Overview

Before beginning this section review with your students the objectives listed in the Student Edition. Students will be able to describe the structure of the heart and blood vessels (cardiovascular system), how these structures function in transporting materials all around the body, and how materials move into and out of the blood vessels. Students will also describe the structure of the lymphatic system, how it picks up excess fluids in body tissues and returns them to the cardiovascular, and the role of the lymphatic system in immunity.

Bellringer

Ask students the following question: Is blood a liquid or a solid? Then, have them write down what they think is found in blood. (Many students will know that plasma (liquid) and blood cells (solid) are in blood. Blood also contains water, hormones, antibodies, nutrients, oxygen, carbon dioxide, salts, ions, wastes, and other materials.) Bio 9A

Motivate

Activity

Circulatory Function Ask students to name possible functions of the circulatory system, and write them on the board. (The circulatory system carries oxygen, carbon dioxide, nutrients, hormones, cells of the immune system, wastes, and other materials; and it is involved in regulating body temperature.) Verbal TAKS 2 Bio 10A

Transport and Distribution

Regardless of your activities—whether you are roller-blading, swimming, singing, reading, or just sleeping—your body transports nutrients, hormones, and gases, and it gets rid of wastes. Two body systems play major roles in these functions. The circulatory system, which includes the cardiovascular and lymphatic systems, transports these materials to different parts of the body. The respiratory system exchanges gases with the environment—it takes in oxygen, O2, and releases carbon dioxide, CO2.

The human cardiovascular system, shown in Figure 1, functions like a network of highways. The cardiovascular system connects the muscles and organs of the body through an extensive system of vessels that transport blood, a mixture of specialized cells and fluid. The heart, a muscular pump, propels blood through the blood vessels. Different kinds of molecules move through the cardiovascular system:

1. Nutrients from digested food are transported to all cells in the body through the blood vessels of the cardiovascular system.
2. Oxygen from the lungs, where the oxygen is taken in, is transported to all cells through blood vessels.
3. Metabolic wastes, such as carbon dioxide, are transported through blood vessels to the organs and tissues that excrete them.
4. Hormones, substances which help coordinate many activities of the body, are transported through blood vessels.
5. The cardiovascular system also distributes heat more or less evenly in order to maintain a constant body temperature. For example, in a warm environment, blood vessels in the skin relax to allow more heat to escape from the body. In a cold environment, blood vessels constrict, conserving heat by diverting blood to deeper tissues. This diversion of blood prevents heat from escaping the body.

Objectives

- List five types of molecules that are transported by the cardiovascular system. 9A
- Differentiate between arteries, capillaries, and veins. 10A TAKS 2
- Relate the function of the lymphatic system to the function of the cardiovascular and immune systems. 10B TAKS 2
- Relate each component of blood to its function. 10A TAKS 2
- Summarize how a person's blood type is determined. 10A TAKS 2

Key Terms

cardiovascular system, artery, capillary, vein, valve, lymphatic system, plasma, red blood cell, anemia, white blood cell, platelet, ABO blood group system, Rh factor

Chapter Resource File

- Lesson Plan General
- Directed Reading Basic
- Active Reading General
- Data Sheet for Quick Lab General

Transparencies

TT Bellringer
TT Cardiovascular System
TT Blood Vessels
Blood Vessels

Blood circulates through the body through a network of vessels. **Arteries (AHRT uh reez)**, shown in Figure 2, are blood vessels that carry blood away from the heart. Blood passes from the arteries into a network of smaller arteries called arterioles (ahr TIHR ee oohls). Eventually, blood is pushed through to the capillaries.

**Capillaries** are tiny blood vessels that allow the exchange of gases, nutrients, hormones, and other molecules in the blood. The molecules are exchanged with the cells of the body. From the capillaries, the blood flows into small vessels called venules (VEHN yoolz). From the venules, blood empties into larger vessels called veins (veenz). **Veins** are blood vessels that carry the blood back to the heart.

**Arteries**

With each contraction, the heart forcefully ejects blood into arteries. To accommodate each forceful pulse of blood, an artery’s wall expands and then returns to its original size. Elastic fibers in the walls of arteries allow arteries to expand.

The wall of an artery is made up of three layers of tissue, as shown in Figure 2. The innermost layer is a thin layer of epithelial tissue called the endothelium. The endothelium is made up of a single layer of cells. Surrounding the endothelium is a layer of smooth muscle tissue with elastic fibers. Finally, a protective layer of connective tissue with elastic fibers wraps around the smooth muscle tissue. Just as a balloon expands when you blow more air into it, the elastic artery expands when blood is pumped into it.

**Figure 2** Blood vessels

Blood vessels transport blood and allow for the exchange of substances.

**Capillaries** (exchange gases, nutrients, wastes, and hormones)

**Arteriole** (connects arteries to capillaries)

**Connective tissue**

**Smooth muscle**

**Endothelium**

**Valve**

**Artery** (carries blood away from the heart)

**Vein** (returns blood to the heart)

**Study Tip**

- **Reviewing Information**
  You can remember that arteries take blood away from the heart and veins carry blood toward the heart by remembering the letter **A** at the beginning of the word **artery** and at the beginning of the word **away**.

**Teach**

**Teaching Tip**

**Blood-Brain Barrier** Provide students with the information contained in the Medicine Connection feature at the bottom of this page. Point out that, while the exclusion of most chemicals from the brain is advantageous, it can be a serious problem when physicians try to treat disorders involving the brain and brain function. A major difficulty in treating brain tumors, for example, is that most of the chemical agents used to treat cancer cannot reach targets across the blood-brain barrier. The blood-brain barrier also prevents most of the anti-retroviral drugs now used to treat AIDS from entering the central nervous system. In addition to infecting cells of the immune system, HIV directly infects cells within the brain itself and the blood-brain barrier prevents these drugs from battling HIV-infected cells in the brain.

**Using the Figure**

Direct students’ attention to **Figure 2**. Point out that veins have a much wider inside diameter than arteries. This difference relates to the differences in function of these two kinds of vessels. Arteries transport blood away from the heart under high pressure and force it into tiny capillaries. Veins transport blood rapidly and under low pressure back to the heart. Point out the thicker muscular wall of the artery in the figure. Also point out the valve located in the vein.

**Interactive Reading** Assign Chapter 38 of the Holt Biology Guided Audio CD Program to help students achieve greater success in reading the chapter.

**MEDICINE CONNECTION**

The blood-brain barrier is made up of a single layer of endothelial cells that are tightly packed together and line the inner surfaces of capillaries in the brain. Endothelial cells in other parts of the body have gaps between them through which water, ions, molecules, and even some blood cells can easily diffuse. Water is the only constituent of the blood that can diffuse freely across the blood-brain barrier. Substances required by the brain, such as glucose and other nutrients, are actively transported into the fluid surrounding the brain cells.

This barrier’s most important function is to provide neurons with the exact amount of glucose they need. If glucose levels go up or down even slightly, neurons can begin to malfunction. The blood-brain barrier also maintains a precise balance of necessary ions within the brain. The connections between neurons are sensitive to ion concentrations, and even minor changes can affect nerve transmission.

**Interactive Reading Assign Chapter 38 of the Holt Biology Guided Audio CD Program to help students achieve greater success in reading the chapter.**
**Teach, continued**

**Real Life**

### How long are all of your capillaries?

**Answer** Bio 11C

Student answers will vary, but should indicate that in general exercise increases circulation.

**Demonstration** — **Basic**

Show the class a picture of a person in a hospital bed. Ask why hospital workers try to get patients to walk, if only for a few minutes each day. (Students should recognize that muscle movements squeeze the walls of veins, thus preventing blood from accumulating and clotting in parts of the body such as the legs. Other methods of enhancing circulation used in hospitals include special compression hoses and pumps that promote blood flow through the lower extremities.) Ask students what happens to them if they stand in one place for a long period of time, as during a school assembly or concert. (Most will have experience some discomfort and possibly dizziness if they have stood for a long time.) Tell students that they can help move blood back to the heart while standing if they repeatedly bend their legs at the knees.

**TAKS** 2 Bio 10A, 10B

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**Capillaries**

No cell in your body is more than a few cell diameters away from a capillary. At any moment, about 5 percent of your blood is in capillaries. In capillaries, gases, nutrients, hormones and other molecules are transferred from the blood to the body's cells. Carbon dioxide and other wastes are transferred from the body's cells to the capillaries. 1 2

The extensive back-and-forth traffic in the capillaries is possible because of two key properties. Capillary walls are only one cell thick, so gas and nutrient molecules easily pass through their thin walls. Capillaries are also very narrow, with an internal diameter of about 8 µm (0.0003 in.)—a diameter only slightly larger than the diameter of a red blood cell. Thus, blood cells passing through a capillary slide along the capillary's inner wall, as shown in the photo in Figure 2. This tight fit makes it easy for oxygen and carbon dioxide to diffuse to and from red blood cells through the capillaries. 1 2

**Veins**

The walls of veins consist of a much thinner layer of smooth muscle, than the walls of arteries. They are farther from the heart pump and exposed to lower pressures. Veins do not receive the pulsing pressure that arteries do.

As shown in Figure 2, veins also differ from arteries in that they are larger in diameter. A large blood vessel offers less resistance to blood flow than a narrower one, so the blood can move more quickly through large veins. The largest veins in the human body are about 3 cm in diameter—about the same diameter as your thumb. 1 2

Most veins have one-way valves. A **valve** is a flap of tissue that ensures that the blood or fluid that passes through does not flow back. Valves in veins, such as the one shown in Figure 3, prevent the blood from flowing backward during its trip to the heart. When the skeletal muscles in your arms and legs contract, they squeeze against the veins, causing the valves to open and thus, allowing the blood to flow through. When the skeletal muscles relax, the valves close, preventing the backflow of blood.

Sometimes the valves in the veins become weak and the veins become dilated (larger in diameter). Veins that are dilated because of weakened valves are called varicose veins. Dilated veins that occur in the anal area are called hemorrhoids. 1 2

**Lymphatic System**

Because the blood plasma is rich in proteins, most of the fluid remains in the capillaries due to osmotic pressure. However, every time the heart pumps, some fluids are forced out of the thin walls of the capillaries. The fluid that does not return to the capillaries collects in spaces around the body's cells. The fluid that collects around the...
cells is picked up by the lymphatic system and returned to the blood supply.  

The lymphatic system collects and recycles fluids leaked from the cardiovascular system and is involved in fighting infections. As shown in Figure 4, the lymphatic system is made up of a network of vessels called lymphatic vessels and tiny bean-shaped structures called lymph nodes. Lymph tissue is also located in various places throughout the body, including the thymus, tonsils, spleen, and bone marrow.

Lymphatic vessels carry the leaked fluid, called lymph, back to two major veins in the neck. Similar to veins, lymphatic vessels contain valves that prevent the backflow of the fluid. The fluid is pushed through the lymphatic vessels when the skeletal muscles in the arms and legs contract.

The lymphatic system also acts as a key element in the immune system. Immune cells in the lymph nodes and lymphatic organs help defend the body against bacteria, viruses, other infecting microbes, and cancerous cells. Lymph nodes, which are concentrated in the armpits, neck, and groin, sometimes get tender and swell when they are actively fighting infection and filled with white blood cells. Health-care professionals are trained to detect certain types of infections by feeling for the lymph node swellings on the body.

Cancer is a group of related diseases that occur when cells keep dividing but new cells are not needed. These extra cells may form a mass of tissue, called a tumor. Tumors can be either benign (not cancerous) or malignant (cancerous). Cancer can begin in any organ or tissue of the body. The original tumor is called the primary tumor and is usually named for the part of the body where it begins.

Metastasis means the spread of cancer. Cancer cells can break away from a primary tumor and travel through the bloodstream or lymphatic system to other parts of the body. Cancer cells may spread to lymph nodes near the primary tumor. Cancer cells can also spread to other parts of the body, distant from the primary tumor. Doctors use the term metastatic disease or distant disease to describe cancer that spreads to other organs or to lymph nodes other than those near the primary tumor. When cancer cells spread and form a new tumor, the new tumor is called a secondary, or metastatic, tumor.

**Teaching Tip**

**Stability and Homeostasis** Point out to students that swollen lymph nodes contain large numbers of immune system cells (white blood cells) that are actively engulfing bacteria or virus particles. For this reason, the nodes become inflamed and tender when the body is fighting an infection. **TAKS 2 Bio 4B**

**Using the Figure** — **GENERAL**

Direct students’ attention to Figure 4. Have them examine the vessels and lymph nodes, including the tonsils and spleen. Ask them to identify some ways in which the lymphatic system is different from the cardiovascular system. (The lymphatic system does not run in a circuit, as the cardiovascular system does. The lymphatic system also does not have its own pump, like the heart of the cardiovascular system.) **TAKS 2 Bio 10A**

**Teacher’s Notes**

Instruct students to allow their arms and hands to hang in a relaxed manner for 1 to 2 minutes before beginning the experiment. This demonstration will also work on the veins in the back of the hand.

The effect will be more pronounced if the blood is squeezed out of the vein between the first and second finger. Have students do this by gently stroking the vein toward the heart.

**Answers to Analysis**

1. toward the elbow, and so toward the heart
2. Blood will have to go against gravity, enlarging the vein slightly.
3. Blood will pool in the veins in the legs.
Logical

7,200,000,000 cells/h

60 s/min

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represented in this model. Between the two layers, are not blood cells, normally found cells. Note that platelets and white red water represents red blood presents plasma, a yellow fluid. The vegetable oil represents the heavier components to the bottom of the tube. Lighter components stay at the top. The vegetable oil represents plasma, a yellow fluid. The red water represents red blood cells. Note that platelets and white blood cells, normally found between the two layers, are not represented in this model.

Demonstration — BASIC

Add red water to a test tube to make it about 40 percent full. Then carefully add vegetable oil until the test tube is full. Explain to students that the fluids in the test tube resemble a centrifuged blood sample. Centrifuging pulls the heavier components to the bottom of the tube. Lighter components stay at the top. The vegetable oil represents plasma, a yellow fluid. The red water represents red blood cells. Note that platelets and white blood cells, normally found between the two layers, are not represented in this model.

Real Life

Answer Bio 11C

Student answers will vary, but should be well researched. Students should present their research results to the class.

Math Skills

A human adult has about 5 L (1.25 gal) of blood. Plasma is more than 90 percent water. The body contains some 30 trillion red blood cells and about 60 billion white blood cells. Every second about 2 million new red blood cells are made in the bone marrow to replace those that die at the end of their 120-day life span. Have students calculate how many new red blood cells are made every hour. (2,000,000,000 cells/s) × [60 s/min] × [60 min/h] = 7,200,000,000 cells/h)

Logical

TAKS 2 Bio 4B

Real Life

Several proteins from vampire bats stop blood from clotting.

These proteins, including one named draculin, are being used to develop drugs to fight heart disease.

Finding Information

Investigate other drugs that are currently being developed to help fight heart disease. Bio 11C

Components of Blood

Blood has been called the river of life because it is responsible for transporting so many substances throughout the body. In life-threatening situations, a person’s blood volume is carefully monitored, as shown in Figure 5. Typically, blood appears to us as red, watery fluid. Blood is composed of water, but it also contains a variety of molecules dissolved or suspended in the water, as well as three kinds of cells.

Plasma

About 60 percent of the total volume of blood is plasma, the liquid portion of blood. Plasma is made of 90 percent water and 10 percent solutes. The solutes include metabolites, wastes, salts, and proteins.

Water

Water in the plasma acts as a solvent. It carries other substances.

Metabolites and Wastes

Dissolved within the plasma are glucose and other nutrient molecules. Vitamins, hormones, gases, and nitrogen-containing wastes are also found in plasma.

Salts (Ions)

Salts are dissolved in the plasma as ions. The chief plasma ions are sodium, chloride, and bicarbonate. The ions have many functions, including maintaining osmotic balance and regulating the pH of the blood and the permeability of cell membranes.

Proteins

Plasma proteins, the most abundant solutes in plasma, play a role in maintaining the osmotic balance between the cytoplasm of cells and that of plasma. Water does not move by osmosis from the plasma to cells because the plasma is rich in dissolved proteins. In fact, the total amount of protein in cells and in plasma is the same, making cytoplasm and plasma essentially isotonic with respect to each other.

Some plasma proteins help thicken the blood. The thickness of blood determines how easily it flows through blood vessels. Other plasma proteins serve as antibodies, defending the body from disease. Still other plasma proteins, called clotting proteins or blood-clotting factors, play a major role in blood clotting. When blood is collected for clinical purposes, the blood-clotting factors are removed from the blood and stored for later use.

Blood Cells and Cell Fragments

About 40 percent of the total volume of blood is cells and cell fragments that are suspended in the plasma. There are three principal types of cells in human blood: red blood cells, white blood cells, and platelets.

Red blood cells—cells that carry oxygen. Each milliliter of human blood contains about 5 million red blood cells. Red blood cells are also called erythrocytes (eh RHETH roh sayets).
Most of the interior of a red blood cell is packed with hemoglobin. Hemoglobin is an iron-containing protein that binds oxygen in the lungs and transports it to the tissues of the body. Mature red blood cells do not have nuclei and therefore cannot make proteins or repair themselves. The absence of a nucleus gives a red blood cell its biconcave shape, as shown in Figure 6, and a short life span (about 4 months). New red blood cells are produced constantly by stem cells, specialized cells in bone marrow.

An abnormality in the number or function of red blood cells can result in anemia. Anemia (uh NEE mee uh) is a condition in which the oxygen-carrying ability of the blood is reduced. Anemia may result from blood loss or nutritional deficiencies.

**White Blood Cells** There are only 1 or 2 white blood cells, or leukocytes (LOO kohsites), for every 1,000 red blood cells. White blood cells are cells whose primary job is to defend the body against disease. White blood cells, shown in Figure 6, are larger than red blood cells and contain nuclei.

There are many different kinds of white blood cells, each with a different immune function. For example, some white blood cells take in and then destroy bacteria and viruses. Other white blood cells produce antibodies, proteins that mark foreign substances for destruction by other cells of the immune system.

**Platelets** In certain large cells in bone marrow, bits of cytoplasm are regularly pinched off. These cell fragments, called platelets (PLAYT lihts), are shown in Figure 6. Platelets play an important role in the clotting of blood. If a hole develops in a blood vessel wall, rapid action must be taken by the body, or blood will leak out of the system and death could occur.

When circulating platelets arrive at the site of a broken vessel, they assume an irregular shape, get larger, and release a substance that makes them very sticky. The platelets then attach to the protein fibers on the wall of the broken blood vessel and eventually form a sticky clump that plugs the hole.

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**Visual Activity**

**Blood Composition** Blood has several different components, and learning them can be confusing. Have students construct a Graphic Organizer, such as the one shown at the bottom of this page, that describes the structure and function of each of the blood components discussed in the text. Students should also show the composition of plasma, the fluid portion of the blood.

**Group Activity**

**Blood Diseases** Have students work in small groups to conduct library or Internet research on diseases and disorders of the blood and blood vessels. (Some examples of diseases they could investigate include cancers such as leukemia and lymphoma, anemia, sickle-cell disease, hemophilia, Raynaud’s phenomenon, thalassemia, and von Willebrand disease.) Students should collect information on the causes, symptoms, treatment, and other pertinent information. Have each group prepare a report to present to the entire class.
For wounds such as an open cut, the platelets release a clotting enzyme that activates a series of chemical reactions. Eventually, a protein called fibrin is formed. The fibrin threads form a net, trapping blood cells and platelets, as shown in Figure 7. The net of fibrin and platelets develops into a mass, or clot, that plugs the blood vessel hole. A mutation in a gene for one of the blood-clotting proteins causes hemophilia, a blood clotting disorder.

Blood Type
Occasionally, an injury or disorder is so serious that a person must receive blood or blood components from another person. The blood types of the recipient, the person receiving the blood, and that of the donor, the person giving the blood, must match. Blood type is genetically determined by the presence or absence of a specific complex carbohydrate found on the surface of red blood cells.

One system used to type blood is the ABO blood group system. Under this system, the primary blood types are A, B, AB, and O. The letters A and B refer to complex carbohydrates on the surface of red blood cells that act as antigens, substances that can provoke an immune response.

Blood Doping

Most athletes try to gain an edge over their competitors through conditioning programs and longer hours in training. Some, however, turn to artificial methods, such as blood doping.

What Is Blood Doping?
Blood doping is a practice used by some athletes to increase the amount of oxygen their blood can carry by elevating the number of red blood cells in their body. Several months before a competition, some of the athlete’s blood is carried by elevating the number of red blood cells in their body. By injecting back into the athlete’s bloodstream.

The body senses its deficiency of red blood cells, and steps up its production of red blood cells. After 1 to 2 months, the entire procedure may be repeated. The risks of blood doping far outweigh the benefits. The body clots more easily, raising the risks of heart attack and stroke. Air bubbles are sometimes accidentally injected, and blood cells are sometimes contaminated while out of the body.

Athletes who inject blood cells taken from another person face the dangers of blood incompatibility and transmission of diseases, including AIDS and hepatitis. For these and other reasons, blood doping has been prohibited by many sports-governing bodies.

Blood Clotting Cascade

Stimulus
Blood vessel damage
Platelets release clotting protein (enzyme)
Fibrin net forms, trapping blood cells and platelets
Result
Blood clot

Figure 7
Blood-clotting cascade

The release of enzymes from platelets at the site of a damaged blood vessel initiates a “clotting cascade.”

Discussion
• Why do you think the plasma is reinjected immediately? (to keep blood volume constant)
• Explain the physiological effects of blood doping and the reasons for these effects. (increased endurance due to more oxygen in the blood; decreased heart rate; decreased lactic acid in muscles due to increased oxygen, increased aerobic respiration, and decreased anaerobic respiration)
• Why would doped blood clot more easily? (There are more solids in it.)

Blood Doping

Bring in articles about other performance-enhancing (but often prohibited) practices, such as the use of steroids and certain nutritional supplements, as well as blood doping. Explain how they help an athlete’s performance but harm an athlete’s health.

Transparencies

TT Blood Clotting Cascade
TT Systemic Circulation

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As summarized in Table 1, people with type A blood have the A antigen on their red blood cells. People with type B blood have the B antigen. People with type AB blood have both the A and the B antigen, while those with type O blood have neither antigen. Antibodies are defensive proteins made by the immune system. People with type A blood produce antibodies against the B antigen, even if they have never been exposed to it. In these people, type B red blood cells clump and can block blood flow. For this reason, blood transfusion recipients must receive blood that is compatible with their own.

People with type AB blood are universal recipients (they can receive A, B, AB, or O blood) because they do not have anti-A or anti-B antibodies. Type O individuals are universal donors (they can donate blood to those with A, B, AB or O blood) because their blood cells do not carry A or B antigens and therefore do not react with either anti-A or anti-B antibodies.

### Rh Factor

Another important antigen on the surface of red blood cells is called Rh factor, which was originally identified in rhesus monkeys. People who have this protein are said to be Rh positive (Rh+), and those who lack it are Rh negative (Rh-). When an Rh- mother gives birth to an Rh+ infant, the Rh- mother begins to make anti-Rh antibodies. The mother’s antibodies may be passed to an Rh+ fetus in a future pregnancy, which can lead to fetal death.

### Table 1 Blood Types

<table>
<thead>
<tr>
<th>Blood type</th>
<th>Antigen on the red blood cell</th>
<th>Antibodies in plasma</th>
<th>Can receive blood from</th>
<th>Can donate blood to</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A</td>
<td>B</td>
<td>O, A</td>
<td>A, AB</td>
</tr>
<tr>
<td>B</td>
<td>B</td>
<td>A</td>
<td>O, B</td>
<td>B, AB</td>
</tr>
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<td>A, B</td>
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<td>O, A, B, AB</td>
<td>AB</td>
</tr>
<tr>
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<td>A, B</td>
<td>O</td>
<td>O, A, B, AB</td>
</tr>
</tbody>
</table>

### Real Life

**RhOGAM** is a blood product that can suppress the ability to respond to Rh+ red blood cells. It is given to an Rh- woman who is pregnant with an Rh+ fetus to prevent her from developing antibodies that would harm her baby.
Overview
Before beginning this section review with your students the objectives listed in the Student Edition. Students will map how the structures of the cardiovascular system pump blood around the body. They will also describe electrical activity in the heart. Finally, they will list some disorders of the heart.

Bellringer
Ask students to write a few sentences that describe how the muscle tissue of the heart is different from other types of muscle tissue. (Answers may vary.)

Demonstration
Show students that when blood is far from the heart, it travels with less pressure. You will need plastic syringes and two pieces of hosing that fit snugly on their ends. One hose should be about 8 cm (3 in.) long and the other about 15 cm (6 in.). Fill each syringe and force the water out. The stream should travel about 8 to 15 cm (3 to 6 in.) from the end of the longer hose (vein), and 15 to 30 cm (6 to 12 in.) from the end of the shorter hose (capillary). Be sure to apply equal pressure to the plunger each time so students appreciate the fact that it is distance from plunger tip to exit, not pressure on the plunger, that causes the change.

Section 2
The Heart

A Muscular Pump
Blood vessels allow for the movement of blood to all cells in the body. The pumping action of the heart, however, is needed to provide enough pressure to move blood throughout the body. The heart is made up mostly of cardiac muscle tissue, which contracts to pump blood.

Two Separate Circulatory Loops
As shown in Figure 8, the human heart has two separate circulatory loops. The right side of the heart is responsible for driving the pulmonary (PUHL muh nehr ee) circulation loop, which pumps oxygen-poor blood through the pulmonary arteries to the lungs. Gas exchange—the release of carbon dioxide and pick up of oxygen—occurs in the lungs. The oxygenated blood is then returned to the left side of the heart through pulmonary veins.

The left side of the heart is responsible for driving the systemic circulation loop, which pumps oxygen-rich blood through a network of arteries to the tissues of the body. Oxygen-poor blood is then returned to the right side of the heart through the veins.
Circulation of Blood

As shown in Figure 9, the heart has a wall that divides the right and left sides of the heart. At the top of the heart are the left and right atria (AY tree uh). The atria (singular, atrium), are chambers that receive blood returning to the heart. Below the atria are the left and right ventricles, thick-walled chambers that pump blood away from the heart. A series of one-way valves in the heart prevent blood from moving backward. Figure 9 summarizes the path blood follows through the heart:

1. Two large veins called the inferior vena cava and superior vena cava collect all of the oxygen-poor blood from the body. The venae cavae empty blood directly into the right atrium of the heart.
2. The blood from the right atrium moves into the right ventricle.
3. As the right ventricle contracts, it sends the blood into the pulmonary arteries.
4. The pulmonary arteries carry the blood to the right and left lungs. At the capillaries of the lungs, oxygen is picked up and carbon dioxide is unloaded.
5. The freshly oxygenated blood returns from the lungs to the left side of the heart through the pulmonary veins, which empty the blood directly into the left atrium.
6. From the left atrium, the blood is pumped into the left ventricle.

**Figure 9** Blood flow through the heart

- The arrows trace the path of blood as it travels through the heart.
- Superior vena cava sends O₂-poor blood from upper body to right atrium.
- Aorta sends blood to the coronary arteries, the brain, and the rest of the body.
- Pulmonary arteries send blood to the lungs.
- Inferior vena cava sends O₂-poor blood from lower body to right atrium.

**Study Tip**

Interpreting Graphics

In human anatomy, the terms left and right always refer to the left and right from the perspective of the subject. This will help you understand why the terms left and right appear reversed in anatomical drawings, such as that of the heart in Figures 8 and 9.

**Teach**

**Teaching Tip**

**Nourishing the Heart**  Point out to students that the heart cannot get nutrients and oxygen from the blood in its own chambers. This is because the heart muscle is too thick for diffusion to be an effective means of distribution. Instead, the heart must rely on the coronary arteries to sustain it. These two arteries lie in grooves that spiral around the heart. An obstruction in one of their branches often necessitates bypass surgery to restore proper blood flow to the heart. Restricted blood flow can result in angina pectoris, which is chest pain, or a myocardial infarction, which is a heart attack. Heart cells die during an infarction, which limits the heart’s pumping efficiency.

**TAKS 2**  Bio 10A, 10B (grade 11 only)

**Using the Figure**

*Basic*

Have students examine Figure 9. Have them use their fingers to trace the path that blood follows through the heart. Tell students that although the heartbeat is described for convenience as occurring first on the right side and then on the left, the movement of blood occurs on both sides simultaneously. Have students compare the sizes of the left and right ventricle walls. Ask why the left ventricle wall is thicker than the right. (Blood is pumped to the entire body from the left ventricle. Blood from the right ventricle goes only as far as the lungs.)

**TAKS 1**  Bio/IPC 2A

**Visual**

**Demonstration**

Show students a transparency containing a diagram of a fish’s cardiovascular system. Point out that the fish’s cardiovascular system has only one circuit in it, rather than the two circuits found in mammals. Trace the pathway of blood from the heart, over the gills, to body tissues, and back to the heart. Ask students why the number of cardiovascular system circuits of fish and mammals might be different. (Fish are ectothermic animals that have lower metabolic demands than mammals; therefore, their needs for oxygen are also lower.)

**TAKS 1**  Bio/IPC 2A

**REAL WORLD**

**Connection**

Aerobic exercise conditions the heart and lungs by increasing the oxygen available to the body and by enabling the heart to use oxygen more efficiently. During dynamic aerobic exercise, such as walking, tennis, soccer, and volleyball, the cardiorespiratory system responds by increasing oxygen supply to the muscles. This occurs as a result of the nervous system increasing cardiac output and reducing vascular resistance in small blood vessels. Cardiac output (the amount of blood pumped with each heart beat) is increased by increasing the heart rate and/or by increasing the strength of the heart beat. The reduction in vascular resistance results in higher levels of oxygen being delivered to body tissues. A conditioned athlete’s resting heart rate is lower than that of an unconditioned person. The athlete’s cardiac output is also greater than an unconditioned person’s. Going from the resting to maximal exercise states, oxygen consumption increases by 10 times in untrained people and by 20 to 30 times in conditioned athletes. **TAKS 2**  Bio 10A; Bio 11C
TAKS 2 Bio 10A; Bio 5A, 11A

Synchronized.

atria and then of the ventricles is
muscle cells in the same chamber.
contractions of the other heart
ventricles to contract) trigger
ventricular node (which stimulates
contractions. In addition, cardiac
control only the rate of the heart’s
stimulation from nerves. Nerves
heart muscle are not produced by
initiated, beat. Contractions of the

cells have an intrinsic, or self-

out to students that cardiac muscle
cells have an intrinsic, or self-

ated, beat. Contractions of the
heart muscle are not produced by
stimulation from nerves. Nerves
control only the rate of the heart’s
contractions. In addition, cardiac
muscle cells influence each other.
The sinoatrial node and the atrio-
ventricular node (which stimulates
the ventricles to contract) trigger
contractions of the other heart
muscle cells in the same chamber.
Thus, contraction of the cells of the
atria and then of the ventricles is
synchronized.

The sinoatrial (SA) node
Sinoatrial
SA node, or pacemaker, fires
Sinoatrial
SA node, for short) act as the pacemaker of
the heart. These cells “fire” an electrical stimulus in a regular
rhythm. Each stimulus is followed immediately by a contraction that
travels quickly in a wave and causes both atria to contract almost
simultaneously, as shown in Figure 10.
The wave of contraction spreads from the atria to the ventricles,
but almost one-tenth of a second passes before the ventricles start
to contract. The delay permits the atria to finish emptying blood
into the ventricles before the ventricles contract simultaneously.
The wave of contraction is conducted rapidly over both ventricles
by a network of nerve fibers in the heart.

On average, heart contractions occur at a rate of about 72 times
per minute. During sleep the rate decreases, and during exercise it
increases. The SA node is controlled by two sets of nerves with
antagonistic (opposite) signals and is influenced by many factors,
including hormones, temperature, and exercise.

Initiating Contraction

Contraction of the heart is initiated by a small cluster of cardiac muscle
cells called the sinoatrial (SIE noh ay tree uhl) node, which is
embedded in the upper wall of the right atrium. The cells that make
up the sinoatrial node (SA node, for short) act as the pacemaker of
the heart. These cells “fire” an electrical stimulus in a regular
rhythm. Each stimulus is followed immediately by a contraction that
travels quickly in a wave and causes both atria to contract almost
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by a network of nerve fibers in the heart.

Monitoring the Cardiovascular System

Heart disease is one of the leading causes of death among people in
the United States. Health professionals use several different meth-
ods to monitor the health of the circulatory system.

Blood pressure

Blood pressure is measured with a blood pressure cuff and gauge,
shown in Figure 11. Blood pressure is expressed in terms of
millimeters of mercury (mm Hg) and is usually reported as the systolic
pressure written over the diastolic pressure. The first number, the
systolic pressure, is the pressure exerted when the heart contracts
and blood flows through the arteries. The diastolic pressure is
the pressure exerted when the heart relaxes.

When the heart’s rhythm is disrupted causing
the heartbeat to be too fast, too slow, or
irregular, an artificial pacemaker may become
necessary. These disruptions may be caused by
a blockage in the electrical pathway that regu-
lates heart rhythm, or by some other defect in
the heart’s natural pacemaker. An artificial
pacemaker is a small, battery-operated device
that helps the heart beat in a regular rhythm.
Some pacemakers are permanently implanted
in the chest wall, and some are worn exter-
nally. The pacemaker sends electrical impulses
to the heart, which helps to regulate the
heart’s rhythm. An electrode is placed next to
the heart wall and small electrical charges
currents travel through the wire to the heart.
Normal blood pressure values are from 100 to 130 for systolic pressure and from 70 to 90 for diastolic pressure. An example of a normal reading would be written 120/80 mm Hg. These figures indicate the blood is pushing against the artery walls with a pressure of 120 mm Hg as the heart contracts and 80 mm Hg as the heart rests.

Many Americans suffer from a condition called high blood pressure, or hypertension. High blood pressure places a strain on the walls of the arteries and increases the chance that a vessel will burst. Left untreated, hypertension can lead to heart damage, brain damage, or kidney failure. Regular aerobic activity can help people to maintain a healthy blood pressure. Hypertension can be easily diagnosed and usually can be controlled by medicine, diet, and exercise.

Electrocardiograms (ECGs or EKGs) A common way to monitor the heart’s function is to measure the tiny electrical impulses produced by the heart muscle when it contracts. Because the human body is composed mostly of water with dissolved ions, it conducts electrical currents. A small portion of the heart’s electrical activity reaches the body surface. As shown in Figure 12, an instrument called an electrocardiograph uses special sensors to detect the electrical activity. A recording of these electrical impulses is called an electrocardiogram, abbreviated as ECG or EKG. In one normal heartbeat, three successive electrical-impulse waves are recorded, as shown in Figure 12.

Heart Rate It takes only a watch with a second hand to measure your pulse. Your pulse is a series of pressure waves within an artery caused by the contractions of the left ventricle. A person’s pulse is an indicator of his or her heart rate—how fast or slow the heart is beating. Each time the blood surges from the aorta, the elastic walls in the blood vessels expand and stretch. This rhythmical expansion can be felt as a pulse in areas where the vessel nears the surface of the skin. The number of pulses counted per minute represents the number of heartbeats per minute. The most common site for taking a pulse is at a radial artery, on the thumb side of each wrist. The average pulse rate ranges from 70 to 90 beats per minute for adults.

Electrocardiogram

Atria contract

Ventricles relax

Ventricles contract

Figure 12 Monitoring heart contractions. The electrical changes with each heart contraction can be detected with an electrocardiograph. The characteristic up-and-down waves are analyzed to assess the health of the heart.

Teaching Tip Advanced

Heart Attacks Tell students that hypertension, or high blood pressure, is a serious health condition because it is the major cause of heart failure, kidney failure, and stroke. Ask students to use outside sources to research hypertension and prepare a report that explains the causes of this condition, how it can be prevented or treated, and the incidence of hypertension in the United States compared with that of other countries. Bio 11B, 11C

Group Activity General

Measuring Blood Pressure Have the school nurse demonstrate how a sphygmomanometer works. Remind students that blood pressure readings include two numbers, the systolic and diastolic pressures, represented as a ratio. The systolic reading, the first value, is the pressure on the artery walls exerted by the contracting ventricles. The diastolic reading, the second value, is the pressure on the blood vessel walls during ventricular relaxation.

Exploring Further

What Is a Heart Attack? TAKS 2 Bio 10A

Teaching Strategies

Bring in a sheep heart or a picture of a human heart and point out the coronary arteries to students.

Discussion

• Identify the ways arteries become blocked. (blood clots, atherosclerosis, arteriosclerosis)

• Why do doctors recommend that certain people take an aspirin a day? (Aspirin acts as an anticoagulant, keeping the blood flowing.)

• How can aspirin help prevent heart attacks? (Thinner blood is less likely to clot, but it will not prevent plaques from coming loose or other causes for heart attacks.)

Transparencies

TT Electrocardiogram

TT Electric Regulation of the Heart

Chapter 38 • Circulatory and Respiratory Systems
Diseases of the blood vessels serving the heart and brain are leading causes of premature death and disability in the United States. When either the heart or the brain does not get enough blood, parts of the organ die. A heart attack occurs when an area of the heart muscle stops working and dies. When an area of the brain dies the result is a stroke. Death or varying degrees of disability may result. Factors that contribute to heart attacks and strokes are cigarette smoking, lack of physical activity, diets high in saturated fats, and unmanaged stress.

**Exploring Further**

**TAKS 2**

**What Is a Heart Attack?**

You may feel a sharp, crushing, squeezing pain in your chest. You may have mild pain in your jaws or down an arm. You may break into a cold sweat and feel nauseated. Some of these symptoms occur in almost 2 million Americans each year when they experience a heart attack. Some people experience almost no symptoms.

**Why Do Heart Attacks Occur?**

Heart attacks usually happen when the arteries that deliver oxygen to the heart, the coronary arteries, become blocked. Heart cells begin to die very quickly without blood. If a large part of the heart is affected, the victim can die immediately or within a few days or weeks.

**Blockage of Arteries**

A blood clot formed somewhere in the body can break loose and flow to the heart or to the brain, where it blocks the flow of blood. Blood flow is also blocked by the buildup of fatty deposits, including cholesterol, a condition called atherosclerosis (ahr tuh er uh skluh ROH sihs).

- **When calcium is deposited in the fatty buildup, the condition is called arteriosclerosis (ahr tuh er uh skluh ROH sihs), or hardening of the arteries. Hardened arteries cannot expand to handle the volume of blood that enters every time the heart contracts. Pressure builds up in the artery and causes the heart to work harder.**

**Prevention**

High blood pressure, high cholesterol levels, and cigarette smoking are all controllable risk factors in heart disease. Not smoking at all, early diagnosis and treatment of high blood pressure, regular medical checkups, a healthy diet, and regular exercise can all help prevent a heart attack or decrease the severity of one.

**Section 2 Review**

1. Summarize the path of blood through the body starting and ending with blood that has just returned from the lungs to the heart. 10A

2. List the sequence of events that results in atrial and ventricular contraction. 10A

3. Describe the function of the SA node. 10A

4. Identify three ways that the condition of the cardiovascular system can be monitored. 10A

5. Differentiate between a heart attack and a stroke. 10A 10B 11C

6. When the right ventricle contracts, it pumps blood to the lungs. A. lungs. B. aorta. C. right atrium. D. rest of the body. 10A

**Answers to Section Review**

1. left atrium, left ventricle, aorta, arteries, capillaries, veins, vena cava, right atrium, right ventricle, pulmonary arteries, lungs, and pulmonary veins TAKS 2 Bio 10A

2. When the sinoatrial node is activated, it causes the atria to contract. After about one-tenth of a second pause, the ventricles contract. TAKS 2 Bio 10A

3. The SA node acts as a heart pacemaker by providing an electrical stimulation that regulates the heart’s rhythm. TAKS 2 Bio 10A

4. EKG, blood pressure, and pulse can be used to monitor cardiovascular system condition. TAKS 2 Bio 10A

5. A heart attack occurs when a blood vessel in the heart becomes blocked. A stroke occurs when a blood vessel in the brain becomes blocked. TAKS 2 Bio 10A, 10B; Bio 11C

6. A. Correct. Blood moves from the right ventricle to the lungs for oxygenation, then back to the heart. B. Incorrect. Blood from the left ventricle enters the aorta. C. Incorrect. Blood moves from the right atrium to the right ventricle. D. Incorrect. Blood leaving the left ventricle moves to the rest of the body except the lungs. TAKS 2 Bio 10A
Gas Exchange

A person can go without water for a few days and without food for more than a week. But if a person stops breathing for more than a few minutes, he or she will die. Breathing is the means by which your body obtains and releases gases. Oxygen is used by your cells to completely oxidize glucose and then make ATP, the main energy currency in your cells. Without oxygen, your body cannot obtain enough energy from food to survive. Excess carbon dioxide produced as a waste product of aerobic respiration is toxic to cells and must be removed.

The Path of Air

Breathing is only one part of gas exchange. The gases must be transported by the cardiovascular system and then exchanged at the cells. All of the organs and tissues that function in this exchange of gases make up the respiratory system, as shown in Figure 13.

A breath of air enters the respiratory system through the nose or mouth. Air is made up of many gases. About 21 percent of air is oxygen gas. Hairs in your nose filter dust and particles out of the air. Tissues that line the nasal cavity moisten and warm the air.

Objectives

- Summarize the path that air follows when it enters the body through the nose or mouth.  
- Describe the role of the rib muscles and diaphragm in breathing.  
- Describe how breathing rate is regulated.  
- Summarize how oxygen and carbon dioxide are transported in the blood.  
- Identify three serious diseases of the lungs.

Key Terms

- pharynx
- larynx
- trachea
- bronchus
- alveolus
- diaphragm

Discussion/Question

Point out that air pressure affects respiration in humans. Gases are exchanged between the air in the alveoli and the blood in the capillaries entirely by diffusion. Have students postulate why a person breathes deeper and faster at higher altitudes, where there is decreased pressure. (At high altitudes, hemoglobin's affinity for oxygen is lower. At 6,000 m [9,000 ft], the oxygen saturation of hemoglobin is only 67 percent, compared to 98 percent at sea level. One must become acclimated over time to the low levels of oxygen.) Athletes who train at high altitudes tend to perform better in lower altitudes than those who train in low altitudes.

Bellringer

Ask students to write a sentence or two describing why their breathing rate would increase from exercise or fright. (In either case, the respiratory center in the brain would stimulate the muscles involved in breathing to increase their rate of contraction and prepare the body to meet either actual or potential oxygen needs.)
**Real Life**

The lungs of human fetuses do not function until birth. A fetus’s umbilical cord contains blood vessels that lead to and from the placenta, which contains fetal and maternal capillaries. The O₂ in the mother’s capillaries diffuses to the fetus’s capillaries, and the CO₂ in the fetus’s capillaries diffuses into the mother’s capillaries.

**Finding Information**

Determine the signal that stimulates the baby to start breathing at birth. 0 1A

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**Lungs**

The lungs, which are among the largest organs in the body, are suspended in the chest cavity, bounded on the sides by the ribs and on the bottom by the diaphragm (DIE uh fram). The diaphragm is a powerful muscle spanning the rib cage under the lungs, and it aids in respiration. A double membrane surrounds both lungs. The outermost membrane is attached to the wall of the thoracic cavity, and the inner membrane is attached to the surface of the lungs. Between both membranes is a small space filled with fluid. 0 1 2 3

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**Calculating the Amount of Air Respired**

**Background**

Most adults take in about 0.5 L of air with each breath. The normal breathing rate is about 8 to 15 breaths per minute.

**Analysis**

1. Calculate the volume of air in liters an adult breathes per minute if his or her breathing rate is 15 breaths per minute.

2. Calculate the volume of air in liters an adult breathes per hour if his or her breathing rate is 15 breaths per minute.

3. Critical Thinking

**Inferring Conclusions**

The breathing rate of an infant is about 40 breaths per minute. Why might infants have higher respiratory rates than adults?

**Transparencies**

- TT Inhalation and Exhalation

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**Attention Grabber**

**Newborns**

In addition to using lungs for the first time, a newborn’s heart and cardiovascular system change with the first breath. An opening, the foramen ovale, lies between the left and right atria. Another structure, the ductus arteriosus, connects the pulmonary artery to the aorta. Upon inspiration for the first time, the lungs are inflated, closing the opening and separating pulmonary circulation from the systemic circulation.

**TAKS 2 Bio 10B (grade 11 only)**
Breathing

Air is drawn into and pushed out of the lungs by the mechanical process known as breathing. Breathing occurs because of air pressure differences between the lungs and the atmosphere, as shown in Figure 14. To draw air into the lungs, a process called inhalation, the rib muscles contract. This draws the rib cage up and out, and the diaphragm contracts, moving downward. The volume of the chest cavity increases, which reduces the air pressure within the cavity below the atmospheric pressure. Because air flows from a high pressure area to a low pressure area, air is drawn into the lungs.

Normal exhalation (breathing out) is a passive process. The rib cage and diaphragm muscles relax, which returns the rib cage and diaphragm to their resting position. The relaxation of these muscles decreases the volume in the chest cavity and increases the air pressure in the lungs. Because the air pressure is now higher in the lungs than in the atmosphere, air is forced out—from a high pressure area to a low pressure area.

Breathing Rate

You took your first breath within moments of being born. Since then, you have repeated the process more than 200 million times. What controls how fast or slow you breathe? Receptors in the brain and cardiovascular system continually monitor the levels of oxygen and carbon dioxide in the blood. The receptors enable the body to automatically regulate oxygen and carbon dioxide concentrations by sending nerve signals to the brain. The brain responds by sending nerve signals to the diaphragm and rib muscles in order to speed or slow the rate of breathing.

It may surprise you to know that carbon dioxide levels have a greater effect on breathing than do oxygen levels. For example, if the concentration of carbon dioxide in your blood increases, such as during exercise, you respond by breathing more deeply, ridding your body of excess carbon dioxide. When the carbon dioxide level drops, your breathing slows. Factors such as stress, pain, and fear also influence breathing rate.

The signals that travel from the breathing center of the brain are not subject to voluntary control. You cannot simply decide to stop breathing indefinitely. You can hold your breath for a while, but even if you lose consciousness your respiratory control center will take over and force your body to breathe.

Figure 14 Inhilation and exhalation

The diaphragm and the muscles between the ribs are involved in the movement of the chest cavity during breathing.

Inhalation

Exhalation

When the diaphragm contracts, it moves down and air rushes in. When the diaphragm relaxes, it moves up and air is forced out.

Career

Anesthesiologists Anesthesiologists (anesthetists) are physicians who complete a four-year college program, four years of graduate medical training, and four more years of anesthesiology residency. Their primary role in the operating room is to ensure the patient’s comfort during surgery and also to make informed medical judgments to protect the patient. These include treating and regulating changes in critical life functions, including breathing, heart rate, and blood pressure. These specialists immediately diagnose and treat any medical problems that might arise during surgery or recovery.

Anesthesiologists also work in intensive care units to help restore critically ill patients to stable condition. Anesthesiologists are involved in pain management, including diagnosis and treatment of acute and chronic problems. The field of anesthesiology is growing, and opportunities for employment are excellent. Starting salary will vary by subspecialty and region.

Career Applications

Anesthesiologists are involved in pain management, including diagnosis and treatment of acute and chronic problems. They are also involved in the operating room to ensure the patient’s comfort during surgery and to make informed medical judgments to protect the patient. These include treating and regulating changes in critical life functions, including breathing, heart rate, and blood pressure. These specialists immediately diagnose and treat any medical problems that might arise during surgery or recovery.
Gas Transport

Breathing is the first step to getting oxygen to the trillions of cells in your body. When oxygen molecules diffuse from the air into your alveoli, their journey has just begun, as shown in Figure 15. As oxygen passes into the plasma of the bloodstream, it is picked up by red blood cells that carry an iron-containing protein called hemoglobin. 

Oxygen Transport

Each hemoglobin molecule contains four atoms of iron. The iron atoms in the hemoglobin give red blood cells their red color. The iron atoms bind reversibly with oxygen. Reversible binding means that at the appropriate time, the oxygen can be released elsewhere in the body and be taken up by the cells that need it.

Figure 15 summarizes the path of oxygen and carbon dioxide through the body:

1. Oxygen from the outside air reaches the lungs.
2. The oxygen diffuses from the alveoli to the pulmonary capillaries. At the high oxygen levels that occur in the blood within the lungs, most hemoglobin molecules carry a full load of oxygen.
3. The oxygen-rich blood then travels to the heart. The heart pumps the blood to the tissues of the body.
4. Oxygen diffuses into the cells for use during aerobic respiration. In the tissues, oxygen levels are lower. This causes the hemoglobin to release its oxygen.
5. In tissues, the presence of carbon dioxide produced by cellular respiration makes the blood more acidic and causes the hemoglobin molecules to assume a different shape, one that gives up oxygen more easily. The carbon dioxide diffuses from the cells to the blood.
6. Most of the carbon dioxide travels to the heart as bicarbonate (HCO₃⁻) ions.
7. The heart pumps the blood to the lungs. In the lungs, carbon dioxide is released in its gaseous form to the alveoli.
8. The carbon dioxide is expelled.
Environmental Science

Carbon Dioxide Transport

At the same time that the red blood cells are unloading oxygen to tissues, they are also taking in carbon dioxide from the tissues. Carbon dioxide is carried by the blood in three forms:
1. About 7 percent of CO₂ is dissolved in the blood plasma.
2. About 23 percent of CO₂ is attached to hemoglobin molecules inside red blood cells.
3. The majority of CO₂, 70 percent, is carried in the blood as bicarbonate ions.

How is CO₂ carried as bicarbonate ions? In the presence of a certain enzyme, carbon dioxide combines with water to form carbonic acid, H₂CO₃. This is shown in the equation below. The carbonic acid then breaks up to form a bicarbonate ion, HCO₃⁻, and a hydrogen ion, H⁺:

\[ H₂O + CO₂ \rightleftharpoons H₂CO₃ \rightleftharpoons HCO₃⁻ + H⁺ \]

Thus, most of the CO₂ travels in the blood as bicarbonate ions. The hydrogen ions make the blood more acidic. When the blood reaches the lungs, the series of reactions is reversed:

\[ HCO₃⁻ + H⁺ \rightleftharpoons H₂CO₃ \rightleftharpoons H₂O + CO₂ \]

A bicarbonate ion combines with a hydrogen ion to form carbonic acid, which in turn forms CO₂ and water. The CO₂ diffuses out of the capillaries into the alveoli and is exhaled into the atmosphere.

**Modeling the Role of Bicarbonate in Homeostasis**

**Materials**
- two 250 mL beakers, 250 mL distilled water, 2.8 g baking soda, glass stirring rod, 4 strips of wide-range pH paper, 2 drinking straws

**Procedure**
1. Label one beaker A and another B. Fill each beaker halfway with distilled water.
2. Add 1.4 g of baking soda to beaker B, and stir well.
3. Test and record the pH of the contents of each beaker.
4. Gently blow through a straw into the water in beaker A. Test and record the pH of the resulting solution.
5. Repeat step 4 for beaker B.

**Analysis**

1. **Describe** what happened to the pH in the two beakers during the experiment.
2. **State** the chemical name for baking soda.
3. **Propose** the chemical reaction that might have caused a change in pH in beaker A.
4. **Summarize** the effect the baking soda had on the pH of the solution in beaker B after blowing.
5. **Critical Thinking**
   - **Applying Information**
     - Relate what happened in beaker B to what occurs in the bloodstream.

**Answers to Analysis**

1. A becomes acidic; B becomes basic.
2. sodium bicarbonate, HCO₃⁻
3. H₂O + CO₂ → H₂CO₃
4. It buffered the carbonic acid.
5. Most of the CO₂ in the blood travels as bicarbonate ions.

**Teaching Tip**

**Respiratory Control Center**

Tell students that changes in blood gas and pH levels trigger changes in the rate of respiration. Chemoreceptors in the carotid arteries (on either side of the neck) and in the aorta detect CO₂ and O₂ concentration in the blood as well as blood pH. When these receptors detect high CO₂ levels, low O₂ levels, or low blood pH, they send signals to the respiratory control center located in the medulla oblongata of the brain. In addition, other receptors that detect high CO₂ levels and low pH in the cerebrospinal fluid of the brain send signals to the respiratory control center. When the respiratory control center receives these signals, it sends signals to the muscles involved in breathing. The muscles contract more frequently, which results in an increase in the respiration rate. This, in turn, lowers CO₂ levels, raises O₂ levels, and raises blood pH.

**Skills Acquired**
- Inferring, analyzing

**Teacher’s Notes**

Carefully review the chemical equations on this page.

**IPC Benchmark Fact**

Remind students that the chemical change of H₂CO₃ into HCO₃⁻ + H⁺ (and vice versa) is an example of an oxidation/reduction reaction, that is, electrons are shifted from one substance to another. Have advanced students write the half reactions for this chemical reaction and identify the substances oxidized and reduced. **TAKS 4 IPC 8A**

Nearly 335,000 Americans die each year from lung disease, which is the third leading cause of death in the United States. During the last ten years, the death rate for lung disease has risen faster than that of any of the top five causes of death.

Air pollution contributes to lung disease, including respiratory tract infections, asthma, emphysema, and lung cancer. The major types of air pollution include excess ozone, particulate matter, nitrogen dioxide, and sulfur dioxide. Excess ozone in the atmosphere results primarily from the action of sunlight on hydrocarbons and nitrogen oxides emitted during fuel combustion. Particulate matter air pollution is a mixture of substances that includes particles, dust, and aerosols. Principal sources of nitrogen dioxide are automobiles and fuel combustion by electric utilities. Sulfur dioxide is formed when fuel containing sulfur and fuel combustion by electric utilities. Sulfur dioxide is formed when fuel containing sulfur is burned. Major sources of sulfur dioxide are electric utilities and industrial fuel combustion. **Bio 11C**
Respiratory Diseases

Respiratory diseases affect millions of Americans. A chronic pulmonary—or lung—disease is one for which there is no cure. 1

Asthma

Asthma (AZ muh) is a chronic condition in which the bronchioles of the lungs become inflamed, because of their sensitivity to certain stimuli in the air. The bronchial walls tighten and extra mucus is produced, causing the airways to narrow. In severe asthma attacks, the alveoli may swell enough to rupture. Stressful situations and strenuous exercise may trigger an asthma attack. Left untreated, asthma can be deadly. Fortunately, prescribed inhalant medicines may help to stop an asthma attack by expanding the bronchioles. People of all ages can have asthma. 1 2

Emphysema

Emphysema (ehm fuh SEE muh) is a chronic pulmonary disease resulting from a chemical imbalance that destroys elastic fibers in the lungs. Normally, these elastic fibers allow the lungs to expand and contract. Emphysema begins with the destruction of alveoli. Damage to the alveoli is irreversible and results in constant fatigue and breathlessness. Severely affected individuals must breathe from tanks of oxygen in order to live. Smoking is the cause of up to 90 percent of emphysema cases. Emphysema claims millions of lives annually. 2

Lung Cancer

Lung cancer is one of the leading causes of death in the world today. As shown in Figure 16, cancer is a disease characterized by abnormal cell growth. In the United States alone, about 28 percent—155,000—of all cancer deaths each year are attributed to lung cancer. Once cancer is detected, the affected lung is sometimes removed surgically. Even with such drastic measures, lung cancer usually is not curable. About 15 percent of lung cancer victims live more than 5 years after diagnosis. 2

Answers to Section Review

1. mouth, trachea, bronchi, bronchioles, and alveoli  
   TAKS 2 Bio 10A, 10B (grade 11 only)
2. The diaphragm moves down; the ribs move up and out.  
   TAKS 2 Bio 10A, 10B (grade 11 only)
3. Levels of oxygen and carbon dioxide in the blood regulate the rate of breathing. Increased blood carbon dioxide concentration triggers the brain to send a message to the diaphragm and rib muscles that speeds up the rate of breathing.  
   TAKS 2 Bio 10A
4. Seventy percent of the carbon dioxide in the blood is carried as bicarbonate ions.  
   TAKS 2 Bio 10A, 10B (grade 11 only)
5. Yes, any physical effort increases the oxygen needed and energy required to breathe.  
   TAKS 2 Bio 10A, 10B (grade 11 only); Bio 11C
6. A. Incorrect. The function of the larynx is to produce sound. B. Correct. The alveoli are air sacs where gas exchange takes place. C. Incorrect. The trachea transports air to the bronchi. D. Incorrect. The bronchi are tubes that lead to the lungs.  
   TAKS 2 Bio 10A
Key Concepts

1. **The Circulatory System**
   - The human cardiovascular system is made up of blood vessels, blood, and the heart, which together function to transport materials, remove wastes, and distribute heat.
   - Arteries carry blood away from the heart. Materials are exchanged at the capillaries. Veins contain valves and carry blood back to the heart. Fluids not returned to the capillaries are picked up by lymphatic vessels.
   - Blood consists of plasma (water, metabolites, wastes, salts, and proteins), red blood cells, white blood cells, and platelets.
   - Blood types are defined by the presence or absence of complex carbohydrates on the surface of red blood cells.

2. **The Heart**
   - The right side of the heart receives oxygen-poor blood from the body and circulates it to the lungs. In the lungs, gases are exchanged. The left side of the heart receives oxygenated blood from the lungs and circulates it to the rest of the body.
   - Atria receive blood entering the heart. Ventricles pump blood away from the heart.
   - Contraction of the heart is initiated by the sinoatrial node. The health of the cardiovascular system can be monitored by measuring blood pressure, electrical impulses, and pulse rate.
   - Blockages in blood vessels can lead to heart attacks or strokes.

3. **The Respiratory System**
   - A series of tubes and bunched air sacs (alveoli) take in oxygen and remove carbon dioxide.
   - Breathing is caused by pressure changes within the chest cavity.
   - The concentration of carbon dioxide in the blood is the most critical factor affecting a person’s breathing rate and depth.
   - Oxygen is transported to tissues by combining with hemoglobin molecules inside red blood cells. Most carbon dioxide is transported to the lungs as bicarbonate ions.
   - Asthma, emphysema, and lung cancer limit lung function.

**Alternative Assessment**

Have students make a board game with questions about normal and abnormal function of the circulatory and respiratory systems.

**TAKS 2 Bio 10B (grade 11 only)**

**Key Terms**

**Section 1**
- cardiovascular system (872)
- artery (873)
- capillary (873)
- vein (873)
- valve (874)
- lymphatic system (875)
- plasma (876)
- red blood cell (876)
- anemia (877)
- white blood cell (877)
- platelet (877)
- ABO blood group system (878)
- Rh factor (879)

**Section 2**
- atrium (881)
- ventricle (881)
- vena cava (881)
- aorta (882)
- coronary artery (882)
- sinoatrial node (882)
- blood pressure (882)
- pulse (883)
- heart attack (884)
- stroke (884)

**Section 3**
- pharynx (886)
- larynx (886)
- trachea (886)
- bronchus (886)
- alveolus (886)
- diaphragm (886)

**Answer to Concept Map**

The following is one possible answer to Performance Zone item 15.

```
Circulatory system
  is composed of
    blood vessels
      such as
        arteries
        capillaries
        veins
      largest is
        aorta
    lymphatic system
    heart
      has
        atria
        ventricles
      regulates
        systemic circulation
        pulmonary circulation
```
Using Key Terms

1. The chamber of the heart that sends blood to the lungs is the \(10A\) right atrium.\(10B\)
   - a. left ventricle
   - b. right ventricle
   - c. left atrium
   - d. right atrium

2. The pacemaker of the heart is the \(10A\) sinoatrial node.\(10C\)
   - a. left ventricle
   - b. coronary sinus
   - c. right atrium
   - d. inferior vena cava

3. A disease in which the elastic fibers in the alveoli are destroyed is called \(10A\) emphysema.\(10B\)
   - a. atherosclerosis
   - b. arteriosclerosis
   - c. asthma
   - d. pneumonia

4. The layer labeled A is \(2C\) endothelium.\(10A\)
   - a. connective tissue
   - b. smooth muscle
   - c. valve

5. For each pair of terms, explain the differences in their meanings:
   - a. plasma, lymph
   - b. blood pressure, pulse
   - c. heart attack, stroke

Understanding Key Ideas

6. Lymphatic vessels \(10A\)
   - a. return fluid to the blood
   - b. produce antibodies
   - c. transport blood
   - d. control blood clotting

7. What type of blood contains A antibodies (but not B antibodies) in the plasma and lacks Rh antigens? \(10A\)
   - a. AB negative
   - b. A positive
   - c. B negative
   - d. O positive

8. Blood in the pulmonary veins is \(10A\)
   - a. oxygen-rich
   - b. iron-poor
   - c. oxygen-poor
   - d. calcium-rich

9. The diaphragm contracts and the pressure in the chest cavity decreases during \(10A\)
   - a. bronchitis
   - b. inhalation
   - c. exhalation
   - d. asthma attacks

10. Breathing rate will automatically increase when \(10A\)
    - a. blood pH is high
    - b. the amount of carbon dioxide in the blood increases
    - c. blood acidity decreases
    - d. hemoglobin is unloaded

11. Which organ receives the richest oxygen supply from blood returning from the lungs? \(10A\)
    - a. stomach
    - b. heart
    - c. brain
    - d. kidney

12. Which is not a factor that contributes to chronic coronary disease? \(10A\)
    - a. a diet rich in fat
    - b. unmanaged stress
    - c. cigarette smoking
    - d. vigorous exercise

13. BIOWatch For what types of athletic events would blood doping most likely increase an athlete’s performance? Explain your reasoning. \(11C\)

14. Explain Further One of the effects of aspirin is that it thins the blood. Why is aspirin sometimes prescribed for people at risk for heart attack? \(10A\)

15. Concept Mapping Make a concept map that outlines the path of blood through the body. Try to include the following terms in your map: artery, capillary, vein, lymphatic system, pulmonary circulation, systemic circulation, atrium, ventricle, aorta, and vena cava. \(2C\)

Assignment Guide

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Review and Assess
TAKS Obj 1 Bio/IPC 2C
TAKS Obj 2 Bio 10A, 10B
TEKS Bio 3D, 3E, 3F, 10A, 10B, 11C
TEKS Bio/IPC 2C
Critical Thinking

16. Forming Reasoned Opinions The frequency of blood clots and heart attacks is much lower among the Inuit, the nomadic hunters of the North American Arctic, than it is among other North Americans. This difference is credited to fish oils in the Inuit diet that cause blood platelets to be more slippery. How might slippery platelets affect the clotting ability of the Inuit’s blood?  

17. Interpreting Information What role do cell surface markers play in blood typing?  

18. Evaluating Results As altitude increases, the atmosphere becomes thinner. When a runner who trained at sea level competes at a location 500 m above sea level, how will his or her performance compare with his or her training performance?  

19. Inferring Function How is body temperature regulated by blood vessel diameter?  

Alternative Assessment

20. Finding Information Use the media center or Internet resources to find out which foods are recommended as foods that prevent heart disease.  

21. Multicultural Perspective Dr. Charles Drew was an African-American physician. Write a report that discusses the life of Dr. Drew and his many accomplishments. How did his work with blood help save many lives?

TAKS Test Prep

The chart below shows the relationship between daily salt intake and blood pressure in humans. Use the chart and your knowledge of science to answer questions 1–3.

![Chart Image]

1. A person who consumes 23 g of salt per day is likely to have a systolic pressure of about
   A 120 mm Hg.  
   B 130 mm Hg.  
   C 140 mm Hg.  
   D 150 mm Hg.  

2. People with a normal systolic pressure likely have a daily salt intake that does not exceed
   A 4 g.  
   B 16 g.  
   C 19 g.  
   D 27 g.  

3. What conclusion can be drawn from the chart?
   A Increasing one's salt intake leads to an increased systolic pressure.  
   B Raising one's systolic pressure leads to a greater appetite for salt.  
   C A person can control hypertension by consuming more salt.  
   D A daily salt intake of 10 g or less is associated with a risk to health.

TAKS Doctor

1. Incorrect. This is the blood pressure associated with about 10 g per day of salt intake.  
   B. Incorrect. This is the blood pressure associated with about 16 g per day of salt intake.  
   C. Incorrect. This is the blood pressure associated with about 20 g per day of salt intake.  
   D. Correct. Consumption of 23 g of salt per day is correlated with a blood pressure of 150 mm Hg.  

2. F. Incorrect. 16 g is a better choice because 4 g is not an excessive amount.  
   G. Correct. A blood pressure of 130 mm Hg is at the high end of normal and is correlated to 16 g per day of salt.  
   H. Incorrect. Daily consumption of 19 g of salt is associated with a blood pressure of about 140 mm Hg, above normal.  
   J. Incorrect. Daily consumption of 27 g of salt is associated with a blood pressure of about 160 mm Hg, above normal.  

3. A. Correct. There seems to be a direct relationship between salt intake and blood pressure.  
   B. Incorrect. Increased systolic blood pressure does not itself increase a person’s appetite for salt.  
   C. Incorrect. Consuming more salt makes hypertension worse.  
   D. Incorrect. A daily salt intake of 10 g or less does not increase blood pressure above normal nor cause damage in any other way to the cardiovascular system.

Critical Thinking

16. Clotting ability is most likely diminished because platelets will not stick as readily.  

17. Cell surface markers called antigens exist on blood cells. Blood types are named for the antigens present.  

18. It will decrease because the runner will not get as much oxygen as obtained at sea level.  


Alternative Assessment

20. Answers will vary but should include fish, fresh fruits, vegetables, and foods low in saturated fat.  

21. Answers will vary. Dr. Drew found a way to keep blood plasma fresh. He also started the first blood bank.

22. Respiratory therapists treat patients who have breathing difficulties. Respiratory therapists use respirators and oxygen tents. They develop treatment programs for long-term care, and they operate and maintain oxygen delivery equipment. Most attend two years of college with an emphasis on math and science courses. Respiratory therapists must be professionally certified. Many are employed by hospitals or physicians. The growth prospects of the field are excellent. Starting salary will vary by region.