9.1 Cellular Respiration: An Overview

Lesson Objectives

- Explain where organisms get the energy they need for life processes.
- Define cellular respiration.
- Compare photosynthesis and cellular respiration.

Lesson Summary

Chemical Energy and Food  Chemical energy is stored in food molecules.
- Energy is released when chemical bonds in food molecules are broken.
- Energy is measured in a unit called a calorie, the amount of energy needed to raise the temperature of 1 gram of water 1 degree Celsius.
- Fats store more energy per gram than do carbohydrates and proteins.

Overview of Cellular Respiration  Cellular respiration is the process that releases energy from food in the presence of oxygen.
- Cellular respiration captures the energy from food in three main stages:
  - glycolysis
  - the Krebs cycle
  - the electron transport chain
- Glycolysis does not require oxygen. The Krebs cycle and electron transport chain both require oxygen.
  - Aerobic pathways are processes that require oxygen.
  - Anaerobic pathways are processes that occur without oxygen.

Comparing Photosynthesis and Cellular Respiration  The energy in photosynthesis and cellular respiration flows in opposite directions. Their equations are the reverse of each other.
- Photosynthesis removes carbon dioxide from the atmosphere, and cellular respiration puts it back.
- Photosynthesis releases oxygen into the atmosphere, and cellular respiration uses oxygen to release energy from food.

Chemical Energy and Food

For Questions 1–4, complete each statement by writing the correct word or words.

1. A calorie is a unit of energy.

2. The Calorie used on food labels is equal to 1000 calories.

3. A Calorie is also referred to as a kilocalorie.

4. Cells use the energy stored in chemical bonds of foods to produce compounds that directly power the cell’s activities, such as ATP.
Overview of Cellular Respiration

For Questions 5–10, complete each statement by writing the correct word or words.

5. The equation that summarizes cellular respiration, using chemical formulas, is
   \[ \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O} + \text{Energy} \]

6. If cellular respiration took place in just one step, most of the energy would be lost in the form of light and heat.

7. Cellular respiration begins with a pathway called glycolysis, which takes place in the cytoplasm of the cell.

8. At the end of glycolysis, about 90 percent of the chemical energy is locked in the bonds of the pyruvic acid molecule.

9. Cellular respiration continues in the mitochondria of the cell with the Krebs cycle and electron transport chain.

10. The pathways of cellular respiration that require oxygen are said to be aerobic. Pathways that do not require oxygen are said to be anaerobic.

11. Complete the illustration by adding labels for the three main stages of cellular respiration.

![Diagram of cellular respiration stages: Glycolysis, Krebs cycle, Electron transport]
Comparing Photosynthesis and Cellular Respiration

For Questions 12–15, write True if the statement is true. If the statement is false, change the underlined word or words to make the statement true.

12. The energy flow in photosynthesis and cellular respiration occurs in the opposite direction. ___

13. Photosynthesis deposits energy in Earth’s “savings account” for living organisms. ___

14. Cellular respiration removes carbon dioxide from the air. ___

15. Photosynthesis takes place in nearly all life. ___

16. Complete the table comparing photosynthesis and cellular respiration.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Photosynthesis</th>
<th>Cellular Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>energy capture</td>
<td>energy release</td>
</tr>
<tr>
<td>Location of reactions</td>
<td>chloroplasts</td>
<td>cytoplasm and mitochondria</td>
</tr>
<tr>
<td>Reactants</td>
<td>carbon dioxide, water, and light</td>
<td>glucose and oxygen</td>
</tr>
<tr>
<td>Products</td>
<td>oxygen and glucose</td>
<td>carbon dioxide, water, and energy</td>
</tr>
</tbody>
</table>

A Comparison of Photosynthesis and Cellular Respiration

Apply the Big Idea

17. How does an understanding of the process of cellular respiration support the theory that the cell is the basic functional unit of life?

SAMPLE ANSWER: Cellular respiration is the fundamental process by which energy for life processes is obtained from food molecules. It occurs in both the cytoplasm and specialized structures of a cell—the mitochondria—instead of in a specialized tissue or organ of the body. It occurs in the same way in almost all cells.
Glycolysis

1. THINK VISUALLY Complete the diagram by writing on the lines provided the names and numbers of molecules used and produced during glycolysis.

```
Glucose

2 ATP

2 ADP

CCC

CCC

4 ADP

2 NAD^+

4 ATP

2 NADH

2 Pyruvic Acid
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2. Why is it an investment for the cell to use two ATP at the beginning of glycolysis?
The end result of glycolysis is the production of four ATP. Using two ATP at the start of glycolysis gives the cell a net gain of two ATP.

3. What are two advantages of glycolysis?
(1) Glycolysis occurs very quickly, which allows it to supply ATP if energy demand suddenly increases. (2) Glycolysis can quickly supply energy to cells when oxygen is not available.
The Krebs Cycle

For Questions 4–7, write True if the statement is true. If the statement is false, change the underlined word or words to make the statement true.

mitochondrion 4. The pyruvic acid produced in glycolysis enters the chloroplast if oxygen is present in a cell.

acetic 5. In the matrix, pyruvic acid is converted to lactic acid before the Krebs cycle begins.

True 6. The compound that joins with a 4-carbon molecule in the Krebs cycle is called acetyl-CoA.

True 7. Carbon dioxide is the only product of the Krebs cycle that is not re-used or used in other stages of cellular respiration.

8. Complete the flowchart to show which of the Krebs cycle's many products go on to the third stage of cellular respiration.

Electron Transport and ATP Synthesis

For Questions 9–14, complete each statement by writing the correct word or words.

9. In eukaryotes, the electron transport chain is composed of a series of electron carriers located in the inner membrane of the mitochondrion.

10. In prokaryotes, the electron transport chain is in the cell membrane.

11. Oxygen serves as the final electron acceptor of the electron transport chain.

12. NADH and FADH₂ pass high-energy electrons to the electron transport chain.

13. The transfer of high-energy electrons down the electron transport chain causes hydrogen ions to be transported across the mitochondrial membrane.

14. ATP synthases produce the force needed to add one phosphate group to each ADP molecule by spinning when hydrogen ions flow through them.
The Totals

15. How many ATP molecules per glucose molecule does a cell gain from each of the three stages of cellular respiration?

A cell gains 2 ATP molecules per glucose molecule from glycolysis, 2 more ATP molecules from the Krebs cycle, and 32 ATP molecules from the electron transport chain.

16. Besides glucose, what other kinds of molecules can be used to produce ATP in cellular respiration?

Lipids, proteins, and complex carbohydrates that can be broken down into glucose

17. Why is cellular respiration considered an efficient process?

The 36 ATP molecules generated represent about 36 percent of the total energy available. In fact, the cell is more efficient at using food than a typical automobile engine is at burning gasoline.

Apply the Big Idea

18. Where does the heat that warms your body come from? Explain your answer.

Heat that warms the body comes from the body cells that contain mitochondria. During cellular respiration, each molecule of glucose leads to the production of 36 ATP molecules. However, the process recovers only 36 percent of the chemical energy in glucose. The remaining energy is released as heat.
9.3 Fermentation

Lesson Objectives

- Explain how organisms get energy in the absence of oxygen.
- Identify the pathways the body uses to release energy during exercise.

Lesson Summary

Fermentation Fermentation releases energy from food molecules by producing ATP without oxygen. Cells convert NADH to the electron carrier NAD⁺. This allows glycolysis to produce a steady stream of ATP. There are two forms of fermentation. Both start with the reactants pyruvic acid and NADH.

- alcoholic fermentation produces ethyl alcohol and carbon dioxide
  - occurs in yeast and a few other microorganisms
  - produces alcoholic beverages and causes bread dough to rise
- lactic acid fermentation produces lactic acid
  - occurs in most organisms, including humans
  - used to produce beverages such as buttermilk and foods such as cheese, yogurt, and pickles

Energy and Exercise The body uses different pathways to release energy.

- For short, quick bursts of energy, the body uses ATP already in muscles as well as ATP made by lactic acid fermentation.
- For exercise longer than about 90 seconds, cellular respiration is the only way to continue generating a supply of ATP.

Fermentation

For Questions 1–6, write True if the statement is true. If the statement is false, change the underlined word or words to make the statement true.

True 1. Glycolysis provides the pyruvic acid molecules used in fermentation.

NAD⁺ 2. Fermentation allows glycolysis to continue by providing the NADPH needed to accept high-energy electrons.

aerobic 3. Fermentation is an aerobic process.

cytoplasm 4. Fermentation occurs in the mitochondria of cells.

True 5. Alcoholic fermentation gives off carbon dioxide and is used in making bread.

True 6. Most organisms perform fermentation using a chemical reaction that converts pyruvic acid to lactic acid.
7. Compare and contrast fermentation and cellular respiration by completing the compare/contrast table. Write your answers in the empty table cells.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Fermentation</th>
<th>Cellular Respiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>produces ATP without oxygen</td>
<td>long-term, large production of ATP</td>
</tr>
<tr>
<td>Reactants</td>
<td>glucose, ATP, pyruvic acid, NADH</td>
<td>glucose, ATP, pyruvic acid, NADH and FADH$_2$, oxygen</td>
</tr>
<tr>
<td>Products</td>
<td>NAD$^+$, ethyl alcohol and CO$_2$ in alcoholic fermentation or lactic acid in lactic acid fermentation, ATP</td>
<td>CO$_2$, H$_2$O, ATP</td>
</tr>
</tbody>
</table>

8. Compare and contrast alcoholic fermentation and lactic acid fermentation by completing the compare/contrast table. Write your answers in the empty table cells.

<table>
<thead>
<tr>
<th>Type of Fermentation</th>
<th>Summary Equation</th>
<th>Use in Industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcoholic</td>
<td>Pyruvic acid + NADH $\rightarrow$ Alcohol + CO$_2$ + NAD$^+$</td>
<td>used to produce alcoholic beverages, causes bread dough to rise</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>Pyruvic acid + NADH $\rightarrow$ Lactic acid + NAD$^+$</td>
<td>used to produce cheese, yogurt, sour cream, pickles and other foods</td>
</tr>
</tbody>
</table>

9. What causes humans to become lactic acid fermenters?

*Brief periods without oxygen will cause many of the cells of a human body to produce ATP by lactic acid fermentation.*
Energy and Exercise

10. What are three main sources of ATP available for human muscle cells?
   The three sources are ATP already in muscles, ATP made by lactic acid fermentation, and ATP produced by cellular respiration.

11. During a race, how do your muscle cells produce ATP after the store of ATP in muscles is used?
   After the ATP in muscles is used, the muscles produce ATP by lactic acid fermentation.

12. Why does a sprinter have an oxygen debt to repay after the race is over?
   Lactic acid fermentation produces lactic acid as a byproduct. The only way to get rid of the lactic acid is in a chemical pathway that requires extra oxygen.

13. A runner needs more energy for a longer race. How does the body generate the necessary ATP?
   Cellular respiration is the only way to continue generating a supply of ATP.

14. Why are aerobic forms of exercise so beneficial for weight control?
   The body stores energy in the form of glycogen. These stores of glycogen are usually enough for 15–20 minutes of activity. After that, the body begins to break down other stored molecules, including fats, for energy.

Apply the Big Idea

15. Compare and contrast the role of fermentation and cellular respiration in the actual production of ATP. In your response, consider which process produces ATP and which process contributes to its production.
   For every molecule of glucose, cellular respiration produces 36 ATP molecules, while fermentation produces two ATP molecules. In fermentation, the two ATP molecules are produced during glycolysis. Fermentation supplies glycolysis with NAD+ to keep it going. In cellular respiration, ATP is produced during glycolysis, the Krebs cycle, and the electron transport chain.
Chapter Vocabulary Review

For Questions 1–7, match the term with its definition.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>1. anaerobic  A. Innermost compartment of a mitochondrion</td>
</tr>
<tr>
<td>D</td>
<td>2. glycolysis  B. Process that forms either lactic acid or ethyl alcohol when no oxygen is present</td>
</tr>
<tr>
<td>C</td>
<td>3. Krebs cycle C. Stage of cellular respiration that starts with pyruvic acid and produces carbon dioxide</td>
</tr>
<tr>
<td>G</td>
<td>4. calorie    D. Process in which glucose is broken down into two molecules of pyruvic acid</td>
</tr>
<tr>
<td>A</td>
<td>5. matrix     E. “In air”</td>
</tr>
<tr>
<td>E</td>
<td>6. aerobic    F. “Without air”</td>
</tr>
<tr>
<td>B</td>
<td>7. fermentation G. Amount of energy needed to raise the temperature of 1 gram of water 1°C</td>
</tr>
</tbody>
</table>

For Questions 8–10, write the letter of the correct answer on the line at the left.

8. Which is the process that releases energy by breaking down food molecules in the presence of oxygen?
   A. cellular respiration  C. glycolysis  
   B. electron transport  D. photosynthesis

9. Which is the electron carrier that accepts electrons during glycolysis?
   A. ADP  C. NAD⁺  
   B. ATP  D. NADP⁺

10. When comparing cellular respiration and photosynthesis, these two processes are best described as
    A. energy-releasing processes.  C. opposite processes.  
    B. energy-storing processes.  D. similar processes.

11. Complete the illustration by adding the words “aerobic” or “anaerobic” on the lines provided.