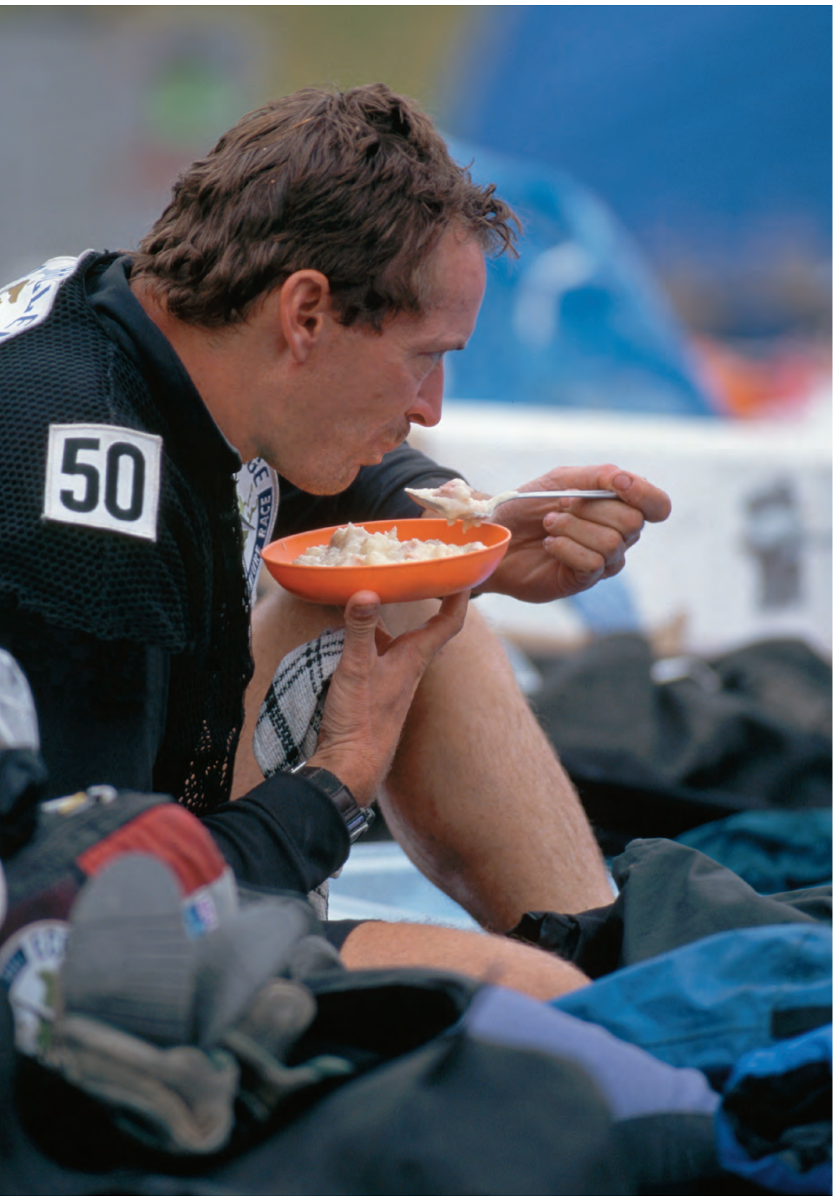
LESSON **12**

Recipe for Energy—Cellular Respiration



CORBIS/KEVIN T. GILBERT

Many athletes "carbo load" before a game or meet. Is this a good idea? Why?

INTRODUCTION

You might think of nutrients and oxygen as two of the ingredients, or raw materials, that are needed to maintain life and growth. But how do the cells use these two substances? What happens to the wastes produced as a result? These are the questions you are about to explore.

In this lesson, you will observe what happens when a fuel combines with oxygen. The fuel you

OBJECTIVES FOR THIS LESSON

Use a model to determine the raw materials and products of combustion.

Recognize that combustion is a form of oxidation.

Recognize that cellular respiration is a form of oxidation.

Compare and contrast combustion and cellular respiration.

Use an indicator to detect a gaseous waste common to combustion and cellular respiration.

Determine a form of energy released during exhalation.

Observe and document the flow of inhaled and exhaled air through a model.

Use the model to discover whether a gaseous waste product of cellular respiration is present in inhaled and exhaled air.

Determine whether the gaseous waste product of cellular respiration can pass through a membrane.

will use is candle wax, and the burning process is called combustion, a form of oxidation during which a great deal of energy is released very rapidly. You will identify two of the waste products of combustion. You will then determine whether either of these products is similar to those produced during another form of oxidation called cellular respiration by exploring whether they are present in the air you inhale and exhale. You'll also determine which ingredient is common to combustion and cellular respiration. You'll combine these observations to develop a brand-new recipe—a recipe for cellular respiration!

OXIDATION—ONE PROCESS, TWO FORMS

By now you know that oxygen is a gas—a gas that humans inhale with every breath they take. In this lesson, you will be studying what happens when a substance combines with oxygen. This process is called oxidation. You will examine two very different forms of oxidation. The first is called combustion. Combustion is a form of oxidation that is accompanied by the rapid release of energy, in the form of heat and light. This rapid burning produces waste products.

Cellular respiration is another form of oxidation; in other words, it is also a process by which a substance combines with oxygen. Cellular respiration, like combustion, also produces waste products. Cellular respiration is not nearly as dramatic as combustion. Nevertheless, it is a process that is essential to life—one that goes on continually in just about every cell of the body.

MATERIALS FOR LESSON 12

For you

- 1 copy of Student Sheet 12.2: Inhaled Versus Exhaled Air
- 1 copy of Student Sheet 12.3: Venn Diagram: Combustion and Cellular Respiration
- 1 pair of safety goggles

For your group

- 1 plastic box
- 1 test tube rack
- 1 tea candle
- 1 wooden block
- 1 aluminum foil square
- 1 Inhaled Versus Exhaled Air Apparatus
- 2 large test tubes
- 2 medium test tubes
- 2 pairs of scissors
- 2 plastic funnels
- 4 drinking straws
- 1 dispensing bottle of bromthymol blue solution
- 2 50-mL graduated cylinders
- 2 membranes
- 2 pieces of string
- 2 thermometers
- 1 250-mL beaker, unlabeled
- 1 250-mL beaker labeled "Carbonated Water"
- 1 250-mL beaker labeled "Tap Water"
- 2 red pencils
- 2 blue pencils
- Water (or access to a sink)

Getting Started

1. Have one person from your group pick up your materials. You will work as a group for the "Getting Started" activity.

2. Review the Safety Tips with your teacher.

SAFETY TIPS

Do not get near the candle flame. If you have long hair, tie it back.

Always wear safety goggles when you are working with bromthymol blue.

For sanitary reasons, do not share the straws.

If the bromthymol blue solution comes into contact with your eyes or skin, rinse it off immediately with water.

To prevent the liquid from spilling, inhale and exhale slowly and gently through the straw mouthpiece.

Notify your teacher immediately of any chemical spills.

3. Using the graduated cylinder, measure 15 mL of bromthymol blue solution. Pour the solution into the unlabeled 250-mL beaker. Put the wooden block in the beaker and place the candle on top of the block (see Figure 12.1). Set it in a place where everyone in your group can see it.

Figure 12.1 *How to set up the candle in the beaker*

4. After your teacher lights the candle, watch what happens as it burns. Answer the following questions in your science notebook:

A. What is the candle made of?

B. In addition to the bromthymol blue, the candle, and the block of wood, what other substance is present in the beaker?

C. What two ingredients, therefore, are involved in the burning of the candle?

D. What is released very quickly as the candle burns?

E. If you wanted to put out the candle, what gas would need to be removed from the candle's environment?

5. Now set a square piece of foil over the top of the beaker. Fold the edges of the foil down over the sides of the beaker.

A. What happened to the flame when you covered the beaker with foil? Why?

B. What gas do you think remains in the covered beaker when the flame has gone out?

C. What else do you see in the beaker?

6. Do not remove the foil. Swirl the solution gently around the bottom of the beaker for 1 minute, as shown in Figure 12.2.

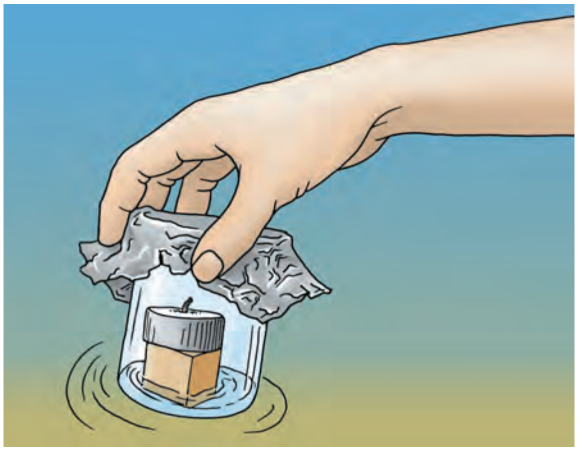


Figure 12.2 *Swirl the solution gently in a slow, circular motion.*

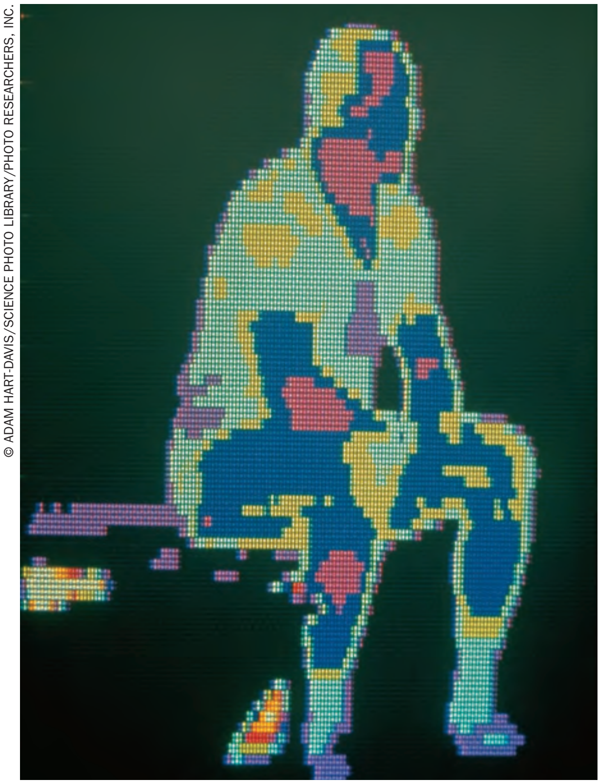
A. What happened to the bromthymol blue solution?

B. What substance do you think caused this change?

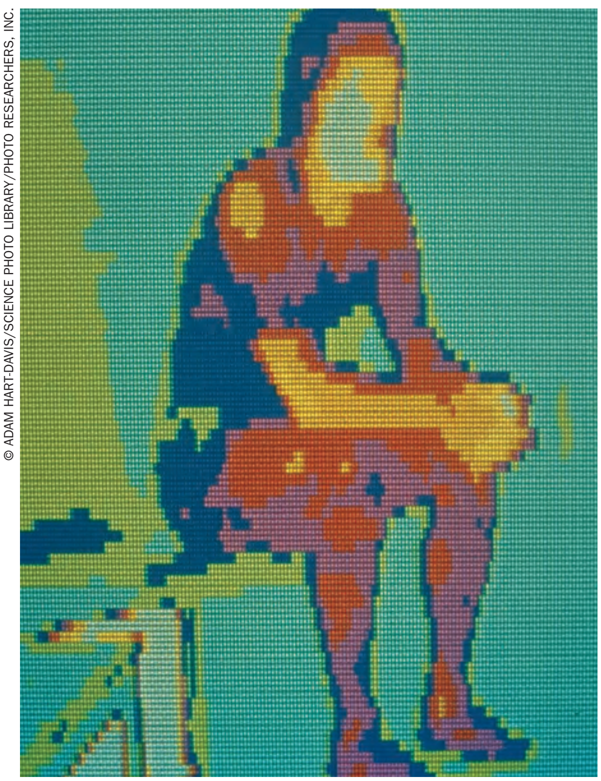
C. Bromthymol blue is a special chemical called an indicator. On the basis of what you discovered during this inquiry, how would you define an indicator? What other indicators have you used in previous lessons in this module?

7. Follow your teacher's instructions for cleanup.

8. Review this activity with your teacher. Agree on the two ingredients necessary for combustion of the candle and the products that were released during the process of combustion.



These heat images, or thermograms, show a man immediately before (above) and after playing a game of handball. What do you think the color changes indicate?



Inquiry 12.1
Investigating Cellular Respiration

PROCEDURE

1. Now it is time to apply what you observed during "Getting Started" to an important process that goes on in the human body. How is combustion similar to another form of oxidation—a process called cellular respiration—that occurs in your cells? How are the two processes different? Before you begin to explore these issues, answer the following questions in your science notebook:

   A. What did you see as the candle burned that would be absent in the type of oxidation that occurs in your body cells?

   B. What ingredient of combustion do you think is also an ingredient for cellular respiration?

   C. On the basis of what you discovered in the first section of this module, what do you think is the second essential ingredient for cellular respiration?

2. When a candle burns, you can easily observe the energy that is released in the form of heat and light. But what evidence can you find to show that your body releases energy during cellular respiration? Working with your partner, follow these steps to find out.

   A. Use a graduated cylinder to measure 5 mL of the tap water that your teacher has provided for you. Pour the water into a test tube. Place the thermometer into the water and allow it to sit for about 30 seconds. Read the temperature. Record this as the "Starting Temperature." Record it in your science notebook.

   B. Leave the thermometer in the water. Put a straw in the test tube, bend the straw slightly toward you, and blow steadily through it into the water for about 2 minutes. Read and record the temperature of the water.

3. Discuss the following questions with your partner. Then answer them in your science notebook.

   A. Did the temperature of the water change after you exhaled into it? If so, what was the change?

   B. What is temperature a measurement of?

   C. What would a change in the temperature of the water indicate about your exhaled air?

   D. How would you relate this change to a product of cellular respiration?

4. Follow your teacher's instructions for cleanup.

Inquiry 12.2
Using a Model to Show Evidence of a Waste Product of Cellular Respiration

PROCEDURE

1. In Inquiry 12.1, you observed evidence of a product of cellular respiration in your exhaled air. In this inquiry, you will use a model to identify a waste product of cellular respiration. Watch as your teacher displays a transparency showing the model.

2. Work with your group to explore how the model works and complete the inquiry by following these steps:

A. Fill each of the two test tubes with enough tap water (about 20 mL) so that when the stoppers are replaced on the tubes, the longer piece of plastic tubing in the stopper extends no more than 1 cm into the liquid. There should also be at least 2.5 cm of space between the bottom of the shorter plastic tubing and the surface of the liquid.

B. Place the tubes in the test tube rack.

C. If your apparatus does not have a mouthpiece in place on the rubber tube, create one by cutting a straw in half and inserting one of the pieces of the straw into the end of the rubber tube extending from the plastic Y-tube (see Figure 12.3).

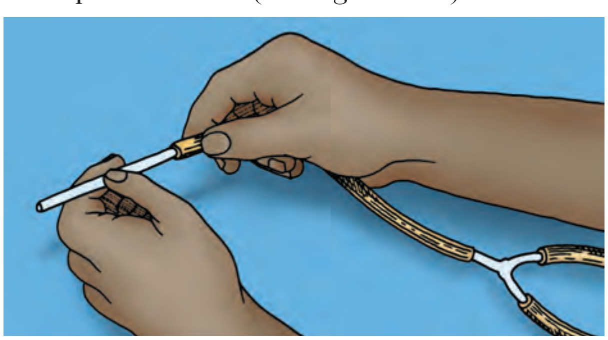


Figure 12.3 *How to insert the straw into the tube*

D. Have one student in your group breathe through the straw mouthpiece until everyone can observe the path of inhaled and exhaled air through the model. The student who is breathing through the apparatus should try to inhale and exhale at the same rate and with the same amount of force.

E. Color code the path that inhaled and exhaled air take through the apparatus on the illustration on Student Sheet 12.2. Use a red pencil for inhaled air and a blue pencil for exhaled air. Answer the following question in your science notebook:

On the basis of your observations, what is the main thing about the way the apparatus is assembled that seems to determine whether inhaled or exhaled air bubbled through the water in the test tube?

3. Remove the stoppers and empty the water into the sink.

4. Using the graduated cylinder, pour enough bromthymol blue solution (about 10 mL) into each of the large test tubes so that when the rubber stoppers are placed on the two tubes, the longer piece of plastic tubing extends no more than 1 cm into the liquid. There should be at least 2.5 cm of space between the bottom of the shorter plastic tubing and the surface of the liquid.

5. Replace the straw mouthpiece and have a different group member repeat the exercise until you see a definite color change in one of the test tubes.

6. Follow your teacher's directions for cleaning up and returning materials.

7. Discuss two of the products of cellular respiration found in exhaled air that you have discovered so far. Answer the following questions in your science notebook:

A. Did you see a color change in the bromthymol blue solution in either test tube after someone in your group had breathed into it?

B. In which test tube did the color change occur?

C. What substance caused this change?

D. During what process in your cells is this substance released?

Inquiry 12.3

Exploring the Movement of Carbon Dioxide Through a Membrane

PROCEDURE

1. In Inquiry 12.2, you found evidence of carbon dioxide in your exhaled air. You found no evidence of carbon dioxide in your inhaled air.

   How do you think the carbon dioxide was carried to your lungs?

2. Your blood transports oxygen to body cells, where it is exchanged for carbon dioxide. But how do both gases get past the membranes of your body cells? Work with your partner and follow these steps to find out.

A. Place a large test tube in the rack.

B. Pick up a wet membrane from the beaker. Tie one end of the membrane with string. (Refer to Step 3B of the Procedure in Lesson 6 if you need directions on how to do this correctly.)

C. Measure 13 mL of carbonated water in the graduated cylinder. Use a funnel to pour it from the cylinder into the membrane (see Step 3D of the Procedure in Lesson 6 for additional directions).

D. Rinse the outside of the membrane with water. Hold the membrane by the open end and lower it into a large test tube. Place the open end of the membrane down the side of the test tube. Place the test tube in the test tube rack.

Why do you need to rinse the outside of the membrane with water?

E. Measure 7 mL of bromthymol blue solution in a graduated cylinder. Pour it into the test tube containing the membrane. Let the test tube and membrane sit for about 30 seconds.

F. Observe the contents of the test tube. Use the following questions to guide your observations. Record your answers in your science notebook.

1. Did the color of the bromthymol blue solution change? If so, what caused the color change?

2. What does this color change tell you about the ability of carbon dioxide to pass through a membrane?

3. Through what process does carbon dioxide pass through membranes?

4. How do you think oxygen passes through membranes?

3. Return your materials to the designated area. Put the membranes back in the beaker of water. Make sure they are submerged.

4. Work with your group to complete the Venn diagram on Student Sheet 12.3.

REFLECTING ON WHAT YOU'VE DONE

1. With the class, discuss the responses you have written on Student Sheets 12.2 and 12.3.

2. On the basis of what you have learned in this lesson, answer the following questions in your science notebook.

A. What are the ingredients, or raw materials, for cellular respiration?

B. What are the products of cellular respiration?

C. Which product of cellular respiration enables humans to perform life activities?

D. Which of the products of cellular respiration are wastes? How are they transported to the lungs?

E. Inhaled air contains about 0.03 percent carbon dioxide and 20 percent oxygen. Exhaled air contains about 4 percent carbon dioxide and 16 percent oxygen. On the basis on what you've learned in this lesson, explain why this is so.

F. Summarize in one sentence the "recipe" for cellular respiration. Mention both the raw materials and the products.

G. Why do you think people need to eliminate the wastes of cellular respiration from the body?

3. Discuss your answers to these questions, as well as the other observations you have made during this lesson, with the class.

POLIO:
Machines and Medicine Control a Killer

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Dr. Jonas Salk administers his polio vaccine to an 8-year-old girl during the field trials of the new vaccine in 1954.

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Dr. Albert Sabin in his laboratory at the University of Cincinnati College of Medicine in Ohio

You're lucky. Before you started school, your doctor gave you a medicine (called a vaccine) to protect you from polio. Until the middle of the 20th century, the polio vaccine didn't exist, and each year thousands of people got sick. In 1950, more than 33,000 Americans got polio, which is also called infantile paralysis. Most of them were children. Some of them became crippled or died from the disease.

In 1953, Dr. Jonas Salk invented a vaccine that protects people from polio. The vaccine is made from the same virus that causes polio, but the virus in the vaccine has been killed. It won't make you sick. It tells your body's immune system what the polio virus "looks like." Then, if live polio virus should get into your body, special cells in your blood system would recognize it as dangerous and rush to destroy it.

The polio vaccine that Dr. Salk developed is injected with a needle. You probably took your polio vaccine by drinking it. This is called an oral vaccine. The oral polio vaccine was developed by Dr. Albert Sabin.

Many people with polio are not extremely sick. They just feel like they have the flu. But sometimes the polio virus travels to the nerves in the spinal cord, which relays messages to the muscles. The nerves cannot send signals to control the muscles. If the virus damages the nerves going to the legs, for example, the patient's legs become weak. People with this kind of polio need crutches or wheelchairs to get around.

Sometimes polio damages the nerves that control breathing. These patients need help getting air in and out of their lungs. In 1926, an

American engineer named Philip Drinker invented a machine to help polio victims breathe. The machine, called an iron lung, is a metal box big enough to hold a polio patient. The patient's head sticks out through a rubber collar that keeps air from getting in or out. At the other end is a flexible diaphragm that is moved back and forth by a motor. As the diaphragm is pulled outward, the pressure inside the iron lung decreases. A force is created that expands the patient's chest. This draws air through the patient's mouth and into the lungs. When the diaphragm is pushed inward, the pressure inside the iron lung increases, the chest is pushed in, and air is forced out of the patient's lungs.

The iron lungs proved that many people could survive polio if they got help breathing. Since the iron lung was invented, doctors and engineers have worked together to make iron lungs that are smaller and easier to use. Today, there are mechanical ventilators (machines that help people breathe) that are small enough to be carried around like a suitcase. These ventilators gently push air into a patient's lungs through small tubes.

Thanks to the pioneering work in vaccine development of two doctors—Salk and Sabin—polio has virtually disappeared in many countries, including the United States. And thanks to the work of scientists like Phillip Drinker and others, mechanical ventilators are saving the lives of many people who need breathing support—from tiny premature infants to older persons with lung disease. ☐

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These two young polio patients are able to see each other through the mirrors that have been mounted over their heads. In the middle part of the 20th century, thousands of children developed polio every year. This photograph was taken in Tennessee in 1952.

WHY SO MANY?

Peppi and Bollo are ready to continue their exploration of the human respiratory system.

"Did you say that there are *hundreds of millions* of alveoli?" asks Bollo.

"Right. Most humans have about 300 million of them. If you laid the lung tissue of an adult human out flat, it would cover the area of a tennis court."

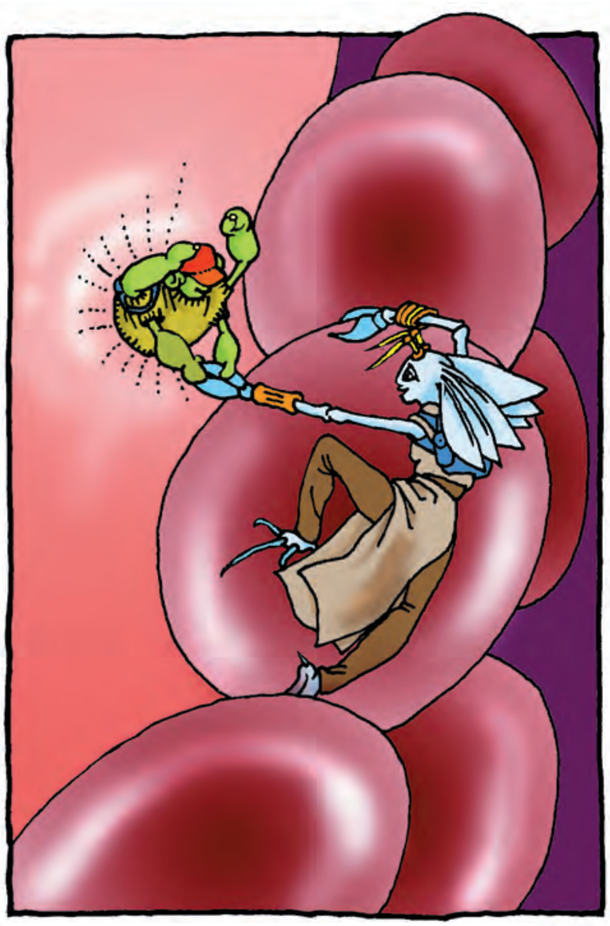
"Why are there so many?"

"Remember when we were inside the small intestine and saw the villi?" asks Peppi. "What did you find out about them?"

"We learned that the large surface area makes absorption work more efficiently," says Bollo. "Hey, I've got it—I bet the alveoli help make gas exchange easier."

"Right again! The alveoli make gas exchange more efficient because they provide so much space for it to happen. They help the body get oxygen fast. Let's hop aboard an oxygen molecule and see just how fast."

Peppi and Bollo are pulled farther and farther down the bronchial tree. Ahead, they see an alveolus. It's covered by tiny blood vessels. ("Capillaries," says Peppi.) From inside, the vessels look like a net. Some of the capillaries are dark red; others are bright red.



All aboard for a ride on a red blood cell!

Still traveling aboard an oxygen molecule, the spies approach the wall of the alveolus. Suddenly, they burst through the wall of the alveolus, and then through the wall of a blood vessel. (It doesn't take much effort, because the wall of each organ is one cell thick.) They find themselves attached to a strong new partner—a red blood cell.

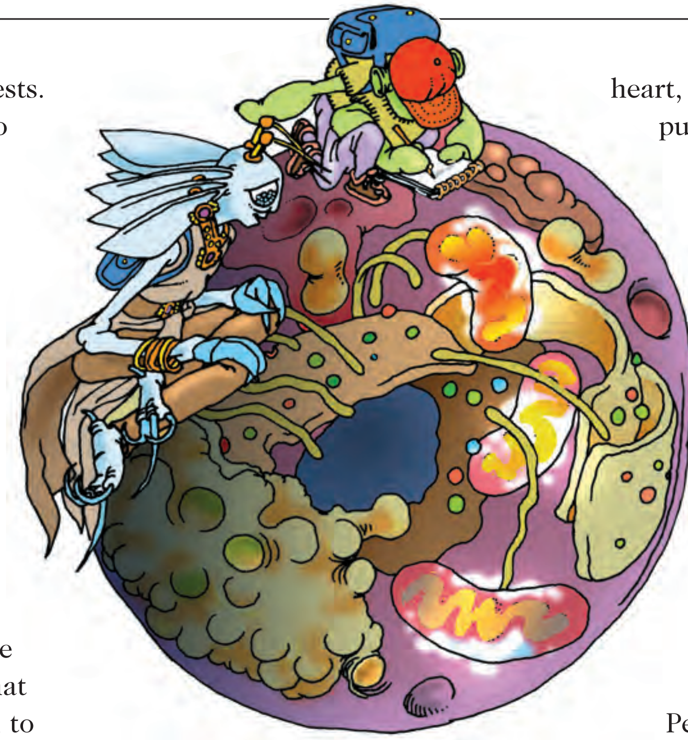
"We made it," says Peppi. "Welcome to the bloodstream. The oxygen is on its way to the cells. And because the cells can't live without oxygen, I'm sure we'll be welcome guests. But first, we've got to take a side trip through the heart. Our route is a pulmonary vein."

Peppi and Bollo are moved into the heart and are pumped out into a huge artery.

"Where are we going to end up?" asks Bollo.

"It doesn't matter," says Peppi. "The important thing is that all cells need oxygen to survive. When the oxygen arrives in body cells, tiny structures in the cells, called mitochondria, take over. It is in these tiny, sausage-shaped structures that the real work takes place. The oxygen combines with nutrients (usually glucose) from digested food in a form of oxidation called cellular respiration. There's no flame, of course, but this process releases the energy that humans need to live.

"Carbon dioxide and water are produced during cellular respiration, too," Peppi continues. "They're considered waste products. They pass into the blood. The carbon dioxide is carried back to the lungs and released during exhalation."



Peppi points out the mitochondria in a cell.

On the Way Home

Once they've made their stop at a body cell and unloaded the oxygen, Bollo notices that things have changed. That bright-red blood is now dark red.

"That color change is important. Bright-red blood has oxygen in it. Dark-red blood has less oxygen and more carbon dioxide," explains Peppi.

The spies, floating in the plasma with some of the carbon dioxide, move back toward the heart, then move through the pulmonary artery and toward the lungs.

Again, they move through two thin walls, but this time the process is reversed. They're moving back into the lungs from the bloodstream.

The diaphragm relaxes, the rib muscles let the chest cavity deflate, and whoosh! Up and out! Peppi and Bollo are back in civilization.

Thinking It Over

"Breathing is more complicated than I thought," says Bollo. "It's not just a matter of in and out."

"Breathing is a physical process, and it's something that we can see people do. Sometimes we can even hear it! But breathing also is a necessary step leading to a chemical process called cellular respiration. Cellular respiration is the process by which glucose is broken down in cells in the presence of oxygen to supply energy for life activities."

"Is glucose the only nutrient used for energy?" asks Bollo.

"Some cells depend almost entirely on glucose," replies Peppi. "Others seem to prefer fats as a source of energy. Sometimes, when there are not enough amino acids in a cell to build a complete protein, the protein, too, can be used for energy or converted to fat."

"So the human body really makes use of those nutrients!" says Bollo.

"It sure does! And, speaking of food, I'm hungry. And my backpack is empty. Do you have any leftovers?" ☐