidney lies on each side of the spine, partially surrounded by ribs. Each kidney is connected to a tube called a **ureter**, which leads to the urinary bladder. The **urinary bladder** is a smooth muscle bag that stores a solution of wastes.

Nephron: The unit of the kidney

Each kidney is made up of about one million tiny filters. A filter is a device that removes impurities from a solution.

Figure 37.14

The kidneys filter wastes from the blood. Explain **How does blood enter and leave the kidneys?**



Word Origin

nephron from the Greek word *nephros*, meaning “kidney”; A nephron is a functional unit of a kidney.

Each filtering unit of the kidney is called a **nephron**. A nephron is shown in *Figure 37.14*.

Blood entering a nephron carries wastes produced by body cells. As blood enters the nephron, it is under high pressure and immediately flows into a bed of capillaries called the glomerulus. Because of the pressure, water, glucose, vitamins, amino acids, protein waste products (called urea), salts, and ions from the blood pass out

of the capillaries into a part of the nephron called the Bowman's capsule. Blood cells and most proteins are too large to pass through the walls of a capillary, so these components stay within the blood vessels.

The liquid forced into the Bowman's capsule passes through a narrow, U-shaped tubule. As the liquid moves along the tubule, most of the ions and water, and all of the glucose and amino acids, are reabsorbed into the bloodstream. This reabsorption of substances is the process by which the body's water is conserved and homeostasis is maintained. Small molecules, including water, move back into the capillaries by diffusion. Other molecules and ions move back into the capillaries by active transport.

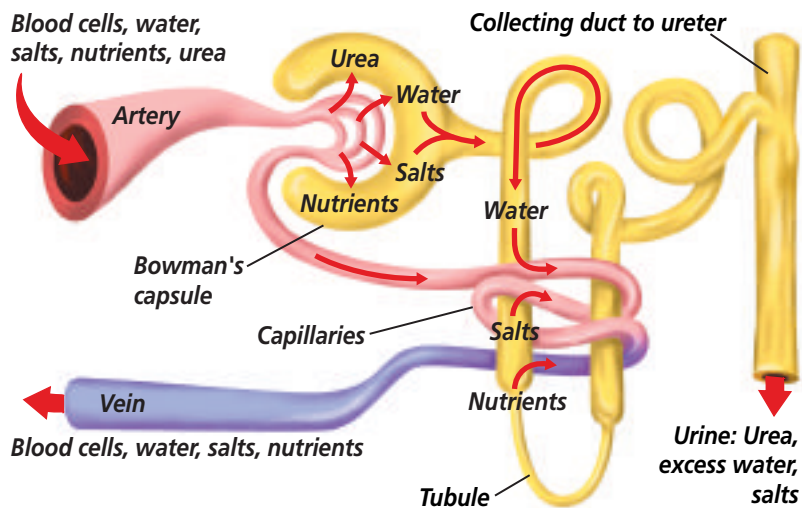
Reading Check Explain how molecules move across capillaries.

The formation of urine

The liquid that remains in the tubules—composed of waste molecules and excess water and ions—is **urine**.

Figure 37.15

Filtration and reabsorption take place in the nephron.



The production of urine is shown in *Figure 37.15*. You produce about 2 L of urine a day. This waste fluid flows out of the kidneys, through the ureter, and into the urinary bladder, where it may be stored. Urine passes from the urinary bladder out of the body through a tube called the **urethra** (yoo REE thruh).

The Urinary System and Homeostasis

The major waste products of cells are nitrogenous wastes, which come from the breakdown of proteins. These wastes include ammonia and urea. Both compounds are toxic to your body and, therefore, must be removed from the blood regularly.

In addition to removing these wastes, the kidneys control the level of sodium in blood by removing and reabsorbing sodium ions. This helps control the osmotic pressure of the blood. The kidneys also regulate the pH of blood by filtering out hydrogen ions and allowing bicarbonate to be reabsorbed back into the blood. Glucose is a sugar that is not usually filtered out of the blood by the kidneys. Individuals who have the disease known as diabetes have excess levels of glucose in their blood. The *MiniLab* on this page shows how urine is used to test for diabetes.

MiniLab 37.2

Experiment

Testing Simulated Urine for Glucose Glucose is normally not present in the urine. When the concentration of glucose becomes too high in the blood, as happens with diabetes, glucose is excreted in urine.

Procedure

- Copy the data table.
- Using a grease pencil, draw two circles on a glass slide. Mark one circle N, the other A.
- Use a clean dropper to add two drops of simulated “normal urine” to circle N.
- Use a clean dropper to add two drops of simulated “abnormal urine” to the circle marked A.
- Hold a small strip of glucose test paper in a forceps and touch it to the liquid in the drop labeled N. Remove it, wait 30 seconds, and record the color. A green color means glucose is present. Use a new strip of glucose test paper to test drop A and record the color.
- Test several simulated “unknown urine” samples for the presence of glucose. Use a clean slide for each test.

Data Table

Simulated Urine Sample	Color of Test Paper	Glucose Present?
Normal (N)		
Abnormal (A)		
Unknown X		
Unknown Y		
Unknown Z		

Analysis

- Analyze** Which of the “unknown” samples could be from a person who has diabetes?
- Explain** Which part of the test procedure could be considered your control?

Section Assessment

Understanding Main Ideas

- Identify the organs that make up the urinary system and interpret the function of each.
- What is the function of a nephron in the kidney? Describe what happens in the glomerulus, Bowman’s capsule, and U-shaped tubule.
- Identify the major components of urine, and explain why it is considered a waste fluid.
- What is the kidney’s role in maintaining homeostasis in the body?

Think Critically

- During a routine physical, a urine test indicates the presence of proteins in the patient’s urine. Explain what this could indicate about the patient’s health.

Skill Review

- Sequence** Trace the sequence of urinary waste from a cell to the outside of the body. For more help, refer to *Sequence* in the **Skill Handbook**.



INVESTIGATE BioLab

Before You Begin

The exchange of oxygen and carbon dioxide between the body and the atmosphere is external respiration. The amount of air inhaled and exhaled each minute during external respiration can be measured using a clinical machine called a spirometer. It also can be measured, although less accurately, using a balloon. In this lab you will calculate the total volume of air inhaled and exhaled each minute. This is done by finding the tidal volume, the volume of air in each breath, and multiplying it by the number of breaths per minute.



Measuring Respiration

PREPARATION

Problem

How can you measure respiratory rate and estimate tidal volume?

Objectives

In this BioLab, you will:

- **Measure** resting breathing rate.
- **Estimate** tidal volume by exhaling into a balloon.
- **Calculate** the amount of air inhaled per minute.

Materials

round balloon clock or watch with
string (1 m) second hand
metric ruler

Safety Precautions

CAUTION: *Always use laboratory materials appropriately.*

Skill Handbook

If you need help with this lab, refer to the **Skill Handbook**.

PROCEDURE

Part A: Breathing Rate at Rest

1. Copy Data Table 1.
2. Have your partner count the number of times you inhale in 30 s. Repeat this step two more times.
3. Calculate the average number of breaths. Multiply the result by two to get the average resting breathing rate in breaths per minute.

Data Table 1

Resting Breathing Rate	
Trial	Inhalations in 30 s
1	
2	
3	
Average number breaths	
Breaths per minute	

Part B: Estimating Tidal Volume

1. Copy Data Table 2.
2. Take a regular breath and exhale normally into the balloon. Pinch the balloon closed.
3. Have a partner fit the string around the balloon at the widest part.
4. Measure the length of the string, in centimeters, around the circumference of the balloon. Record this measurement.
5. Repeat steps 2–4 four more times.
6. Calculate the average circumference of the five measurements.
7. Calculate the average radius of the balloon by dividing the average circumference by 2π ($\pi = 3.14$).
8. Calculate the average tidal volume using the formula for determining the volume of a sphere. Use the average balloon radius for r and 3.14 for π . (Volume of a sphere = $\frac{4\pi r^3}{3}$)
9. Your calculated volume will be in cubic centimeters: $1 \text{ cm}^3 = 1 \text{ mL}$.

Data Table 2

Tidal Volume	
Trial	String Measurement
1	
2	
3	
4	
5	
Average circumference	
Average radius	
Average tidal volume	

Part C: Amount of Air Inhaled

1. Copy Data Table 3.
2. Multiply the average tidal volume by the average number of breaths per minute to calculate the amount of air you inhale per minute.
3. Divide the number of milliliters of air by 1000 to get the number of liters of air you inhale per minute.

Data Table 3

Amount of Air Inhaled	
mL/min	
L/min	

ANALYZE AND CONCLUDE

1. **Make Comparisons** Compare your average number of breaths per minute and tidal volume per minute with those of other students.
2. **Think Critically** An average adult inhales 6000 mL of air per minute. Compare your estimated average volume of air with this figure. What factors could account for any differences?
3. **Make Predictions** Predict what would happen to your resting breathing rate after exercise.
4. **ERROR ANALYSIS** List reasons that explain why there are differences between your results and those of other students. What changes could you make to this experiment to obtain more accurate results?

Apply Your Skill

Apply Concepts The largest amount of air that can be exhaled is called vital capacity. Determine your estimated average vital capacity by following a procedure similar to the one you used to determine average tidal volume.



Web Links To find out more about respiratory volumes, visit ca.bdol.glencoe.com/respiration

Finding Transplant Donors

The ability to replace a diseased heart, liver, kidney, pancreas, or other organ from a human donor has been an important advancement for medical science. Organs suitable for transplanting are scarce, and there are thousands of transplant patients waiting for them. Transplant recipients include children born with malformed hearts or digestive systems, patients suffering from severe liver or heart disease, burn victims in desperate need of skin grafts, or people whose kidneys have stopped functioning.

The waiting list A patient who is a good candidate for a transplant is placed on a waiting list. A national computer database keeps track of each patient's blood and tissue type, organ size, and other medical factors. When an organ becomes available, the computer produces a list of all the patients for whom the organ is medically suitable. Patients are ranked according to the severity of their illness, the length of time they have been waiting, and the distance between the donor and the transplant hospital.

Perspectives A donor organ must be transplanted within hours. Deciding who should receive an organ involves questions of medical urgency and logistics. Although over 20 000 successful organ transplants were performed in the United States in the year 2000, almost 80 000 people remained on the waiting list. One of the most important issues concerning organ transplantation today is the fact that there are more people awaiting organs than there are donor organs available.

Revising policies In 1998, the Department of Health and Human Services asked the national organization that coordinates the matching of organs with patients to revise their policies and make organs available to patients based on medical need regardless of location. If medically suitable recipients are selected based on geographic



Recovering transplant patient

location, a seriously ill patient who lives far from a large population center might have to wait longer than a patient who lives in a big city. However, if the most seriously ill patient is so far away that the transplant cannot be completed within the time limit, another patient must be selected. Policies regarding organ distribution and allocation are being revised to provide a set of medically objective measures by which recipients can be designated.

Forming Your Opinion

Analyze the Issue Research and analyze the medical and ethical considerations involved in organ donation and transplantation. What is your opinion on this issue? Organize a class discussion to share what you learned.



To find out more about organ transplants, visit ca.bdol.glencoe.com/biology_society

Chapter 37 Assessment

STUDY GUIDE

Section 37.1

The Respiratory System



Key Concepts

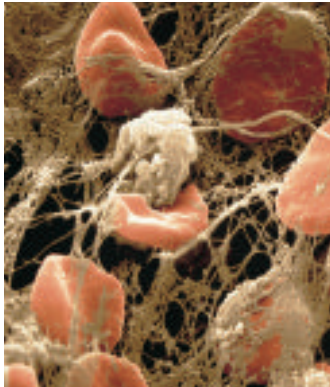
- External respiration involves taking in air through the passageways of the respiratory system and exchanging gases in the alveoli of the lungs.
- Breathing involves contraction of the diaphragm, the rush of air into the lungs, relaxation of the diaphragm, and air being pushed out of the lungs.
- Breathing is partially controlled by the chemistry of the blood.

Vocabulary

alveoli (p. 972)
trachea (p. 971)

Section 37.2

The Circulatory System



Color-enhanced SEM Magnification: 120X

Key Concepts

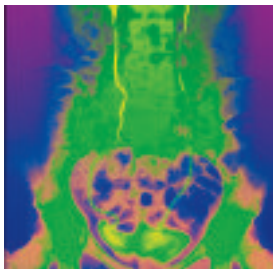
- Blood is composed of red and white blood cells, platelets, and plasma. Blood carries oxygen, carbon dioxide, and other substances through the body.
- Blood cell antigens determine blood group and are important in blood transfusions.
- Blood is carried by arteries, veins, and capillaries.
- Blood is pushed through the vessels by the heart.

Vocabulary

antibody (p. 977)
antigen (p. 977)
aorta (p. 981)
artery (p. 979)
atrium (p. 980)
blood pressure (p. 984)
capillary (p. 980)
hemoglobin (p. 976)
plasma (p. 975)
platelet (p. 977)
pulse (p. 981)
red blood cell (p. 975)
vein (p. 980)
vena cava (p. 981)
ventricle (p. 980)
white blood cell (p. 976)

Section 37.3

The Urinary System



Key Concepts

- The urinary system consists of the kidneys, ureters, the urinary bladder, and the urethra.
- The nephrons of the kidneys filter wastes from the blood.
- The urinary system helps maintain the homeostasis of body fluids.

Vocabulary

kidney (p. 985)
nephron (p. 986)
ureter (p. 985)
urethra (p. 987)
urinary bladder (p. 985)
urine (p. 986)

FOLDABLES

Study Organizer

To help you review the respiratory system, use the Organizational Study Fold on page 971.



Chapter 37 Assessment

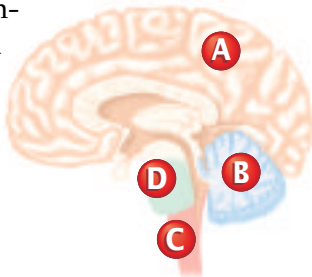
Vocabulary Review

Review the Chapter 37 vocabulary words listed in the Study Guide on page 991. Distinguish between the vocabulary words in each pair.

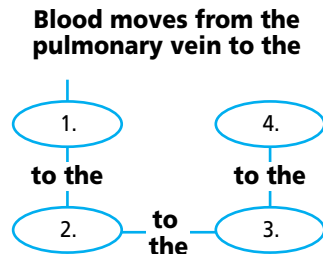
1. aorta—vena cava
2. artery—vein
3. red blood cell—platelet
4. kidney—nephron
5. ureter—urethra

Understanding Key Concepts

6. Homeostasis of blood osmotic pressure is maintained by which organ(s)?
A. lungs **C.** heart
B. kidneys **D.** liver
7. Breathing is an involuntary process controlled by which area of the brain?
A. cerebrum
B. cerebellum
C. medulla oblongata
D. hippocampus
8. A person with Type O blood is given Type AB blood during a transfusion. Which of the following is a possible outcome from the transfusion?
A. The anti-A antibodies in the recipient's blood will attack the A antigens in the donor's blood.
B. The anti-B antibodies in the recipient's blood will attack the B antigens in the donor's blood.
C. The donor cells will clump inside the recipient's body.
D. all of the above
9. Emphysema is a condition that results in the destruction of alveoli in the lungs. What effects would this have on the body?
A. lower levels of oxygen in the blood
B. higher levels of oxygen in the blood
C. lower levels of carbon dioxide in the blood
D. no effect



10. Complete the concept map using the following vocabulary terms: aorta, arteries, left atrium, left ventricle.



Constructed Response

11. **Open Ended** A diet low in saturated fats and cholesterol helps maintain elasticity and prevent clogging of the blood vessels. Why is this type of diet considered healthy for your heart?
12. **Open Ended** In some cities, citizens are advised to avoid heavy outdoor exercise when air pollution levels are high. Explain why it would be wise to heed such a warning.
13. **Open Ended** Explain what normally happens to glucose as blood passes through the kidney. Explain what happens to glucose in a patient with uncontrolled diabetes.

Thinking Critically

14. **Writing About Biology** When the *Streptococcus* bacterium that causes severe sore throats gets into the blood, damage to the valves of the heart can result. How might this damage affect heart function?
15. **REAL WORLD BIOCHALLENGE** Hypertension (high blood pressure) affects more than 50 million Americans. How does hypertension affect various organs of the body? What groups are at risk for hypertension? Analyze the importance of nutrition and exercise and each of their effects on hypertension. Visit ca.bdol.glencoe.com to investigate the answers to these questions. Make a table to help organize and present your findings.



