# 4.6 Fermentation

**KEY CONCEPT** Fermentation allows the production of a small amount of ATP without oxygen.

**MAIN IDEAS**

- Fermentation allows glycolysis to continue.
- Fermentation and its products are important in several ways.

**VOCABULARY**

**fermentation,** p. 122
**lactic acid,** p. 123

**Review**
ATP, glycolysis, cellular respiration, aerobic, anaerobic

**FLORIDA STANDARDS**

**SC.912.L.18.8** Identify the reactants, products, and basic functions of aerobic and anaerobic cellular respiration.

***Connect*** Think about a time that you worked or exercised hard. Maybe you moved heavy boxes or furniture. Maybe, playing basketball, you found yourself repeatedly running up and down the court. Your arms and legs began to feel heavy, and they seemed to lose strength. Your muscles became sore, and even when you rested you kept breathing hard. Your muscles were using fermentation.

**MAIN IDEA**

## Fermentation allows glycolysis to continue.

The cells in your body cannot store large amounts of oxygen for cellular respiration. The amount of oxygen that is provided by breathing is enough for your cells during normal activities. When you are reading or talking to friends, your body can maintain its oxygen levels. When you are doing high levels of activity, as the sprinter is in **FIGURE 4.18**, your body cannot bring in enough oxygen for your cells, even though you breathe faster. How do your cells function without enough oxygen to keep cellular respiration going?

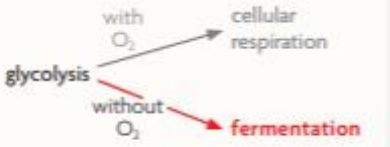
Recall that glycolysis yields two ATP molecules when it splits glucose into two molecules of pyruvate. Glycolysis is always occurring and does not require oxygen. If oxygen is available, the products of glycolysis—pyruvate and the electron carrier NADH—are used in cellular respiration. Then, oxygen picks up electrons at the end of the electron transport chain in cellular respiration. But what happens when oxygen is not there to pick up electrons? The production of ATP without oxygen continues through the anaerobic processes of glycolysis and fermentation.

**FIGURE 4.18** Muscle cells use anaerobic processes during hard exercise.

**Fermentation** does not make ATP, but it allows glycolysis to continue. Fermentation removes electrons from NADH molecules and recycles $NAD^+$ molecules for glycolysis. Why is this process important? Because glycolysis, just like cellular respiration, needs a molecule that picks up electrons. It needs molecules of $NAD^+$.

**VISUAL VOCAB**

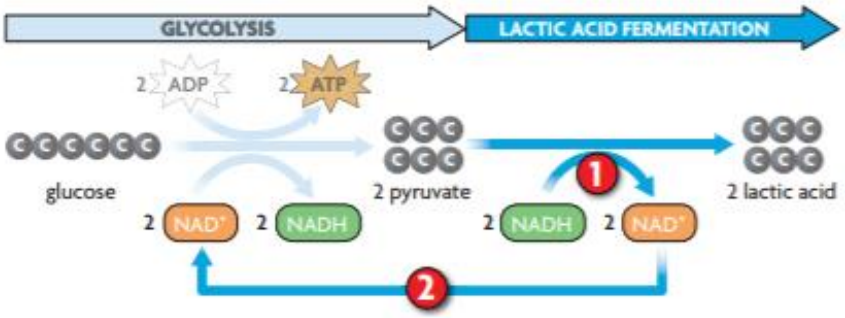
**Fermentation** is an anaerobic process that allows glycolysis to continue.



Without $NAD^+$ to pick up high-energy electrons from the splitting of glucose, glycolysis would stop. When the high-energy electrons are picked up, though, a eukaryotic cell can continue breaking down glucose and other simple sugars to make a small amount of ATP.

Suppose that a molecule of glucose has just been split by glycolysis in one of your muscle cells, but oxygen is unavailable. A process called lactic acid fermentation takes place. Lactic acid fermentation occurs in your muscle cells, the cells of other vertebrates, and in some microorganisms. **Lactic acid,** $C_3H_6O_3$, is what causes your muscles to "burn" during hard exercise.

1. Pyruvate and NADH from glycolysis enter the fermentation process. Two NADH molecules provide energy to convert pyruvate into lactic acid. As the NADH is used, it is converted back into $NAD^+$.
2. Two molecules of $NAD^+$ are recycled back to glycolysis. The recycling of $NAD^+$ allows glycolysis to continue.

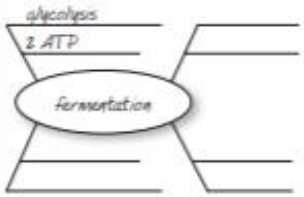



As you can see, the role of fermentation is simply to provide glycolysis with a steady supply of $NAD^+$. By itself, fermentation does not produce ATP. Instead, it allows glycolysis to continue to produce ATP. However, fermentation does produce the lactic acid waste product that builds up in muscle cells and causes a burning feeling. Once oxygen is available again, your cells return to using cellular respiration. The lactic acid is quickly broken down and removed from the cells. This is why you continue to breathe hard for several minutes after you stop exercising. Your body is making up for the oxygen deficit in your cells, which allows the breakdown of lactic acid in your muscles.

**A** **Sequence** **Which process must happen first, fermentation or glycolysis? Explain.**

**TAKING NOTES**

Use a mind map to take notes on the processes involved in fermentation.




**Connecting CONCEPTS**

**Human Biology** Muscle cells need ATP to contract. You will learn how muscles produce your movements in **Chapter 33**.

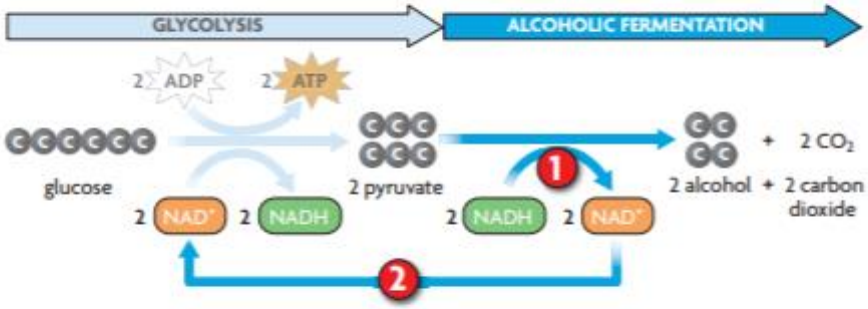
MAIN IDEA

## Fermentation and its products are important in several ways.

How would your diet change without cheese, bread, and yogurt? How would pizza exist without cheese and bread? Without fermentation, a pizza crust would not rise and there would be no mozzarella cheese as a pizza topping. Cheese, bread, and yogurt are just a few of the foods made by fermentation. Milk is changed into different cheeses by fermentation processes carried out by different types of bacteria and molds. Waste products of their fermentation processes give cheeses their different flavors and textures. Additionally, some types of bacteria that use lactic acid fermentation sour the milk in yogurt.

Lactic acid fermentation is not the only anaerobic process. Alcoholic fermentation is used by many yeasts and by some types of plants. Alcoholic fermentation begins at the same point as lactic acid fermentation. That is, glycolysis splits a molecule of glucose and produces two net ATP molecules, two pyruvate molecules, and two NADH molecules. Pyruvate and NADH enter alcoholic fermentation.

1. Pyruvate and NADH from glycolysis enter alcoholic fermentation. Two NADH molecules provide energy to break down pyruvate into an alcohol and carbon dioxide. As the NADH molecules are used, they are converted back into molecules of $NAD^+$.
2. The molecules of $NAD^+$ are recycled back to glycolysis. The recycling of $NAD^+$ allows glycolysis to continue.




The products of this process are two molecules of an alcohol, often ethyl alcohol, two molecules of carbon dioxide, and two molecules of $NAD^+$. Just like lactic acid fermentation, alcoholic fermentation recycles $NAD^+$ and so allows glycolysis to keep making ATP.

**QUICK LAB** **DESIGN YOUR OWN**

SC.912.N.1.1

## Fermentation

One waste product of alcoholic fermentation is carbon dioxide. In this lab you will determine which beverage causes yeast to undergo a higher rate of fermentation.

**PROBLEM** What factors affect the rate of fermentation in yeast?

### MATERIALS

- 2 empty plastic bottles
- 1 package of yeast
- 2 100-mL graduated cylinders
- 2 250-mL beakers
- 2 beverages
- 2 round balloons
- 30 cm string
- metric ruler

### PROCEDURE

1. Write an operational definition for the dependent variable that you will use to measure the rate of fermentation.
2. Develop a technique using a balloon to measure fermentation rate.
3. Design your experiment. Have your teacher approve your experimental design. Write your experimental procedure and conduct your experiment.
4. Construct a data table to record your data. Construct a graph to display your data.

### ANALYZE AND CONCLUDE

1. **Identify** What are the independent variable, dependent variable, and constants?
2. **Analyze** How did the independent variable affect the rate of fermentation? Why?
3. **Experimental Design** Identify possible reasons for any inconsistent results you observed.

**FIGURE 4.19** Fermentation by molds and bacteria produces the different flavors and textures of various cheeses.

Alcoholic fermentation in yeast is particularly useful. When bread or pizza crust is made, yeast is used to cause the dough to rise. The yeast breaks down sugars in the dough through glycolysis and alcohol fermentation. The carbon dioxide gas produced by alcoholic fermentation causes the dough to puff up and rise. When the dough is baked, the alcohol that is produced during fermentation evaporates into the air. The yeast in dough is killed by the heat of baking.

Bacteria that rely upon fermentation play a very important role in the digestive systems of animals. Microorganisms in the digestive tracts of animals, including humans, must obtain their ATP from anaerobic processes because oxygen is not available. Without them, neither you nor other animals would be able to fully digest food. Why? These bacteria continue the breakdown of molecules by taking in undigested material for their needs. The additional breakdown of materials by digestive bacteria allows the host animal to absorb more nutrients from food.

A **Apply** **Explain the importance of alcoholic fermentation in the production of bread's light, fluffy texture.**

## 4.6 ASSESSMENT

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### REVIEWING MAIN IDEAS

1. What is the relationship between glycolysis and **fermentation**?
2. Summarize the process of alcoholic fermentation in yeast.

### CRITICAL THINKING

3. **Compare and Contrast** How are **lactic acid** fermentation and alcoholic fermentation similar? How are they different?
4. **Compare and Contrast** Describe the similarities and differences between cellular respiration and fermentation.

### Connecting CONCEPTS

5. **Cellular Respiration** How is the role of oxygen in cellular respiration similar to the role of $NAD^+$ in fermentation ?