Cellular Respiration and Fermentation

Cellular Basis of Life

Q: How do organisms obtain energy?

WHAT I KNOW

9.1 Why do most organisms undergo the process of cellular respiration?

SAMPLE ANSWER: Cellular respiration occurs in mitochondria and supplies energy for life processes.

WHAT I LEARNED

SAMPLE ANSWER: The process of cellular respiration takes place in stages. During cellular respiration, cells trap bits of chemical energy and use them to make ATP.

9.2 How do cells release energy from food in the presence of oxygen?

SAMPLE ANSWER: Oxygen enables much more energy to be released from food molecules.

SAMPLE ANSWER: Glycolysis does not require oxygen but the Krebs cycle and electron transport do require oxygen. Oxygen serves as the final electron acceptor of the electron transport chain, during which the majority of ATP is produced.

9.3 How do cells release energy from food without oxygen?

SAMPLE ANSWER: Cells use glycolysis to release energy without oxygen.

SAMPLE ANSWER: When oxygen is not present, glycolysis is followed by a pathway that continues the production of ATP. This pathway plus glycolysis is called fermentation. Fermentation releases energy from food molecules by producing ATP.
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

\[ 6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{Energy} \]

6. If cellular respiration took place in just one step, most of the \( \text{energy} \) would be lost in the form of light and \( \text{heat} \).

7. Cellular respiration begins with a pathway called \( \text{glycolysis} \), which takes place in the \( \text{cytoplasm} \) of the cell.

8. At the end of glycolysis, about \( 90 \) percent of the chemical energy is locked in the bonds of the \( \text{pyruvic acid} \) molecule.

9. Cellular respiration continues in the \( \text{mitochondria} \) of the cell with the \( \text{Krebs cycle} \) and electron transport chain.

10. The pathways of cellular respiration that require oxygen are said to be \( \text{aerobic} \). Pathways that do not require oxygen are said to be \( \text{anaerobic} \).

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

- **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 **same** 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>

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.
9.2 The Process of Cellular Respiration

Lesson Objectives

- Describe what happens during glycolysis.
- Describe what happens during the Krebs cycle.
- Explain how high-energy electrons are used by the electron transport chain.
- Identify how much ATP cellular respiration generates.

Lesson Summary

**Glycolysis**

The word **glycolysis** literally means “sugar-breaking.” The end result is 2 molecules of a 3-carbon molecule called pyruvic acid.

- 2 ATP molecules are used at the start of glycolysis to get the process started.
- High-energy electrons are passed to the electron carrier **NAD⁺**, forming two molecules of NADH.
- 4 ATP are synthesized during glycolysis for a net gain of 2 ATP.

**The Krebs Cycle**

The second stage of cellular respiration is the **Krebs cycle**, which operates only when oxygen is available. The Krebs cycle is a series of energy-extracting reactions.

- Pyruvic acid produced by glycolysis enters mitochondria. In the innermost compartment of a mitochondrion, or the **matrix**, pyruvic acid molecules are broken down into carbon dioxide and acetyl-CoA molecules.
- Acetyl-CoA combines with a 4-carbon compound, producing a 6-carbon molecule—citric acid. Energy released by the breaking and rearranging of carbon bonds is captured in ATP, NADH, and FADH₂.
- The Krebs cycle produces four types of products:
  - high-energy electron carriers (NADH and FADH₂)
  - carbon dioxide
  - 2 ATP molecules (per glucose molecule)
  - the 4-carbon molecule needed to start the cycle again

**Electron Transport and ATP Synthesis**

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

- The electron carriers produced during glycolysis and the Krebs cycle bring high-energy electrons to the electron transport chain. Oxygen is the final electron acceptor.
- The passing of electrons through the electron transport chain causes H⁺ ions to build up in the intermembrane space, making it positively charged relative to the matrix.
- The charge difference across the membrane forces H⁺ ions through channels in enzymes known as ATP synthases. As the ATP synthases spin, a phosphate group is added to ADP, generating ATP.

**The Totals**

Together, glycolysis, the Krebs cycle, and the electron transport chain generate about 36 molecules of ATP per molecule of glucose.
Glycolysis

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

   2 ATP
   
   2 ADP
   
   4 ADP
   
   4 ATP
   
   2 NAD^+
   
   2 NADH
   
   2 Pyruvic Acid

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.

4. The pyruvic acid produced in glycolysis enters the chloroplasts if oxygen is present in a cell.
5. In the matrix, pyruvic acid is converted to lactic acid before the Krebs cycle begins.
6. The compound that joins with a 4-carbon molecule in the Krebs cycle is called acetyl-CoA.
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.