CHAPTER 10 LESSON 1

Cellular Respiration: An Overview

Do This →

READING TOOL **Active Reading** As you read your textbook, record key ideas on the summary table for each heading in the chapter. The first one is done for you.

Heading	Summary
Chemical Energy and Food	Heterotrophs get the energy they need from the food they eat. In food it is measured in units called Calories.
Overview of Cellular Respiration	
• Stages of Cellular Respiration	
• Oxygen and Energy	
Comparing Photosynthesis and Cellular Respiration	

Answer the key questions on your NB page.

Chemical Energy and Food

1) **KEY QUESTION** *Where do organisms get energy?*

Heterotrophs get the energy they need from the food they eat. Energy is stored in a variety of macromolecules in the body, including fats, proteins, and carbohydrates. The energy is measured in a unit known as a calorie. A calorie is the amount of energy needed to raise the temperature of 1 gram of water by 1 degree Celsius. There are 1000 of these calories in 1 food Calorie (that is seen on a food label). When measuring calories, fats tend to have 9000 calories (9 food Calories) of energy per gram, while proteins and carbohydrates have 4000 calories (4 food Calories). The cells in the body release and use this energy over time using the process of cellular respiration.

Overview of Cellular Respiration

2) **KEY QUESTION** *What is cellular respiration?*

Energy is released from food in the presence of oxygen during a complex process known as cellular respiration. There are many reactions in this process, but simply put, the process takes oxygen and glucose and converts it into carbon dioxide, water, and energy. This process happens over time, and energy is released gradually in the form of ATP.

In Symbols:

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

In Words:

Oxygen + Glucose → Carbon Dioxide + Water + Energy

If cellular respiration took place in just one step, all of the energy from glucose would be released at once, and most of it would be lost in the form of heat.

Stages of Cellular Respiration There are three stages of cellular respiration. During the first stage, called glycolysis, glucose is broken down and small amounts of ATP are produced. In the next stage, the Krebs cycle, pyruvic acid that was produced during glycolysis is broken down, and energy carriers are produced. These energy carriers move into the final stage of cellular respiration, the electron transport chain. Here the electron carriers release their stored energy and produce ATP.

Oxygen and Energy Oxygen is required at the very end of the electron transport chain. Any time a cell's demand for energy increases, its use of oxygen increases, too. The double meaning of respiration points out a crucial connection between cells and organisms.

High energy–yielding pathways in cells require oxygen, and that is the reason we need to breathe, or respire. Pathways of cellular respiration that require oxygen are said to be aerobic ("in air"). The Krebs cycle and the electron transport chain are both aerobic processes. Glycolysis, however, does not directly require oxygen, nor does it rely on an oxygen-requiring process to run. Glycolysis is therefore said to be anaerobic ("without air"). Even though glycolysis is anaerobic, it is considered part of cellular respiration because its products are key reactants for the aerobic stages.

Glycolysis occurs in the cytoplasm. In contrast, the Krebs cycle and electron transport chain, which generate the majority of ATP during cellular respiration, take place inside the mitochondria. If oxygen is not present, another anaerobic pathway, known as fermentation, makes it possible for the cell to keep glycolysis running, generating ATP to power cellular activity.

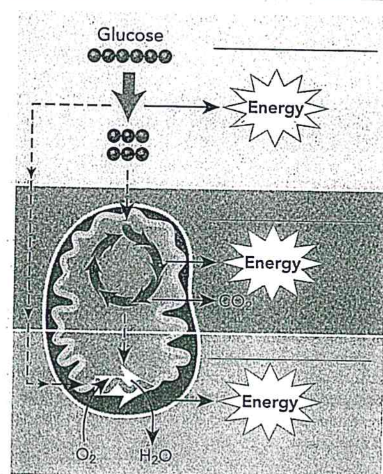
Comparing Photosynthesis and Cellular Respiration

3) **KEY QUESTION** *What is the relationship between photosynthesis and cellular respiration?*

Photosynthesis and cellular respiration are both important processes in the harnessing and extraction of energy. In fact, they work in opposite ways. Photosynthesis is a process that deposits energy, while cellular respiration is a way to withdraw energy. Photosynthesis removes carbon dioxide from the atmosphere, while cellular respiration adds it to the atmosphere. Photosynthesis releases oxygen, while cellular respiration uses it.

The global balance between cellular respiration and photosynthesis is essential to maintain Earth as a living planet. Another necessity is a constant input of energy into the system. This input comes from the sun. You can trace the flow of energy from the sun to organisms that perform photosynthesis and then to a series of organisms that perform cellular respiration.

Visual Reading Tool: Cellular Respiration: An Overview



← Do This!

1. On the diagram, label each stage of cellular respiration: *Electron Transport Chain, Glycolysis, Krebs Cycle.*
2. What is the difference between aerobic and anaerobic processes?

______

______

3. List the two stages of cellular respiration that are aerobic.

______

______

4. In what organelle do the Krebs cycle and the electron transport chain occur in?

______

5. Where does glycolysis take place in the cell?

______

Glycolysis

4 🔍 **KEY QUESTION** *What happens during the process of glycolysis?*

The first set of reactions in cellular respiration is known as glycolysis, which literally means "sugar breaking." During glycolysis, 1 molecule of glucose, a 6-carbon compound, is transformed into 2 molecules of the 3-carbon compound pyruvic acid.

ATP Production Glycolysis requires two ATP molecules to begin breaking down glucose. Throughout glycolysis a total of four ATP molecules are produced. As a result, there is a net gain of two ATP molecules.

NADH Production One of the reactions that occurs during glycolysis removes four electrons. These electrons are in a high-energy state and are transported to NAD^+, also known as nicotinamide adenine dinucleotide. Each NAD^+ molecule accepts a pair of high-energy electrons and a hydrogen ion.

This molecule, now known as NADH, holds the electrons until they can be transferred to other molecules. In the presence of oxygen, these high-energy electrons can be used to produce even more ATP molecules.

The Advantages of Glycolysis One advantage of glycolysis is that it occurs so quickly that thousands of ATP molecules are created in milliseconds. This is helpful when the energy needed by a cell increases. A second advantage is that glycolysis does not require the use of oxygen. As a result, it can provide usable energy to the cell when oxygen is not available. However, if oxygen is available, the pyruvic acid and NADH that are created from glycolysis can be used for other processes in cellular respiration to produce additional ATP molecules.

The Krebs Cycle

5 🔍 **KEY QUESTION** *What happens during the Krebs cycle?*

The Krebs cycle is the second stage of cellular respiration. It occurs when the pyruvic acid that is formed from glycolysis is broken down in a series of reactions. These reactions extract energy and produce the reactant that allows the cycle to start again.

Citric Acid Production At the beginning of the Krebs cycle, the three-carbon compound known as pyruvic acid created from glycolysis passes through the two membrane walls of the mitochondrion. As a result, it moves into a region located in the matrix. One carbon atom splits off from the pyruvic acid and forms carbon dioxide. This is eventually released into the air. The other two carbon atoms form acetic acid and combine with a compound called coenzyme A to form acetyl CoA. As the Krebs cycle unfolds, this acetyl CoA transfers the two carbon atoms to a four-carbon molecule that is already present in the cycle. This results in the formation of citric acid.

Energy Extraction Through a series of many reactions, citric acid is broken down into a 5-carbon compound, and then a 4-carbon compound (releasing 2 CO_2 molecules along the way). This 4-carbon compound can then start the cycle over again by combining with acetyl CoA. Energy released by the breaking and rearranging of carbon bonds is captured in the forms of ATP, NADH, and $FADH_2$.

Electron Transport and ATP Synthesis

6 🔍 **KEY QUESTION** *How does the electron transport chain use high energy electrons from glycolysis and the Krebs cycle?*

The final step of cellular respiration is the electron transport stage. The electron transport chain uses the high-energy electrons from glycolysis and the Krebs cycle to synthesize ATP from ADP.

Electron Transport NADH and $FADH_2$ transport electrons to the electron transport chain. The electrons travel through this chain, and the resulting energy transports hydrogen ions through the membrane and into the intermembrane space. Oxygen will accept the electrons at the end of the chain and combine with hydrogen ions to form water.

ATP Production The inner membrane of the mitochondrion contains enzymes known as ATP synthases. The hydrogen ions are forced through the enzymes, causing the base to spin. As the enzyme molecules spin, they grab an ADP molecule and it attaches to a phosphate group, forming ATP.

The Totals

7 🔍 **KEY QUESTION** *How much ATP does cellular respiration generate?*

Cellular respiration occurs in three phases. When the phases are complete, the end result is 36 ATP molecules that are created with each molecule of glucose. This represents about 36 percent of the total energy of glucose. The rest of the energy is released as heat. When it comes to a way of extracting energy, the process of cellular respiration is more efficient than an automobile engine that runs on gasoline.

Fermentation

8 🔍 **KEY QUESTION** *How do organisms generate energy when oxygen is not available?*

When oxygen is not present, glycolysis is maintained by a pathway that makes it possible to continue to produce ATP without oxygen. The combined process of this pathway and glycolysis is called fermentation. In the absence of oxygen, fermentation releases energy from food molecules by producing ATP.

During fermentation, cells convert NADH to NAD^+ by passing high-energy electrons back to pyruvic acid. This allows glycolysis to keep going and to produce a steady supply of ATP. Fermentation is an anaerobic process that occurs in the cytoplasm of cells. Sometimes, glycolysis and fermentation are together referred to as anaerobic respiration. There are two slightly different forms of the process: alcoholic fermentation and lactic acid fermentation.

Alcoholic Fermentation The process of alcoholic fermentation is conducted by yeast. In this process, NADH combines with pyruvic acid to form alcohol, carbon dioxide, and NAD^+.

The NAD^+ allows glycolysis to continue without oxygen. One common way to see this process is in the baking of bread. The yeast release carbon dioxide, which are the air pockets you see in bread. The alcohol that forms evaporates when the bread is baked.

Lactic Acid Fermentation Lactic acid fermentation is carried out by bacteria. These bacteria convert pyruvic acid and NADH into lactic acid and NAD^+. As with alcoholic fermentation, the NAD^+ allows glycolysis to continue. This process is common in food production. Yogurt, cheese, and sour cream rely on lactic acid fermentation.

Humans are also lactic acid fermenters. During brief periods without enough oxygen, many of the cells in our bodies, most often muscle cells, produce ATP by lactic acid fermentation.

Energy and Exercise

9 🔍 **KEY QUESTION** *How does the body produce ATP during different stages of exercise?*

When people exercise, their bodies use chemical energy to power their movements. Exercise uses up the available ATP quickly in the body. The body has to quickly make ATP in order to provide further energy for the body to exercise.

Quick Energy Under normal circumstances the body is able to take in enough oxygen to fuel cellular respiration. But sometimes, exercise involves rapid movements that occur in fast spurts. In these circumstances, the body uses the supply of ATP in the muscles quickly. While normal aerobic respiration cannot supply enough ATP to flood the muscles quickly, lactic acid fermentation can because it does not require oxygen and is a quicker process. Lactic acid fermentation can provide the muscles enough ATP for short bursts. However, the consequence is the person might need extra oxygen to help remove the excess lactic acid. This is sometimes called oxygen debt. This is why people who exercise rapidly, like sprinters, often huff and puff after exercising.

Long-Term Energy For exercise longer than about 90 seconds, cellular respiration is the only way to continue generating a supply of ATP. Cellular respiration releases energy more slowly than fermentation does, 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 cells 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. Athletes competing in long-distance events, such as the marathon, depend on the efficiency of their respiratory and circulatory systems to provide their muscles with oxygen to support long periods of aerobic exercise.

Do → This!

READING TOOL **Compare and Contrast** As you read your textbook, compare and contrast fermentation and cellular respiration using the Venn diagram. Make sure to list the similarities in the center of the diagram.