

LESSON **12**

Recipe for Energy— Cellular Respiration

Inquiries 3
Periods 3

CONCEPTS

Oxidation occurs when a substance combines with oxygen.

Combustion is a form of oxidation that is accompanied by a rapid release of energy in the form of heat and light.

Cellular respiration is the process by which nutrients are oxidized to release energy.

Energy, carbon dioxide, and water are products of cellular respiration.

Carbon dioxide and a small quantity of heat are eliminated from the body during exhalation.

Exhaled air contains a higher percentage of carbon dioxide than inhaled air does.

Carbon dioxide can pass through a membrane.

STUDENT OBJECTIVES

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.

OVERVIEW

In the first part of this module, students explored how the digestive system breaks down nutrients into simpler substances that are absorbed into the bloodstream, which delivers them to body cells. In Lessons 10 and 11, they examined breathing, the process by which oxygen enters the lungs, and determined their lung capacity. A logical question is: What happens to the oxygen next? A sequence of short, related activities in this lesson helps answer these questions by introducing students to the processes of combustion and cellular respiration—two forms of oxidation. By the time students have completed Lessons 12 and 13, they will recognize that in the body cells, oxygen combines with nutrients—primarily glucose—to release energy for life activities, and that carbon dioxide and water are products of this chemical reaction.

BACKGROUND

Cellular respiration is the process by which nutrients are broken down in the presence of oxygen to release energy. About 60 percent of the chemical energy in foods is released as heat during cellular respiration; however, much of the energy is stored in a chemical called ATP, and some is stored in other chemicals. The body calls on this stored energy to meet its ongoing needs. Some of the heat is used to maintain body temperature. The rest is eliminated from the body through perspiration, radiation, conduction, urination, and exhalation. Water and carbon dioxide are also products of cellular respiration.

The details of cellular respiration are too complicated for most middle school students to understand; however, the fundamental concept—that glucose and oxygen combine and release energy, carbon dioxide, and water—should be

within their grasp. The activities students will perform in Lessons 12 and 13 are designed to enable them to identify the raw materials of cellular respiration, understand how it takes place, and realize why this process is so important to the human body.

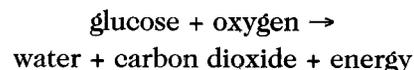
Cellular respiration takes place in a series of steps that are controlled by enzymes. The first step is **glycolysis**. During glycolysis, glucose, the body's major fuel, is broken down into pyruvic acid and energy. Glycolysis does not require oxygen. The pyruvic acid formed during glycolysis may undergo two different processes, depending on whether or not oxygen is present.

1. If oxygen is present in the cell, the pyruvic acid is broken down further, and additional ATP is formed. Carbon dioxide, water, and heat are released. This is called **aerobic respiration**. Aerobic respiration occurs in the cells on folded membranes inside the mitochondria. The **mitochondria** are structures in cells that are responsible for specific metabolic functions. Some cells, such as muscle cells, have large numbers of mitochondria because they need a great deal of energy.
2. **Anaerobic respiration** occurs when there is not enough oxygen available to complete the aerobic phase of cellular respiration. In this case, the pyruvic acid is converted to lactic acid in a process called **fermentation**. Later, when oxygen is available, the lactic acid can be converted to pyruvic acid. The aerobic phase of cellular respiration can then be completed.

Oxygen is the only gas that can be used for cellular respiration; however, the body may use many fuels for this process. The primary fuel is glucose, but the body can draw on fat reserves as an energy source if its supply of glucose is insufficient. Many cells rely on fat as their primary source of energy. Amino acids may also be oxidized by the cells. This may occur when the amino acids required to make a complete protein in a cell are missing. The remaining amino acids are oxidized as an energy source or converted to carbohydrates or fats.

The liver has a key role in managing the balance of nutrients in the body. If there is too much glucose in the blood, the liver converts some of it to a starchlike substance called **glycogen**, which is stored in body tissue. The liver can convert glucose to fat, which is stored in adipose tissue. The liver can also convert digested fats into a form the cells can oxidize to meet the body's energy needs.

In this lesson, students perform activities that help them understand a number of complex chemical processes that occur in the body. As you respond to their questions and facilitate discussion, try to make them see that their investigations will help them develop a "recipe," or equation, for an important form of oxidation called cellular respiration. They will discuss this recipe at the end of the lesson. It may be expressed as



Getting Started

During the “Getting Started” activity, students focus on combustion, which is one form of oxidation. They place a candle on a wooden block that is sitting in a beaker containing bromthymol blue solution. When you light the candle, students will witness rapid oxidation that is distinguished by a release of energy in the forms of light and heat. When they extinguish the candle, students will see smoke. As they swirl the bromthymol blue solution in the beaker, the color of the solution changes to greenish-yellow. This is an indication that carbon dioxide was released during oxidation and that it has dissolved in the solution. The dissolved carbon dioxide forms carbonic acid, and the newly acidic environment initiates the color change. Students are asked to state the ingredients of combustion (wax and oxygen) and the products that they observed (heat and light energy, carbon dioxide, charred wick).

Inquiry 12.1

In Inquiry 12.1, students turn their attention to a second form of oxidation—cellular respiration. They measure the temperature of a small quantity of room-temperature water in a test tube, exhale into the water for about 2 minutes, and measure the temperature again. They should find that the temperature of the water has risen by about 3 °C. This is an indication that energy, in the form of heat, is released during exhalation. (It is essential to stress at this point that the heat released during exhalation is a small portion of the heat released during cellular respiration.)

Inquiry 12.2

In the second inquiry, students analyze how inhaled and exhaled air flows through an apparatus. They then use the apparatus to look for evidence that carbon dioxide is present in exhaled air but not in inhaled air. (In reality, 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. The concentration of carbon dioxide in inhaled air is too low to change

the color of bromthymol blue in a short period of time.)

When students have completed Inquiries 12.1 and 12.2, they should be aware of two of the products of cellular respiration: heat (energy) and carbon dioxide.

Inquiry 12.3

During Inquiry 12.3, students determine whether carbon dioxide can pass through a membrane. They pour carbonated water into a membrane and place it in bromthymol blue solution. They find that the carbon dioxide in the carbonated water diffuses rapidly through the membrane into the bromthymol blue solution, as demonstrated by the fact that the solution quickly turns yellow. In the body, oxygen and carbon dioxide are exchanged as blood circulates through the lung tissue. It is important that gases be able to cross membranes easily between the alveoli, bloodstream, and body cells. Although the permeability of the membrane is not completely analogous to that of the body cells, it is sufficiently similar to ensure a valid demonstration.

Student Misconceptions

The burning candle is a good model to use to help students understand oxidation in an external environment. Help students realize that at the cellular level, the “burning” does not involve a flame, and that it is much slower and less dramatic than it was in the classroom inquiry. The flame is an indication that oxidation is occurring rapidly and that the energy is being released as light and heat. In the body, cellular respiration is controlled by enzymes and occurs slowly in a series of small steps.

Reading Selections

Two reading selections appear at the end of this lesson in the Student Guide. “Polio: Machines and Medicine Control a Killer” (SG page 106) concerns a respiratory disease that had devastating effects on children until the middle of the 20th century. The second selection, “Spies: Why So Many?” (SG page 108) provides background information about respiration.

MATERIALS FOR LESSON 12**For the teacher**

- 1 copy of Inquiry Master 12.2: Teacher’s Key for Student Sheet 12.2
- 1 copy of Inquiry Master 12.3: Teacher’s Key for Student Sheet 12.3
- Bromthymol blue solution
 - 1 dropper bottle of 0.04% bromthymol blue solution
 - 1 1-gallon container for mixing
 - 8 dispensing bottles (250 mL)
 - 8 labels
- 1 1-gallon container of water
- 1 2-L bottle of carbonated water
- 1 400-mL beaker of water
- 1 large trash bag
- 1 pair of scissors
- 1 butane lighter

For each student

- 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 each group of 4 students

- 1 tote tray
- 1 test tube rack
- 1 candle
- 1 wooden block
- 1 12-in square piece of aluminum foil
- 1 Inhaled Versus Exhaled Air Apparatus
- 2 25- × 150-mm test tubes
- 2 20- × 150-mm 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 dialysis membranes
- 2 10-cm 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-colored pencils
- 2 blue-colored pencils
- Water (or access to a sink)

Period 1**PREPARATION FOR PERIOD 1**

1. Assemble the materials students will need for “Getting Started” and Inquiries 12.1 and 12.2 and put them in the tote trays. Include everything except the dialysis membranes, funnels, twine, and carbonated water. You will need to pull the red and blue pencils from the sets of colored pencils provided in the materials kit.

SAFETY TIP

For sanitary reasons, keep the straws sealed until students are ready to use them.

2. Make a copy of Student Sheet 12.2: Inhaled Versus Exhaled Air and Student Sheet 12.3: Venn Diagram: Combustion and Cellular Respiration for each student. Make transparencies of both student sheets and Inquiry Masters 12.2 and 12.3.
3. Label eight 250-mL beakers “Tap Water.” Place a beaker in each tote tray.
4. Have a large trash bag available for disposal of the straws. If you do not have a sink in your classroom, have a container available for disposal of the bromthymol blue solution.
5. Ensure that there are equipment and materials refills (that is, straws, tap water, and bromthymol blue solution) available for each of your classes.
6. Familiarize yourself with the operation of the breathing apparatus.

NOTE This lesson will take three 45- or 50-minute periods to complete. If there are no interruptions, students should be able to complete “Getting Started” and Inquiry 12.1 during the first period. Keep aware of students’ progress so you can determine the most appropriate place to break. Students should complete the remaining inquiries during the second period. The “Reflections” section is particularly important and should take the majority of the third period.

Getting Started

1. Have a volunteer from each group pick up a tote tray. Inform students that they will work in groups for “Getting Started,” in pairs for Inquiry 12.1, and in groups for Inquiries 12.2 and 12.3.
2. Introduce the first activity. Tell students that their challenge will be to determine what happens when something burns, or **oxidizes**, very rapidly. They should pay particular attention to the ingredients that are used during this burning process, which is called **combustion**. They should also identify the products of combustion.
3. Review the Safety Tips.

SAFETY TIPS

Do not get near the candle flame. Any long hair should be tied back.

Always wear safety goggles when working with bromthymol blue.

For sanitary reasons, students should not share a straw with other students.

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

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

Have students notify you immediately of any chemical spills.

Wipe up any spills of bromthymol blue solution with paper towels; then dispose of them in the trash.

Flush the bromthymol blue solution waste down the drain with a generous amount of water.

4. Light the candles. Ask students to perform Steps 3 through 6 in the “Getting Started” section of the Student Guide.
5. When students have completed the activity, have them pour the bromthymol blue into a sink or other container, rinse off the equipment with fresh water, and place the materials in the tote tray.
6. When students have completed the activity, discuss these questions:

SG Step 4

- A. *What is the candle made of?* (Wax.)
- B. *In addition to the bromthymol blue, the candle, and the block of wood, what other substance is in the beaker?* (Oxygen.)
- C. *What two ingredients, therefore, are involved in the burning of the candle?* (Wax and oxygen.)
- D. *What is released very quickly as the candle burns?* (Light and heat.)
- E. *If you wanted to put out the candle, what gas would need to be removed from the environment?* (Oxygen.)

SG Step 5

- A. *What happened to the flame when you covered the beaker with foil? Why?* (When the burning candle was covered, the amount of oxygen in the beaker decreased and the amount of carbon dioxide increased. As a result, the flame went out.)
- B. *What gas do you think remains in the covered beaker when the flame has gone out?* (Carbon dioxide.)
- C. *What else do you see in the beaker?* (Smoke, carbon particles.)

SG Step 6

- A. *What happened to the bromthymol blue solution?* (Its color changed to greenish-yellow.)
- B. *What substance do you think caused this change?* (Try to elicit the answer

from students. The carbon dioxide produced by oxidation of the candle dissolved in the solution when students swirled it. This produced a weak acid, which changed the color of the bromthymol blue.)

- 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?* (Take a moment to discuss the purpose of indicators. Bromthymol blue is a pH indicator that changes from blue to green to yellow depending on the concentration of carbon dioxide dissolved in the solution. Indicators that students have used previously in this module include Benedict’s solution and Lugol solution.)

7. Have students summarize what they learned during “Getting Started” by agreeing on the two ingredients (wax and oxygen) and the products (heat and light energy and carbon dioxide) of combustion. It is important that they understand this concept before they move on to Inquiry 12.1. It may also be helpful to mention that the lighter could be compared with an enzyme. Like an enzyme, the lighter initiates combustion but does not take part in the subsequent burning.

NOTE Do not make direct comparisons between combustion and cellular respiration at this time.

Inquiry 12.1

Investigating Cellular Respiration

PROCEDURE

1. Inform students they will perform three inquiries that will help them discover the similarities and differences between combustion and cellular respiration—two forms of oxidation. They should answer the questions in their science notebooks as they conduct the inquiries. Assure them that any questions not discussed during the inquiries will be covered during the “Reflections.” Explain that they will probably finish Inquiry 12.1 during the first period. They will continue their work during the next period or periods.
2. Direct students’ attention to the Procedure for Inquiry 12.1. Work with the class to answer the questions in Step 1 of the Procedure. This discussion should help students make the connection between combustion, a rapid form of oxidation in which there is a flame, and cellular respiration, a form of oxidation that occurs slowly and does not produce a flame.

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

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

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?* (Nutrients. Students may mention glucose, which is generally the body’s first choice for fuel.)

3. Before students begin working on this inquiry, do the following:
 - A. Tell students to exhale *gently and slowly* through the straws and the straw mouthpieces so that the solutions do not bubble out of the test tube.
 - B. Circulate about the room with the room-temperature tap water. Pour about 60 mL of tap water into the labeled beaker for each group.
4. Have students conduct this inquiry as described in Steps 2A and 2B of the Procedure in the Student Guide.
5. When students have completed the inquiry, have them dispose of the straws, rinse out the test tube with tap water, place the materials in the tote trays, and return the tote trays to the materials distribution center.

Period 2

PREPARATION FOR PERIOD 2

1. Label eight 250-mL beakers “Carbonated Water.” Place a beaker in each tote tray.
2. Place the materials for Inquiries 12.2 and 12.3 in the tote trays.
3. Place the beaker with the water and membranes in a convenient location. Make sure the membranes are immersed.
4. If you do not have a sink in your classroom, have a container available for disposal of the bromthymol blue solution.

Inquiry 12.2

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

PROCEDURE

1. Demonstrate how to complete the assembly of the breathing apparatus using the straw and test tubes.
2. Caution students to be careful when they rest the test tubes in the rack; it could easily tip over. Suggest that one student hold the test tube rack steady while a second student breathes through the straw.
3. Remind students again to inhale and exhale very gently and slowly through the straw mouthpiece when using the breathing apparatus. Also emphasize that they should try to inhale and exhale with the same amount of force.
4. Display the transparency of Student Sheet 12.2. Emphasize that students need to draw enough arrows to show clearly the path taken by both inhaled and exhaled air.
5. Have students conduct the inquiry.

Inquiry 12.3

Exploring the Movement of Carbon Dioxide Through a Membrane

PROCEDURE

1. Point out the location of the container with the membranes and water. Each group will need two membranes.
2. Refer students to the figures in Lesson 6 of their Student Guides if they need guidance on how to tie, open, and fill the membrane.

NOTE Only your first class will have to tie the membranes.

3. Explain cleanup procedures. Tell students that when they have completed the inquiry, they should work with their group to complete Student Sheet 12.3: Venn Diagram: Combustion and Cellular Respiration.
4. Have students pick up their supplies.
5. As students begin their work, circulate about the room and pour about 30 mL of carbonated water into a beaker for each group.
6. As you walk about the room, ensure that all students are completing their student sheets as they conduct their inquiries.
7. When students have completed both inquiries, have them throw away the straws, rinse out the test tubes, place the materials in their tote trays, and return the tote trays to the designated area. Have them rinse out the membranes and return them to the container of water. The membranes should remain tied at one end. The membranes must remain submerged so that they do not dry out.

REFLECTIONS

1. Use the transparencies of Inquiry Masters 12.2 and 12.3 to review students' responses on Student Sheets 12.2 and 12.3.
2. Have students discuss the results of the three inquiries. As the discussion proceeds, have them describe the raw materials and the products of cellular respiration. Focus particularly on heat (energy), carbon dioxide, and water. Key points are as follows:
 - Students should have found that the temperature of the water rose after they exhaled into it. This increase is a small indication of the energy that is released from the body in the form of heat—which is one product of cellular respiration. The body loses most of its excess heat through the skin, by means of radiation and conduction, as well as evaporation of sweat (perspiration).
 - The body stores much of the energy released during cellular respiration in a chemical called ATP. This stored energy is essential for life activities.
 - When the carbon dioxide in students' exhaled air dissolved in the bromthymol blue solution, it formed an acid. That acid caused the solution to turn greenish-yellow. Carbon dioxide is a second product of respiration. Inhaled air contains approximately 0.03 percent carbon dioxide (not enough to cause the bromthymol blue to change color). Exhaled air contains approximately 4 percent carbon dioxide. The bloodstream carries carbon dioxide from the cells to the lungs.
 - Students should be aware that oxygen and carbon dioxide pass back and forth easily through the membranes separating the alveoli, the bloodstream, and body cells. This was modeled when carbon dioxide from the carbonated water passed through the membrane and changed the color of the bromthymol blue solution.
- Water is a third product of cellular respiration. Students might think that the water vapor they exhale is evidence of this. In reality, most of the water vapor in exhaled air comes from the warm, moist membranes of the respiratory tract.
- Students should recognize that the path of air in the breathing apparatus depends on the tube to which the hose is connected. When they blew into the straw, exhaled air passed through the hose connected to the longer tube, which reached below the surface of the water.
3. Ask students why they think we need to eliminate waste products of respiration. Stress the following points:
 - Carbon dioxide is poisonous in large quantities because it makes the body fluids more acidic.
 - Eliminating excess water and heat helps the body maintain a constant temperature. Excess water and heat are removed from the body through the skin by radiation and conduction, as well as through the evaporation of perspiration. Excess water and heat are also eliminated during exhalation and urination. A constant temperature and fluid balance are essential to good health.
4. As students share their ideas for the recipe for cellular respiration, try to ensure they recognize that nutrients and oxygen come together and release energy, water, and carbon dioxide.

HOMEWORK**Period 1**

Have students read “Polio: Machines and Medicine Control a Killer” in Lesson 12 (SG page 106).

Period 2

Ask students to read “Spies: Why So Many?” at the end of the Lesson 12 (SG page 108).

Period 3

Ask students to read the Introduction to Lesson 13 in the Student Guide.

EXTENSIONS**■ Consumer Science**

1. When someone cuts or bites into an apple, the inside of the apple quickly begins to turn brown. The browning is a form of oxidation. Ask students to purchase several different varieties of apples and determine how the browning (oxidation) times vary.

■ Consumer Science

2. Have students perform research to find other types of foods and fruits that are subject to oxidation. Ask them to find out things that scientists are doing to slow the rate of oxidation.

■ Health

3. Ask students to explore and write a paragraph about what happens when a person hyperventilates.

■ Science

4. Challenge students to use the Internet to research the “bends,” a condition sometimes suffered by deep-sea divers. Ask students to write a paragraph explaining this phenomenon.

■ Applied Science

5. Tell students that restaurant owners and movie theater managers often cool their facilities to 16 °C before their patrons arrive, even though most people are most comfortable indoors when the temperature is around 22 °C. Ask why these managers and owners do not set the temperature higher.

ASSESSMENT

Assessment for this inquiry should be based on the following:

1. The student’s participation in the inquiry and adherence to directions:
 - A. Did the student use the equipment in an appropriate manner?
 - B. Did the student do his or her share of the work?
2. The student’s ability to determine the substances released from the body during exhalation:
 - A. Did the student deduce that carbon dioxide was in exhaled air?
 - B. Did the student surmise that heat was released in exhaled air?
3. The student’s understanding of the breathing apparatus:
 - A. Did the student accurately color code the paths of inhaled and exhaled air?
 - B. Did the student draw enough arrows to show clearly the path of inhaled and exhaled air through the apparatus?
 - C. Did the student demonstrate understanding of the mechanics of the model?
4. The student’s ability to determine whether inhaled or exhaled air contains a greater percentage of carbon dioxide.
5. The student’s ability to write a basic equation for cellular respiration.
6. Evidence that the student’s responses to the written questions in this lesson are consistent with your knowledge of his or her ability level.

PREPARATION FOR LESSON 13

1. Students will explore the energy content of foods in Lesson 13 by burning a marshmallow and a walnut. If your room is not well ventilated, you may want to obtain a fan to help circulate the air.
2. Clean a 1-gallon plastic container and fill it with tap water.

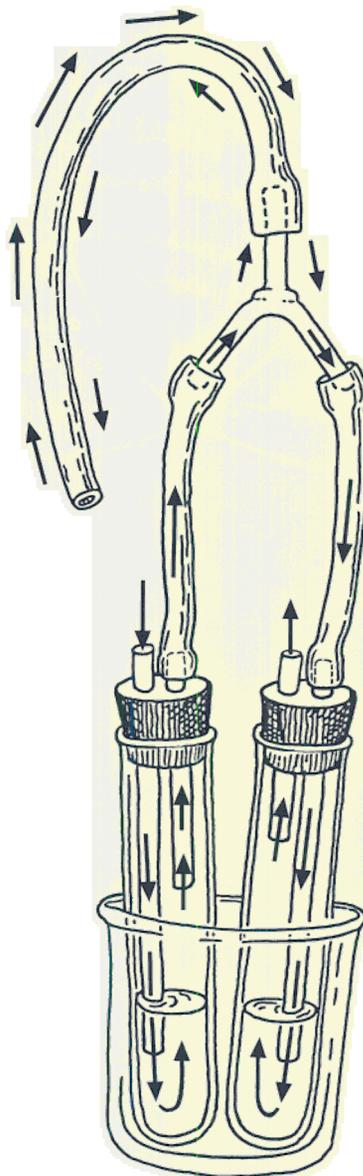
PREPARATION FOR LESSON 15

For Lesson 15, you will need 16 clean, 1-gallon plastic containers with screw-on tops. Consider having student and staff volunteers help you obtain them. Fill the containers with water and replace the tops. You may want to consider tying thick string around the neck of each bottle and creating a loop that will make it easier for students to carry.

Inquiry Master 12.2

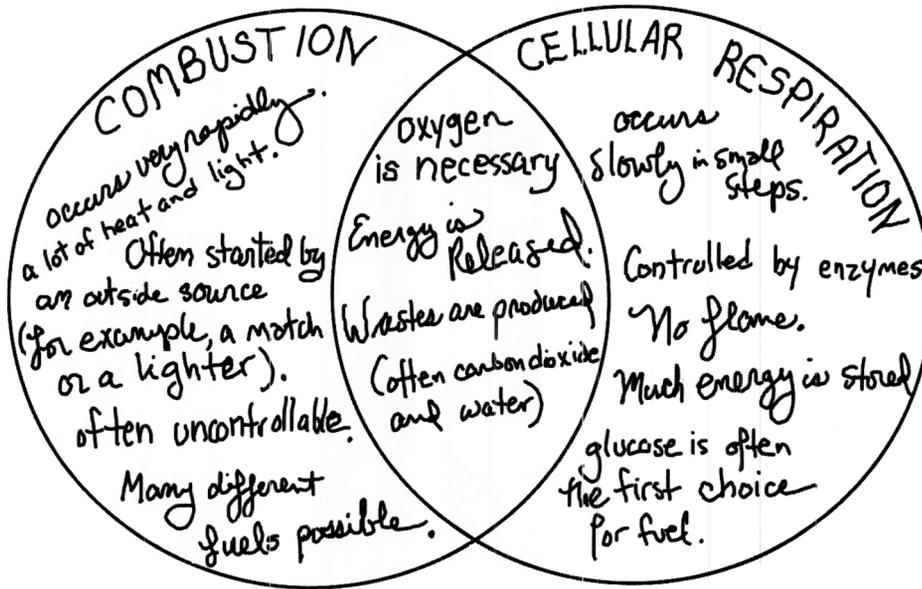
Teacher's Key for Student Sheet 12.2

Directions On the illustration below, use a red pencil to mark the path of inhaled air through the apparatus. Then use a blue pencil to mark the path of exhaled air. Use arrows to indicate the direction of your inhaled and exhaled air through the apparatus. Make sure you use enough arrows to show the entire route that air takes during inhalation and exhalation.



Inquiry Master 12.3

Teacher's Key for Student Sheet 12.3



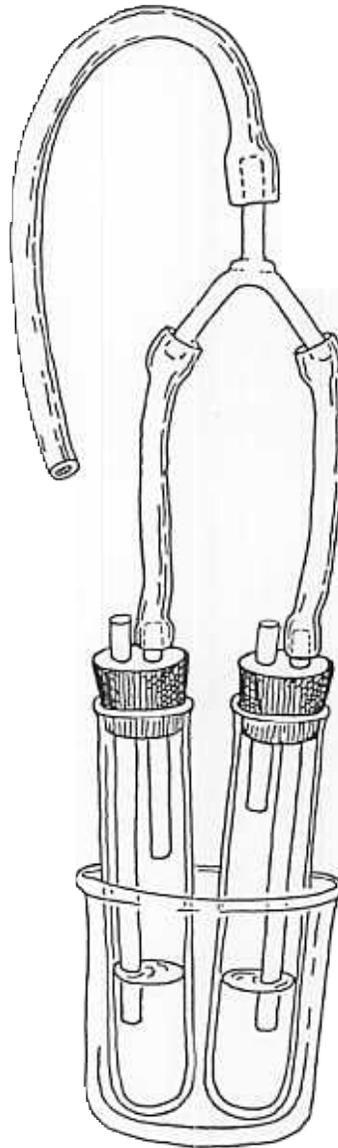
Name: _____

Class: _____ Date: _____

Student Sheet 12.2

Inhaled Versus Exhaled Air

Directions On the illustration below, use a red pencil to mark the path of inhaled air through the apparatus. Then use a blue pencil to mark the path of exhaled air. Use arrows to indicate the direction of inhaled and exhaled air through the apparatus. Make sure you use enough arrows to show the entire route that air takes during inhalation and exhalation.



Name: _____

Class: _____ Date: _____

Student Sheet 12.3

Venn Diagram: Combustion and Cellular Respiration

Directions On the basis of what you know about combustion and cellular respiration, complete the diagram.

