

## Section 9-2

### 1 FOCUS

#### Objectives

- 9.2.1 Describe** what happens during the Krebs cycle.
- 9.2.2 Explain** how high-energy electrons are used by the electron transport chain.
- 9.2.3 Identify** three pathways the body uses to release energy during exercise.
- 9.2.4 Compare** photosynthesis and cellular respiration.

#### Guide for Reading

#### Vocabulary Preview

Explain that a prefix is a letter or group of letters placed at the beginning of a word to change its meaning. Remind students that *anaerobic* means “not in air.” Explain that the prefix *an* means “not.” Then, have a volunteer explain what the Vocabulary word *aerobic* means. (“in air”)

#### Reading Strategy

Before students read the section, have them examine Figures 9-6 and 9-7 and make a list of questions about what they see. Then, as they study the text, they can write answers to their questions.

### 2 INSTRUCT

## The Krebs Cycle

#### Demonstration

To demonstrate production of carbon dioxide in the Krebs cycle, set up a beaker containing bromthymol blue solution. As students watch, blow slowly through a straw into the solution. Wait until it changes color, and then explain that bromthymol blue changes to yellow in the presence of carbon dioxide. Ask: **Where did the carbon dioxide in my breath come from?** (It comes from reactions in the Krebs cycle, when one carbon atom from pyruvic acid becomes part of a molecule of carbon dioxide.) **L2**

# 9-2 The Krebs Cycle and Electron Transport

#### Guide for Reading



#### Key Concepts

- What happens during the Krebs cycle?
- How are high-energy electrons used by the electron transport chain?

#### Vocabulary

aerobic  
Krebs cycle  
electron transport chain

#### Reading Strategy: Using Visuals

Before you read, review **Figure 9-2** on page 222. Then, preview **Figures 9-6** and **9-7**. As you read, notice where the Krebs cycle and electron transport take place.



**▲ Figure 9-5** Hans Krebs won the Nobel Prize in 1953 for his discovery of the citric acid cycle, or Krebs cycle.

At the end of glycolysis, about 90 percent of the chemical energy that was available in glucose is still unused, locked in the high-energy electrons of pyruvic acid. To extract the rest of that energy, the cell turns to one of the world’s most powerful electron acceptors—oxygen. Oxygen is required for the final steps of cellular respiration. Because the pathways of cellular respiration require oxygen, they are said to be **aerobic**.

As you know, the word *respiration* is often used as a synonym for breathing. This is why we have used the term *cellular respiration* to refer to energy-releasing pathways within the cell. The double meaning of respiration points out a crucial connection between cells and organisms: The energy-releasing pathways within cells require oxygen, and that is the reason we need to breathe, to respire.

## The Krebs Cycle

In the presence of oxygen, pyruvic acid produced in glycolysis passes to the second stage of cellular respiration, the **Krebs cycle**. The Krebs cycle is named after Hans Krebs, the British biochemist who demonstrated its existence in 1937. **During the Krebs cycle, pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.** Because citric acid is the first compound formed in this series of reactions, the Krebs cycle is also known as the citric acid cycle.

**A** The Krebs cycle begins when pyruvic acid produced by glycolysis enters the mitochondrion. One carbon atom from pyruvic acid becomes part of a molecule of carbon dioxide, which is eventually released into the air. The other two carbon atoms from pyruvic acid are joined to a compound called coenzyme A to form acetyl-CoA. (The acetyl part of acetyl-CoA is made up of 2 carbon atoms, 1 oxygen atom, and 3 hydrogen atoms.) Acetyl-CoA then adds the 2-carbon acetyl group to a 4-carbon molecule, producing a 6-carbon molecule called citric acid.

**B** As the cycle continues, citric acid is broken down into a 4-carbon molecule, more carbon dioxide is released, and electrons are transferred to energy carriers. Follow the reactions in **Figure 9-6**, and you will see how this happens. First, look at the 6 carbon atoms in citric acid. One is removed, and then another, releasing 2 molecules of carbon dioxide and leaving a 4-carbon molecule. This 4-carbon molecule is then ready to accept another 2-carbon acetyl group, which starts the cycle all over again.

Next, look for ATP. For each turn of the cycle, a molecule similar to ADP is converted to a molecule that is similar to ATP. Finally, look at the electron carriers,  $\text{NAD}^+$  and FAD.



#### SECTION RESOURCES

##### Print:

- **Teaching Resources**, Lesson Plan 9-2, Adapted Section Summary 9-2, Adapted Worksheets 9-2, Section Summary 9-2, Worksheets 9-2, Section Review 9-2
- **Reading and Study Workbook A**, Section 9-2
- **Adapted Reading and Study Workbook B**, Section 9-2
- **Laboratory Manual A**, Chapter 9 Lab
- **Laboratory Manual B**, Chapter 9 Lab

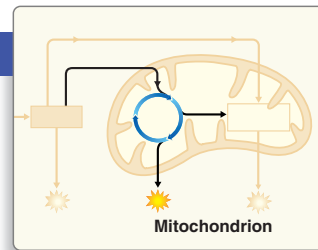
- **Probeware Lab Manual**, How does exercise affect disposal of wastes from cellular respiration?

##### Technology:

- **iText**, Section 9-2
- **Animated Biological Concepts DVD**, 12 Aerobic Respiration, 14 Krebs Cycle, 15 Electron Transport Chain
- **Transparencies Plus**, Section 9-2
- **Lab Simulations CD-ROM**, Cell Respiration
- **Virtual Labs**, Cell Respiration

## FIGURE 9–6 THE KREBS CYCLE

During the Krebs cycle, pyruvic acid from glycolysis is used to make carbon dioxide, NADH, ATP, and FADH<sub>2</sub>.

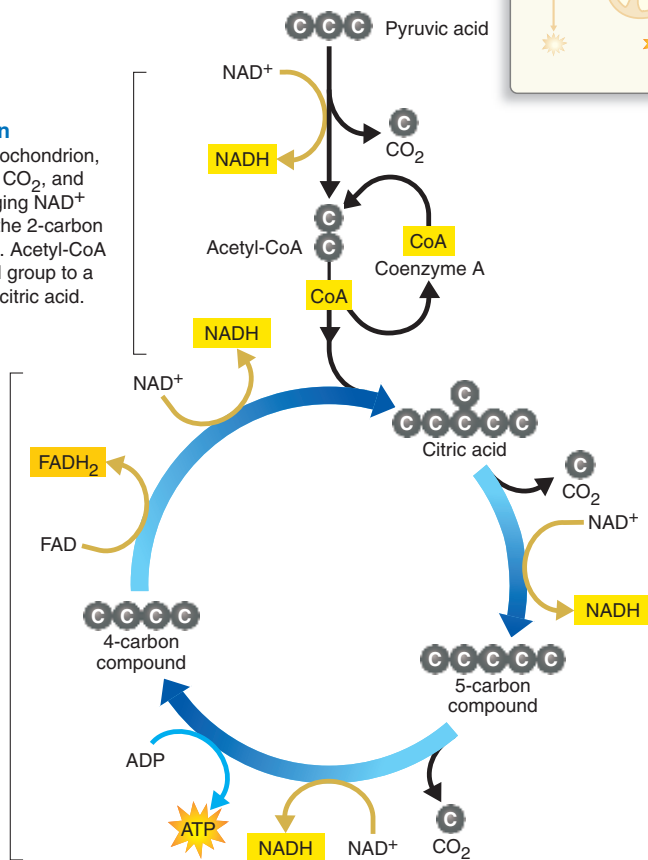


### A Citric Acid Production

As pyruvic acid enters the mitochondrion, a carbon is removed, forming CO<sub>2</sub>, and electrons are removed, changing NAD<sup>+</sup> to NADH. Coenzyme A joins the 2-carbon molecule, forming acetyl-CoA. Acetyl-CoA then adds the 2-carbon acetyl group to a 4-carbon compound, forming citric acid.

### B Energy Extraction

Citric acid is broken down into a 5-carbon compound, then into a 4-carbon compound. Along the way, two more molecules of CO<sub>2</sub> are released, and electrons join NAD<sup>+</sup> and FAD, forming NADH and FADH<sub>2</sub>. In addition, one molecule of ATP is generated. The energy tally from one molecule of pyruvic acid is 4 NADH, 1 FADH<sub>2</sub>, and 1 molecule of ATP.



## Use Visuals

**Figure 9–6** Have students study the cycle of reactions, and then, ask: **Where does this cycle take place in the cell?** (*The Krebs cycle takes place in the mitochondrial matrix.*) Point out that the pyruvic acid produced in glycolysis moves from the cytoplasm through two membranes, the outer and inner membranes of a mitochondrion. Ask a volunteer to indicate the three places in the cycle where carbon dioxide is produced. Ask: **How many ATP molecules are generated for every one turn of the Krebs cycle?** (*One*) You may want to explain that the molecule GTP—guanosine triphosphate—is actually produced first. But the cell quickly uses GTP to produce ATP from ADP, and thus ATP is often considered a product of the Krebs cycle. Ask: **Where is most of the chemical energy in pyruvic acid transferred to as a result of the cycle?** (*Most of the energy is transferred to the electron carriers, NAD<sup>+</sup> and FAD<sup>+</sup>, producing 4 NADHs and 1 FADH<sub>2</sub>.*)

L2

## Make Connections

**Environmental Science** Emphasize that the carbon dioxide produced in the Krebs cycle moves out of organisms as waste through exhalation and other processes. This gas becomes part of the atmosphere and becomes available for intake by plants for use in photosynthesis. Encourage students who need challenges to prepare a presentation to the class about the carbon cycle, which is the cycle of carbon through Earth's environment. L2

At five places in the cycle, a pair of high-energy electrons is accepted by electron carriers, changing NAD<sup>+</sup> to NADH and FAD to FADH<sub>2</sub>. FAD (flavine adenine dinucleotide) and FADH<sub>2</sub> are molecules similar to NAD<sup>+</sup> and NADH, respectively.

What happens to each of these Krebs cycle products? First, the carbon dioxide released is the source of all the carbon dioxide in your breath. Every time you exhale, you expel the carbon dioxide produced by the Krebs cycle. Next, the ATP produced directly in the Krebs cycle can be used for cellular activities. However, what does the cell do with all those high-energy electrons in carriers like NADH? In the presence of oxygen, those high-energy electrons can be used to generate huge amounts of ATP.

**CHECKPOINT** Why is the Krebs cycle also known as the citric acid cycle?



## UNIVERSAL ACCESS

### Inclusion/Special Needs

To help students understand electron transport, review the names and abbreviations of the electron carriers by writing them on the board and pronouncing their names: nicotinamide adenine dinucleotide (NAD<sup>+</sup>) and flavine adenine dinucleotide (FAD). Emphasize that these ions accept high-energy electrons to form NADH and FADH<sub>2</sub>. Make sure students recognize by the abbreviations when the carriers are carrying high-energy electrons. L1

### Advanced Learners

On page 229, students learn about the charge difference that builds up on either side of the inner membrane. This is called a transmembrane electrochemical potential. Ask students who need a challenge to make a presentation to the class about how this electrochemical potential is similar to the potential difference between two terminals in an electric circuit. L3

## Answer to . . .

**CHECKPOINT** The Krebs cycle is also known as the citric acid cycle because citric acid is the first compound formed in this series of reactions.

## Electron Transport

### Use Visuals

**Figure 9-7** After students have studied the figure, ask: **Where does the third stage of respiration take place?** (Within the inner mitochondrial membrane) **Where is the intermembrane space?** (Between the outer membrane and the inner membrane) Emphasize that the NADH and FADH<sub>2</sub> molecules are a product of the Krebs cycle. Then, ask: **What happens that causes NADH to change to NAD<sup>+</sup> and FADH<sub>2</sub> to change to FAD?** (The electron carriers give up their high-energy electrons to the carrier proteins on the electron transport chain.) **What happens to those electrons?** (They are passed from one carrier protein to the next.) **Where does the energy come from that moves hydrogen ions into the intermembrane space?** (The energy comes from the electrons moving down the electron transport chain.) **How is the difference in charge on either side of the membrane used to produce ATP molecules?** (The charge differences cause H<sup>+</sup> ions to pass through ATP synthase in the membrane, and the energy released during the passing converts ADP molecules into ATP molecules.) **L2**

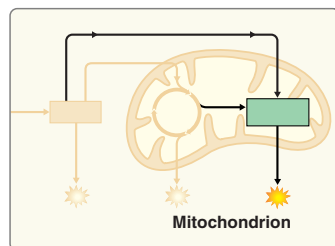
### Go Online

Download a worksheet on the Krebs cycle for students to complete, and find additional teacher support from NSTA SciLinks.

### Make Connections

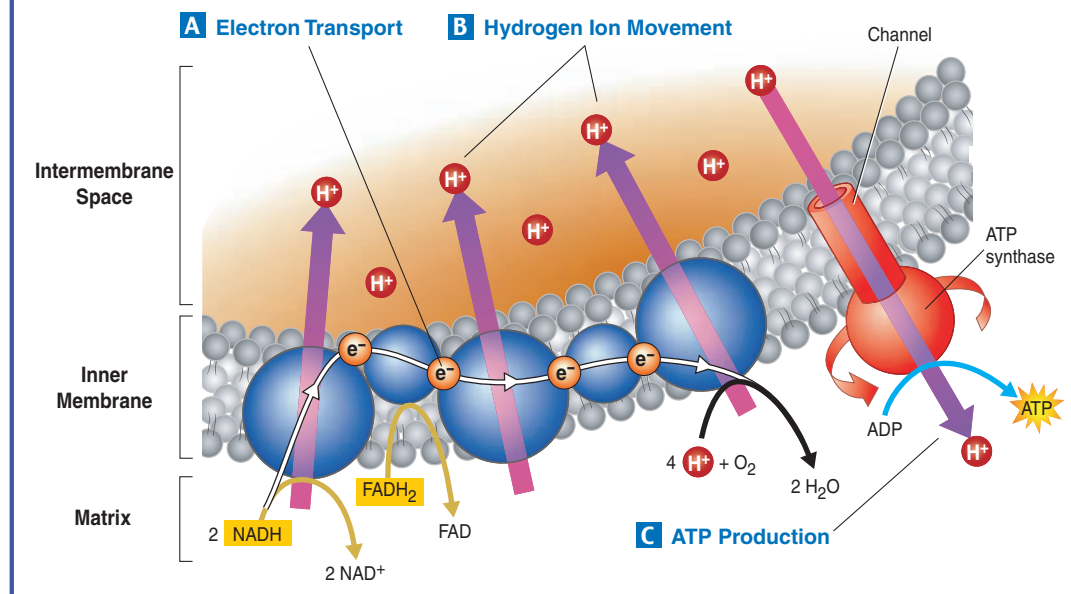
**Chemistry** Remind students that a positive ion has fewer electrons than protons. Since a hydrogen atom contains only one electron and one proton, a positive hydrogen ion is simply one proton. Positive ions are attracted to negative ions, or ions with more electrons than protons. That attraction is the basis of ionic bonds.

**L1 L2**



**FIGURE 9-7** ELECTRON TRANSPORT CHAIN

The electron transport chain uses high-energy electrons from the Krebs cycle to convert ADP into ATP.



**Go Online**  
NSTA SciLinks  
For: Links on the Krebs cycle  
Visit: [www.SciLinks.org](http://www.SciLinks.org)  
Web Code: cbn-3092

## Electron Transport

The Krebs cycle generates high-energy electrons that are passed to NADH and FADH<sub>2</sub>. The electrons are then passed from those carriers to the **electron transport chain**. **The electron transport chain uses the high-energy electrons from the Krebs cycle to convert ADP into ATP.** Look at **Figure 9-7** to see how this happens.

**A** High-energy electrons from NADH and FADH<sub>2</sub> are passed along the electron transport chain. In eukaryotes, the electron transport chain is composed of a series of carrier proteins located in the inner membrane of the mitochondrion. In prokaryotes, the same chain is in the cell membrane. High-energy electrons are passed from one carrier protein to the next. At the end of the electron transport chain is an enzyme that combines these electrons with hydrogen ions and oxygen to form water. Oxygen serves as the final electron acceptor of the electron transport chain. Thus, oxygen is essential for getting rid of low-energy electrons and hydrogen ions, the wastes of cellular respiration.



### HISTORY OF SCIENCE

#### Hans Krebs discovers a cycle

Hans Krebs (1900–1981) grew up in Germany the son of a Jewish physician. In 1933, he was forced to leave Germany because of the Nazi persecution of the Jewish people. Krebs spent the rest of his life in Great Britain, where he taught and did research at universities. In 1937, he worked out the details of a cycle of chemical reactions in the breakdown of sugar in living organisms, a cycle in

which citric acid is formed. He did most of his research about this cycle on pigeon tissues. His work was initially met with disbelief—the prestigious journal *Nature* rejected his paper on the findings. His discovery of what came to be called the Krebs cycle is of great importance in understanding cell metabolism. For his work, Krebs shared the 1953 Nobel Prize in Medicine and Physiology.

**B** Every time 2 high-energy electrons transport down the electron transport chain, their energy is used to transport hydrogen ions ( $H^+$ ) across the membrane. During electron transport,  $H^+$  ions build up in the intermembrane space, making it positively charged. The other side of the membrane, from which those  $H^+$  ions have been taken, is now negatively charged.

**C** How does the cell use the charge differences that build up as a result of electron transport? The inner membranes of the mitochondria contain protein spheres called ATP synthases. As  $H^+$  ions escape through channels into these proteins, the ATP synthases spin. Each time it rotates, the enzyme grabs a low-energy ADP and attaches a phosphate, forming high-energy ATP.

The beauty of this system is the way in which it couples the movement of high-energy electrons with the production of ATP. Every time a pair of high-energy electrons moves down the electron transport chain, the energy is used to move  $H^+$  ions across the membrane. These ions then rush back across the membrane, producing enough force to spin the ATP synthase and generate enormous amounts of ATP. On average, each pair of high-energy electrons that moves down the electron transport chain provides enough energy to produce three molecules of ATP from ADP.

**CHECKPOINT** What is the role of ATP synthase in cellular respiration?

## The Totals

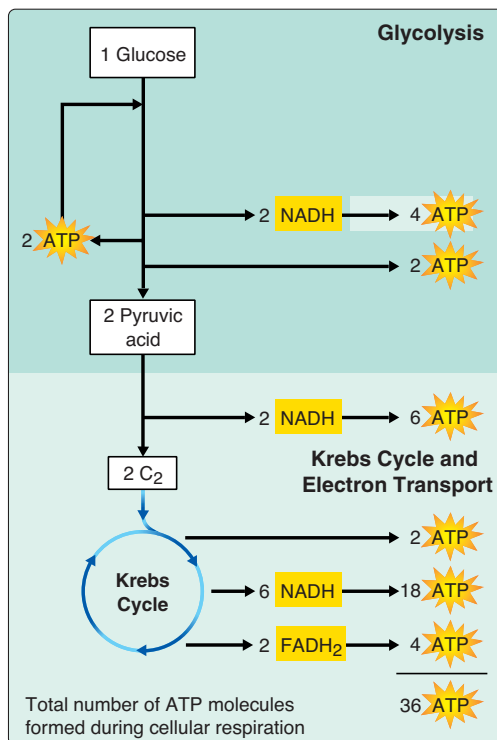
Although glycolysis produces just 2 ATP molecules per molecule of glucose, in the presence of oxygen, everything changes. As **Figure 9–8** shows, the Krebs cycle and electron transport enable the cell to produce roughly 36 ATP molecules per glucose molecule, 18 times as much as can be generated in the absence of oxygen.

Our diets contain much more than just glucose, of course, but that's no problem for the cell. Complex carbohydrates are broken down to simple sugars like glucose. Lipids and proteins can be broken down into molecules that enter the Krebs cycle or glycolysis at one of several places. Like a furnace that can burn oil, gas, or wood, the cell can generate chemical energy in the form of ATP from just about any source.

How efficient is cellular respiration? The 36 ATP molecules represent about 38 percent of the total energy of glucose. That might not seem like much, but it means that the cell is actually more efficient at using food than the engine of a typical automobile is at burning gasoline. What happens to the remaining 62 percent? It is released as heat, which is one of the reasons your body feels warmer after vigorous exercise.

**Figure 9–8** The complete breakdown of glucose through cellular respiration, including glycolysis, results in the production of 36 molecules of ATP.

**Interpreting Graphics** How many molecules of ATP are produced during glycolysis?



## The Totals

### Use Visuals

**Figure 9–8** Students may ask why 4 ATPs in glycolysis are shown in a pale green box. The reason is that the 2 NADH molecules are transported to the electron transport chain, where they are used to make ATP. So, those 4 ATPs are counted under the total for the Krebs cycle and electron transport, not glycolysis. Students may also ask why each NADH from glycolysis produces only 2 ATPs, while each NADH from the Krebs cycle and electron transport produce 3 ATPs. The reason is that energy must be used to import the NADHs from glycolysis from the cytoplasm into the mitochondrion. **L2 L3**

### Build Science Skills

**Calculating** Explain to students that 1 mole of glucose (about 180 g) contains about 686 kilocalories of energy. A mole is the SI unit of the amount of a substance. Remind students that 1 kilocalorie = 1000 calories. Then, ask: **How much energy does respiration yield from 1 mole of glucose?** ( $686 \text{ kilocalories} \times 0.38 = 261 \text{ kilocalories}$ ) **How much energy is lost to heat?** ( $686 \text{ kilocalories} \times 0.62 = 425 \text{ kilocalories}$ ; or  $686 \text{ kilocalories} - 261 \text{ kilocalories} = 425 \text{ kilocalories}$ ) **L2 L3**



## FACTS AND FIGURES

### Releasing energy in a series of steps

The final product of the electron transport chain is water, or  $H_2O$ . If hydrogen and oxygen gas were allowed to combine directly, there would be a great release of wasted energy. Instead, the cell uses a chain of carrier molecules, mostly proteins, embedded in the inner mitochondrial membrane to release the energy of electrons in a series of steps. At each step, the electrons lose a little bit of their energy. The flow of electrons along the

chain begins, for example, when an NADH molecule passes two electrons and two protons to the first carrier protein. The two protons pass into the intermembrane space, making it positively charged. As the process continues, the electrons lose their energy and protons are pumped from the matrix out through the membrane. ATP is made when the  $H^+$  ions are “pushed” back through the membrane, a process called chemiosmosis.

### Answers to . . .

**CHECKPOINT** ATP synthase uses energy from  $H^+$  ions to convert ADP into ATP.

**Figure 9–8** Glycolysis produces 2 ATP molecules per glucose molecule.

## 9-2 (continued)

# Energy and Exercise

## Make Connections

**Health Science** Encourage student volunteers to research the differences between aerobic exercise and anaerobic exercise and the benefits of each. Have the students prepare a presentation to the class. **L2 L3**

## Build Science Skills

**Predicting** After students have read the section Energy and Exercise, give them a list of sports and activities, including weight lifting, playing soccer, dancing, taking a long walk, cutting the grass, running a sprint, and running a marathon. For each activity, ask students to predict how much the muscles doing that activity would use lactic acid fermentation or cellular respiration as a source of energy. **L2**

## Use Community Resources

Invite an aerobics exercise instructor to address the class and explain his or her understanding of the benefits of aerobic and anaerobic exercise. A day before the presentation, encourage students to brainstorm a list of questions to ask the instructor.

**L1 L2**



▲ **Figure 9-9** During a race, runners rely on the energy supplied by ATP to make it to the finish line.

**Applying Concepts** When runners begin a race, how do their bodies obtain energy?

## Energy and Exercise

Bang! The starter's pistol goes off, and the runners push off their starting blocks and sprint down the track. The initial burst of energy soon fades, and the runners settle down to a steady pace. After the runners hit the finish line, they walk around slowly and breathe deeply to catch their breath.

Let's look at what happens at each stage of the race in terms of the pathways the body uses to release energy. To obtain energy, the body uses ATP already in muscles and new ATP made by lactic acid fermentation and cellular respiration. At the beginning of a race, the body uses all three ATP sources, but stored ATP and lactic acid fermentation can only supply energy for a limited time.

**Quick Energy** What happens when your body needs lots of energy in a hurry? In response to sudden danger, quick actions might make the difference between life and death. To an athlete, a sudden burst of speed might win a race.

Cells normally contain small amounts of ATP produced during glycolysis and cellular respiration. When the starting gun goes off in a footrace, the muscles of the runners contain only enough of this ATP for a few seconds of intense activity. Before most of the runners have passed the 50-meter mark, that store of ATP is nearly gone. At this point, their muscle cells are producing most of their ATP by lactic acid fermentation. These sources can usually supply enough ATP to last about 90 seconds. In a 200- or 300-meter sprint, such as in **Figure 9-9**, this may be just enough to reach the finish line.



## FACTS AND FIGURES

### Aerobic and anaerobic training

During strenuous exercise, usually both aerobic and anaerobic pathways are at work in supplying muscles with ATP, though the percentage of each varies by the sport. For example, the quick and all-out action of lifting a heavy weight is 100 percent anaerobic. Running a marathon, by contrast, is about 99 percent aerobic. Playing soccer or basketball is about 20 percent anaerobic and 80 percent aerobic. Athletes can improve ATP pro-

duction through training. Anaerobic training, including sprints and similar bursts of energy, can increase the level of glycogen in the muscles and increase tolerance of lactic acid. Aerobic training, including long runs, can increase the size and number of mitochondria in muscles and increase the delivery of oxygen to muscles by improving the heart and lungs. Thus, both types of training are beneficial.

## Quick Lab

**Objective** Students should conclude that exercise increases the body's production of carbon dioxide. **L2**

**Skills Focus** Analyzing Data, Inferring

**Time** 15 minutes

**Advance Prep** If you are using Probeware, use the instructions in the *Probeware Lab Manual*.

**Safety** Read the safety information on the MSDS for bromthymol blue before doing the lab. Warn students not to inhale or swallow the bromthymol blue solution. Make sure students wash their hands with soap and warm water before leaving the lab.

**Strategies**

- Demonstrate how to slowly blow air through a straw into a test tube that contains water and bromthymol blue solution.
- If students have difficulty understanding the significance of their results, have them think about which process in their own cells produces carbon dioxide and how that process is important to their survival. Then, have them think about how the rate of that process changes during exercise.

**Expected Outcome** Students should observe that the bromthymol blue solution changes color more rapidly after exercise than before exercise.

**Analyze and Conclude**

1. Exercise caused the time for the solution to change color to decrease. Whether the results supported a student's prediction will depend on that prediction.
2. Cellular respiration produces carbon dioxide. Exercise increases the rate of cellular respiration.
3. Answers should include: wearing a lab apron and goggles, and not inhaling through the straw.

**Answers to . . .**

**CHECKPOINT** They need extra oxygen to get rid of lactic acid that has built up in their muscles.

**Figure 9-9** Their bodies obtain energy from ATP already in muscles and new ATP made by lactic acid fermentation and cellular respiration.

Fermentation produces lactic acid as a byproduct. When the race is over, the only way to get rid of lactic acid is in a chemical pathway that requires extra oxygen. For that reason, you can think of a quick sprint building up an oxygen debt that a runner has to repay after the race with plenty of heavy breathing.

**Long-Term Energy** What happens if a race is longer? How does your body generate the ATP it needs to run 2 kilometers or more, or to play in a soccer game that lasts more than an hour? For exercise longer than about 90 seconds, cellular respiration is the only way to generate a continuing supply of ATP. Cellular respiration releases energy more slowly than fermentation, which is why even well-conditioned athletes have to pace themselves during a long race or over the course of a game. Your body stores energy in muscle and other tissues in the form of the carbohydrate glycogen. These stores of glycogen are usually enough to last for 15 or 20 minutes of activity. After that, your body begins to break down other stored molecules, including fats, for energy. This is one reason why aerobic forms of exercise such as running, dancing, and swimming are so beneficial for weight control.


**CHECKPOINT** Why do runners breathe heavily after a race?

## Quick Lab

### How does exercise affect disposal of wastes from cellular respiration?

**Materials** 2 small test tubes, glass-marking pencil, 10-mL graduated cylinder, bromthymol blue solution, 2 straws, clock or watch with second hand

**Procedure** 

1. **Predicting** Record your prediction of how exercise will affect your body's production of carbon dioxide.
2.  If you are using a carbon dioxide probe, see your teacher for instructions.
3. Label two test tubes A and B. Put 10 mL of water and a few drops of bromthymol blue solution in each test tube. Carbon dioxide causes bromthymol blue to turn yellow or green.
4. Your partner will time you during this step. When your partner says "go," slowly blow air through a straw into the bottom of test tube A.

**CAUTION:** Do not inhale through the straw.

5. When the solution changes color, your partner should say "stop," and then record how long the color change took.
6. Jog in place for 1 minute.  
**CAUTION:** Do not do this if you have a medical condition that interferes with exercise. If you feel faint or dizzy, stop immediately and sit down.
7. Repeat steps 4 and 5 using test tube B.
8. Trade roles with your partner. Repeat steps 3 through 7.

**Analyze and Conclude**

1. **Analyzing Data** How did exercise affect the time for the solution to change color? Did these results support your prediction?
2. **Inferring** What process in your body produces carbon dioxide? How does exercise affect this process?
3. **SAFETY** What safety procedures did you follow? Why were these procedures important?



## FACTS AND FIGURES

### Using alternative fuels in cellular respiration

Glucose is a common fuel for cells. Starch is broken down into glucose by the digestive system. Humans and many other animals store glycogen in their liver and muscle cells, and glycogen also can be changed into glucose. But, glucose is not the only fuel. For example, proteins and fats can also be used. Proteins are broken down into their constituent amino acids, and then modified amino acids are fed into the Krebs cycle with the

help of enzymes. Fats, whether taken in with food or stored in the body, provide excellent fuel for respiration. The fatty acids of fats are broken down and carried into the mitochondrial matrix by special transport proteins, and then they enter the Krebs cycle in fragments as acetyl-CoA. Fats yield much more energy than glucose. A gram of fat produces more than double the ATP that a gram of carbohydrate does.

## 9-2 (continued)

# Comparing Photosynthesis and Cellular Respiration

## Build Science Skills

**Using Analogies** Draw a hill on the board, and write *glucose* at the top of the hill. Then, tell students that photosynthesis might be considered an “uphill” process, whereas cellular respiration could be considered a “downhill” process. **L2**

## 3 ASSESS

### Evaluate Understanding

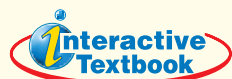
Call on students at random to describe the steps in the process of cellular respiration, one at a time.

### Reteach

Have students reexamine Figures 9-6 and 9-7. Ask each student to write a description of those figures using as many details as possible.

### Thinking Visually

Students should use Figure 9-6 to find the main events in the Krebs cycle, including citric acid production and energy extraction. They should use Figure 9-7 to find the main events in the electron transport chain, including electron transport, hydrogen ion movement, and ATP production. Students should show that the Krebs cycle occurs inside the mitochondrion and the electron transport chain occurs within the inner mitochondrial membrane.



If your class subscribes to the iText, use it to review the Key Concepts in Section 9-2.

### Answer to . . .

**Figure 9-10** *The reactants in the equation for photosynthesis are the products in the equation for cellular respiration, and the products in the equation for photosynthesis are the reactants in the equation for cellular respiration.*

## Comparing Photosynthesis and Cellular Respiration

	Photosynthesis	Cellular Respiration
<b>Function</b>	Energy capture	Energy release
<b>Location</b>	Chloroplasts	Mitochondria
<b>Reactants</b>	CO <sub>2</sub> and H <sub>2</sub> O	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> and O <sub>2</sub>
<b>Products</b>	C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> and O <sub>2</sub>	CO <sub>2</sub> and H <sub>2</sub> O
<b>Equation</b>	$6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{Energy}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$	$6\text{O}_2 + \text{C}_6\text{H}_{12}\text{O}_6 \xrightarrow{\text{Energy}} 6\text{CO}_2 + 6\text{H}_2\text{O}$

**► Figure 9-10** Photosynthesis and cellular respiration can be thought of as opposite processes. **Comparing and Contrasting** Exactly how is the equation for photosynthesis different from the equation for cellular respiration?

## Comparing Photosynthesis and Cellular Respiration

The energy flows in photosynthesis and cellular respiration take place in opposite directions. Earlier in this chapter, the chemical energy in carbohydrates was compared to money in a savings account. Photosynthesis is the process that “deposits” energy. Cellular respiration is the process that “withdraws” energy. As you might expect, the equations for photosynthesis and cellular respiration, shown in **Figure 9-10**, are the reverse of each other.

On a global level, photosynthesis and cellular respiration are also opposites. Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back. Photosynthesis releases oxygen into the atmosphere, and cellular respiration uses that oxygen to release energy from food. The release of energy by cellular respiration takes place in all eukaryotes and some prokaryotes. Energy capture by photosynthesis, however, occurs only in plants, algae, and some bacteria.

## 9-2 Section Assessment

- Key Concept** What happens to pyruvic acid during the Krebs cycle?
- Key Concept** How does the electron transport chain use the high-energy electrons from the Krebs cycle?
- Why is cellular respiration considered to be much more efficient than glycolysis alone?
- How many molecules of ATP are produced in the entire breakdown of glucose?
- Critical Thinking Comparing and Contrasting** Compare the energy flow in photosynthesis to the energy flow in cellular respiration.
- Critical Thinking Using Analogies** How is the chemical energy in glucose similar to money in a savings account?

### Thinking Visually

**Organizing Information** Using **Figure 9-6** and **Figure 9-7** as guides, prepare a poster showing the main events of the process of cellular respiration. For each event, show the reactant and products and where in the mitochondrion the event occurs. Use your poster to explain cellular respiration to a classmate.

## 9-2 Section Assessment

- Pyruvic acid is broken down into carbon dioxide in a series of energy-extracting reactions.
- The electron transport chain uses the high-energy electrons from the Krebs cycle to convert ADP into ATP.
- Cellular respiration enables the cell to produce 34 more ATP molecules per glucose molecule in addition to the 2 ATP molecules obtained from glycolysis.
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- The energy flows in photosynthesis and cellular respiration take place in opposite directions. Photosynthesis is the process that “deposits” energy, while cellular respiration is the process that “withdraws” energy.
- The energy in glucose is “saved” and can be “withdrawn” when the body needs it.

## Should Creatine Supplements Be Banned?

Many athletes now use a dietary supplement called creatine to enhance their performance. Creatine may improve athletic performance, but critics point to potentially serious side effects as a reason to control its use.

Although muscle cells contain only enough ATP for a few seconds of intense activity, most have a reserve nearly twice as large in the form of a molecule called creatine phosphate. When the muscle goes to work and starts to use up its available ATP, phosphates are transferred from creatine phosphate directly to ADP, regenerating ATP in a matter of milliseconds. The more creatine phosphate a muscle contains, the longer it can sustain intense activity. Hoping to increase their capacity for strong, short-term muscle contractions, many athletes have added creatine to their diets. Should athletes be allowed to use creatine supplements?

### The Viewpoints

#### Creatine Supplements Should Be Allowed

Creatine is a natural substance found in human cells and in foods such as meat. Taken in recommended doses, creatine helps build muscle strength and performance, which can mean the difference between winning and losing. When athletes have followed instructions on container labels, no serious side effects have been reported. The risks are small and the rewards of winning are large enough to justify its use.

#### Creatine Supplements Should Be Banned

Like any natural substance, creatine can be abused. Creatine is known to cause water loss, putting the athletes who use it at risk for dehydration, muscle injury, diarrhea, kidney failure, and perhaps even death. Because creatine is considered a dietary supplement and not a drug, the Food and Drug Administration (FDA) has never determined its safety. Until a truly safe dose has been determined by careful scientific studies, athletes should not be allowed to use creatine.



### Research and Decide

- Analyzing the Viewpoints** To make an informed decision, learn more about this issue by consulting library or Internet resources. Then, list the key arguments expressed by the proponents and critics of using creatine as a dietary supplement. What is known? What is not known? What are the benefits? What are the risks?
- Forming Your Opinion** Should athletes be allowed to take creatine to enhance performance? Weigh the pro and con arguments. Research to find out if some professional sports have banned the use of creatine by athletes. What were the reasons for this decision? Do some arguments outweigh others? Which arguments? Explain your answer.
- Writing an Editorial** Write an editorial for a sports magazine that takes a stand on creatine. Your editorial should persuade your readers that your opinion is justified.

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### BACKGROUND

#### The creatine connection

Muscle cells have two backup systems when oxygen is in short supply. One is lactic acid fermentation, but before that begins, a muscle uses up its supply of a compound called creatine phosphate. That molecule can transfer its phosphate to ADP in the reaction: creatine phosphate + ADP → ATP + creatine. A good diet usually supplies an adequate amount of creatine. Meat and fish contain large quantities. In muscle cells,

creatine is changed into creatine phosphate. Creatine supplements add to the amount already supplied in a good diet. Some research has shown that taking a recommended dose of creatine supplement can increase the level of creatine phosphate in muscles 10–20 percent, which can increase energy levels in muscles 2.5–10 percent. Research is incomplete about the health risks of taking the supplement.

After students have read the feature, divide the class into small groups, and allow time for discussion. Then, have each group prepare questions for an interview with one of the following: the coach of one of the high-school teams, a physician associated with high-school teams, a high-school athlete, a salesperson at a health food store that sells creatine supplements, and a professor in the health or physical education department of a local college or university.

Work with each group to decide whom students want to talk to and how to go about setting up the interview. Encourage students to write several questions they want to ask, and anticipate asking follow-up questions.

After completing the interview, group members should collaborate in preparing a report to the class. Encourage students to research additional information to include in their report. Once all groups have given their reports, lead a class discussion of what students learned from the various sources.

### Research and Decide

- Students should list the key arguments discussed in the feature, including increasing strength and performance and the possibility of damage to health.
- Some students may argue for taking the supplements, some may argue against, while others may be ambivalent. No matter which position a student takes, he or she should back up the opinion with facts and logic.
- Students' editorials should concisely state their opinions, with good arguments for their positions.

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Students can research creatine supplements on the site developed by authors Ken Miller and Joe Levine.