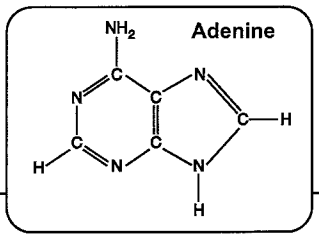
Cellular Energy

Section 8.1
ATP

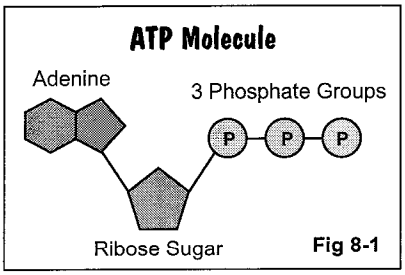


Pre-View 8.1

- **Adenosine triphosphate (ATP)** – a chemical compound used by living organisms to store and release energy
- **Adenosine diphosphate (ADP)** – a chemical compound that can be converted to ATP with the addition of one phosphate group

Introduction to ATP

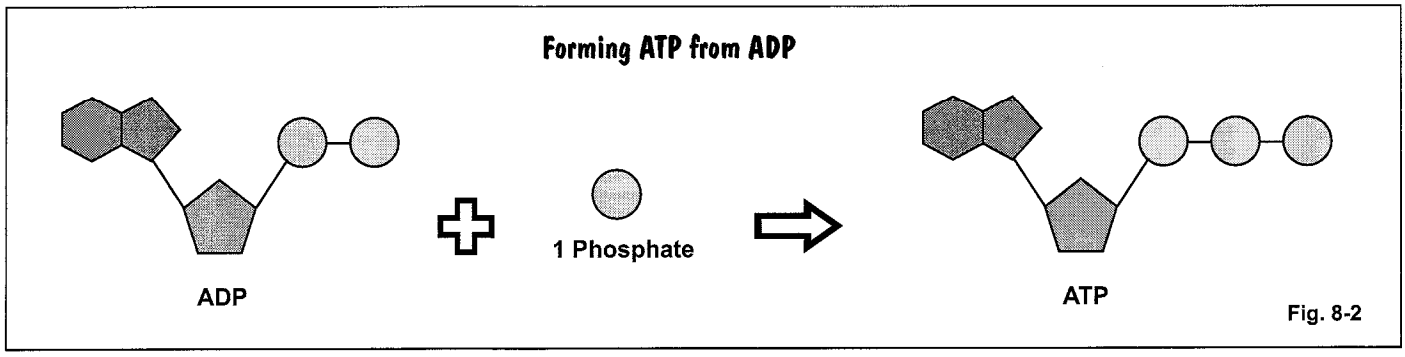
One of the characteristics of living organisms from section 4.1 is that all living organisms use energy. In a cell, energy is released when chemical reactions break chemical bonds. For example, when the chemical bonds in food are broken, cells obtain energy.



There are many different forms of energy, but the main form of energy for living organisms is **adenosine triphosphate**, or **ATP**. ATP is a chemical compound that living organisms use to store and release energy. It is made when organisms break down food such as glucose and starch (carbohydrates). A molecule of ATP has three main parts: adenine, ribose sugar, and three phosphate groups. The general chemical structure is given in figure 8-1.

This molecule is special because it can store energy when it adds the third phosphate group. With only two phosphate groups, the molecule is **ADP**, or **adenosine diphosphate**. It might help to think of ADP as a battery that is not fully charged. When the extra phosphate group is added, it becomes fully charged and is ready to release energy that the cell needs.

Although ATP is great for storing energy, most cells don't have very much ATP because it is not very good for storing energy over longer periods of time. Instead, cells have more ADP molecules. They can use the energy from carbohydrates to add a phosphate to ADP to create more ATP when needed (figure 8-2).



When a cell needs energy, it converts ATP back to ADP. When the third phosphate is removed from ATP, the chemical bond releases energy (figure 8-3) that can then be used by the cell.

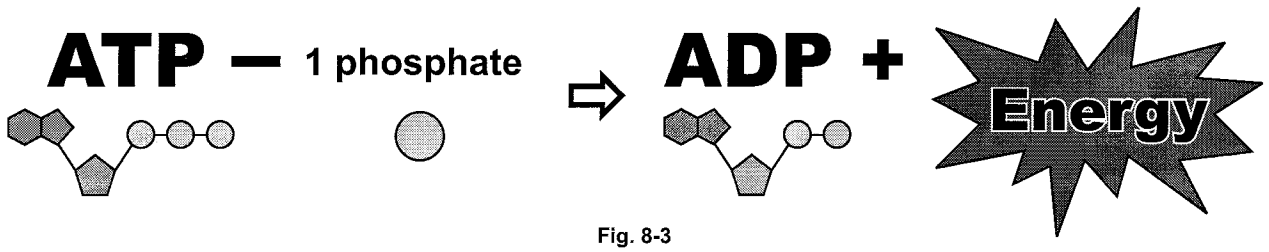


Fig. 8-3

Uses for ATP

The energy from ATP is useful to cells in many ways:

Some of the Uses for ATP

- It helps provide the energy for active transport.
- It helps to move organelles inside the cell.
- It is used to transmit nerve impulses.
- It is used to contract muscles.
- It is used by plants during photosynthesis to make glucose.

The **sodium-potassium pump** is a good example of how a cell uses ATP to move ions by active transport. Amimal cells need a greater number of potassium ions (K^+) inside the cell and a greater number of sodium ions (Na^+) outside the cell in order to transmit nerve impulses. The sodium-potassium pump is a carrier protein found in animal cells that moves these ions across the cell membrane. The sodium-potassium pump works in the following way:

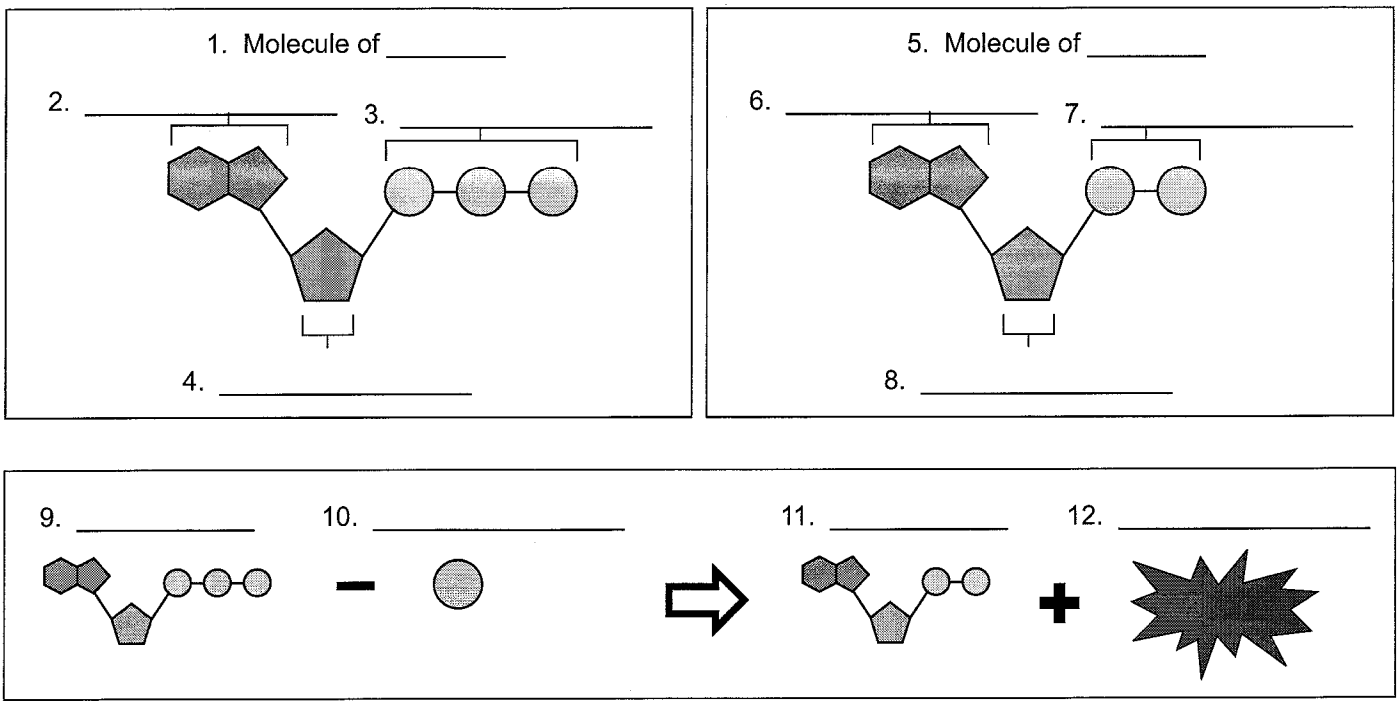
Sodium-Potassium Pump

1) Three sodium ions from inside the cell bind to sites inside the carrier protein.
2) ATP releases energy by giving a phosphate to the carrier protein.
3) Changing shape, the carrier protein releases the three sodium ions to the outside of the cell.
4) Now two potassium ions from outside the cell bind to sites inside the carrier protein.
5) The carrier protein releases the phosphate ion, changes back to its original shape, and releases the potassium ions inside the cell.

Many biological processes rely on ATP to provide energy. The sodium-potassium pump is just one example. Remember, any time a biological process needs energy from ATP, it will get that energy when a phosphate is *removed* from the ATP.

Practice 1

Label the following diagrams. Use the following terms: ADP, adenine, ATP, energy, phosphate(s), and ribose sugar.



Practice 2

Answer the following questions about ATP.

Ⓐ Ⓑ Ⓒ Ⓓ 1. Which of the following is NOT a part of an ATP molecule?

A. adenine
B. bicarbonate
C. phosphate
D. ribose sugar

Ⓐ Ⓑ Ⓒ Ⓓ 2. How is ADP different from ATP?

A. ADP has one more phosphate group and can store more energy.
B. ADP has one less phosphate group and can store more energy.
C. ADP has one more phosphate group and stores less energy.
D. ADP has one less phosphate group and stores less energy.

Ⓐ Ⓑ Ⓒ Ⓓ 3. When is energy released from ATP?

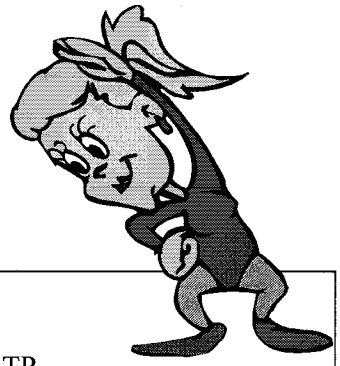
A. A chemical bond is broken and a phosphate is removed.
B. A chemical bond is broken and a phosphate is added.
C. A chemical bond is formed as a phosphate is removed.
D. A chemical bond is formed as a phosphate is added.

Ⓐ Ⓑ Ⓒ Ⓓ 4. Which of the following does NOT use ATP in a cell?

A. active transport
B. moving organelles
C. facilitated diffusion
D. sodium-potassium pump

Cellular Energy

Section 8.2
Aerobic and Anaerobic Cellular Respiration



Pre-View 8.2

- **Cellular respiration** – process used in cells to break down glucose and produce ATP
- **Glycolysis** – the first step in cellular respiration that takes place in the cytoplasm and converts one molecule of glucose to a net of two molecules of ATP
- **Aerobic respiration** – process that requires oxygen to produce a net of 36 molecules of ATP for every one molecule of glucose
- **Mitochondria** – part of the cell where aerobic respiration takes place
- **Krebs cycle** – the part of aerobic respiration that takes place in the mitochondria and produces two molecules of ATP for every one molecule of glucose
- **Electron transport chain** – the part of aerobic respiration that occurs in the mitochondria after the Krebs cycle and produces a net of 36 more ATP molecules for every one molecule of glucose
- **Anaerobic respiration** – process that does not require oxygen and produces a net of 2 molecules of ATP for every one molecule of glucose
- **Lactic acid fermentation** – anaerobic cellular respiration that occurs in animals and some bacteria
- **Alcoholic fermentation** – anaerobic cellular respiration that occurs in plants and other microorganisms such as yeast

In Section 8.1, we stated that organisms get energy from food molecules like glucose and starch. Now let's look more closely at how the cells get energy from these molecules.

ATP is the molecule that cells actually use for energy. Cells go through the process of **cellular respiration** to break down glucose molecules and to produce ATP molecules. All cells go through cellular respiration so they can get the energy they need. Let's look at cellular respiration more closely.

Cellular respiration starts in the cytoplasm with **glycolysis**. Through a series of reactions, one molecule of glucose is converted to a net gain of two ATP molecules that get the process going. Glycolysis is summarized in figure 8-4.

Glycolysis Summary

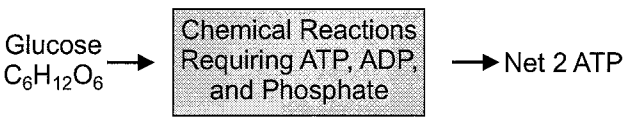


Fig. 8-4

Next there are two possibilities depending on whether or not oxygen is present. One possibility is aerobic respiration, and the other possibility is anaerobic respiration. The pathways for each are shown below in figure 8-5.

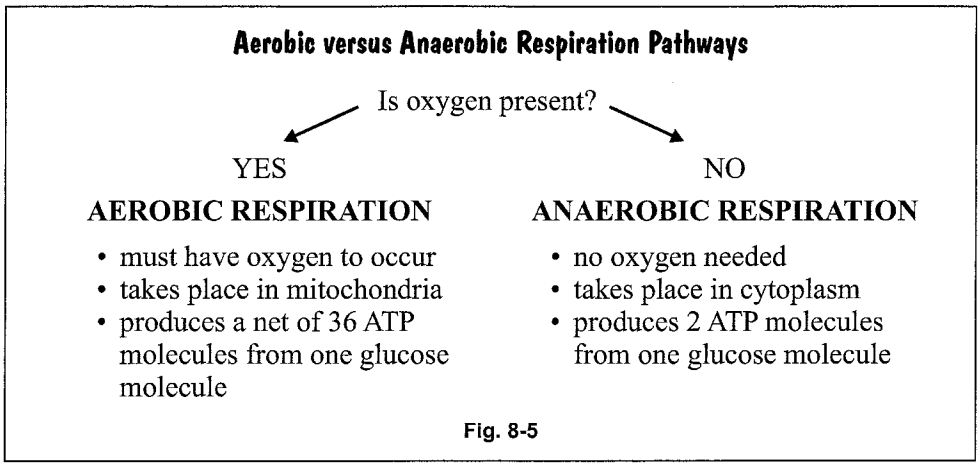


Fig. 8-5

Aerobic Respiration

Aerobic respiration occurs only when oxygen is present. In aerobic respiration, glycolysis occurs in the cytoplasm as mentioned previously, but it is followed by a process called the **Krebs cycle**, which takes place in the mitochondria. The Krebs cycle produces two more ATP. Next, 34 more molecules of ATP are formed through a process called the **electron transport chain**, which also takes place in the mitochondria. With glycolysis, aerobic respiration converts one molecule of glucose into a net of 36 molecules of ATP. (You may have counted 38 molecules of ATP, but 2 of those molecules are used up in the process.) A summary of aerobic respiration is given in figure 8-6.

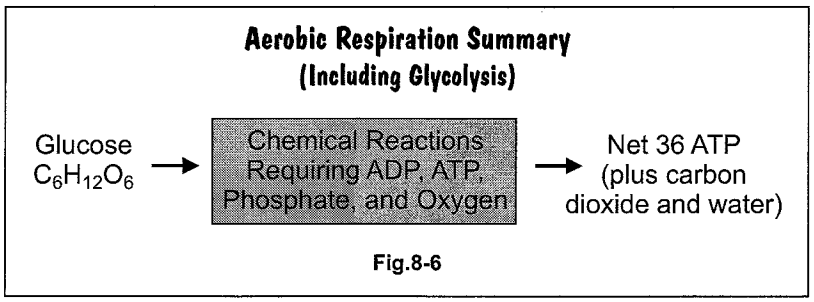


Fig.8-6

To summarize, aerobic respiration converts glucose and oxygen into carbon dioxide, water, and energy. The energy is stored as ATP. It may be helpful to memorize the net chemical reaction for aerobic respiration given below in figure 8-7.

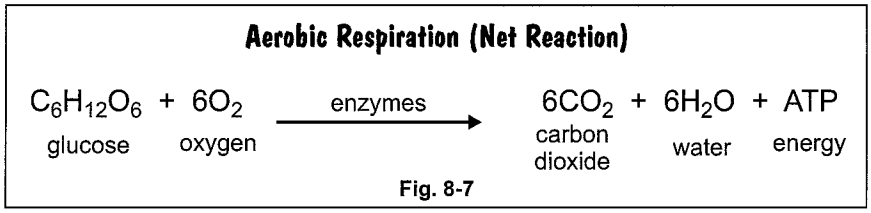


Fig. 8-7

Anaerobic Respiration

Anaerobic respiration happens if no oxygen is available to the cells. It is not very efficient since it produces only two molecules of ATP from one glucose molecule. (Compare that to the 36 ATP molecules produced by aerobic respiration.)

There are several types of anaerobic respiration. In animal cells and in some bacteria cells, glycolysis is followed by **lactic acid fermentation**. This lactic acid builds up in muscle cells, which is why you may feel sore after you exercise. Plant cells and some microorganisms such as yeast go through **alcoholic fermentation** after glycolysis. They produce ethyl alcohol. Both types of anaerobic respiration take place in the cytoplasm of the cells. A summary of anaerobic respiration can be seen below in figure 8-8. The net chemical reactions are given in figure 8-9.

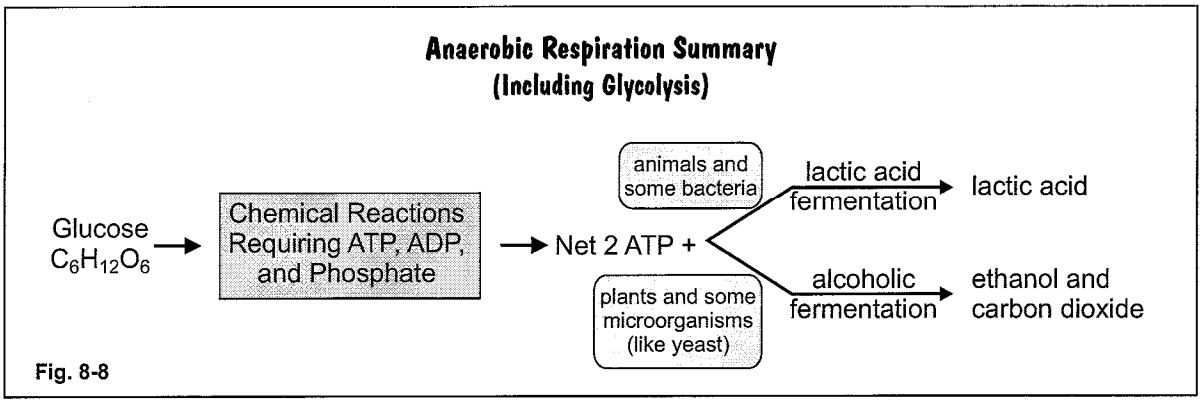


Fig. 8-8

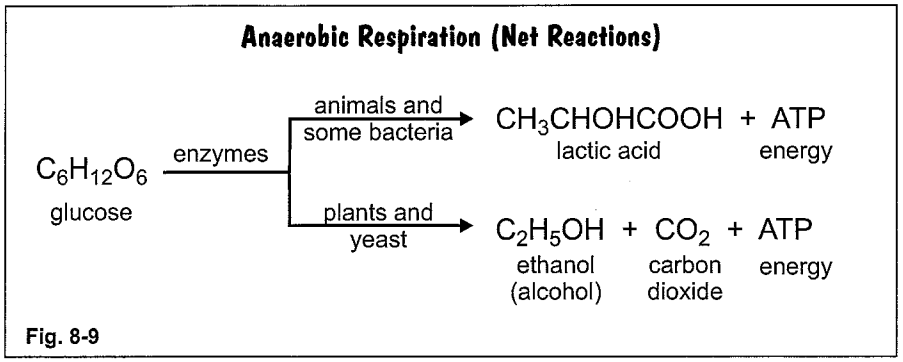


Fig. 8-9

Practice 1

Match each of the following terms with the BEST definition.

_____ 1. cellular respiration

_____ 2. glycolysis

_____ 3. aerobic respiration

_____ 4. anaerobic respiration

_____ 5. alcoholic fermentation

A. the first step of cellular respiration that takes place in the cytoplasm

B. the general type of cellular respiration that occurs when no oxygen is present

C. general process that breaks down glucose to produce ATP

D. the type of anaerobic respiration that occurs in plant cells

E. the general type of cellular respiration that occurs in the mitochondria when oxygen is available to a cell

Practice 2

Answer the following questions about cellular respiration.

Ⓐ Ⓑ Ⓒ Ⓓ 1. Which process starts cellular respiration?

A. lactic acid fermentation
B. the Krebs cycle
C. anaerobic respiration
D. glycolysis

Ⓐ Ⓑ Ⓒ Ⓓ 2. Which of these is NOT a part of aerobic respiration?

A. glycolysis
B. lactic acid fermentation
C. Krebs cycle
D. electron transport chain

Ⓐ Ⓑ Ⓒ Ⓓ 3. How many ATP molecules are produced from one glucose molecule by glycolysis?

A. 2
B. 8
C. 16
D. 36

Ⓐ Ⓑ Ⓒ Ⓓ 4. Where in the cell does most of aerobic respiration occur?

A. in the mitochondria
B. in the cytoplasm
C. in the chloroplast
D. in the Golgi apparatus

Ⓐ Ⓑ Ⓒ Ⓓ 5. Where in the cell does anaerobic respiration occur?

A. in the mitochondria
B. in the cytoplasm
C. in the chloroplast
D. in the Golgi apparatus

Ⓐ Ⓑ Ⓒ Ⓓ 6. During glycolysis, glucose is broken down into pyruvic acid, and two molecules of ATP are formed. What will happen next in a muscle cell if NO oxygen is available?

A. the Krebs cycle
B. glyogenosis
C. lactic acid fermentation
D. alcoholic fermentation

Ⓐ Ⓑ Ⓒ Ⓓ 7. When yeast is deprived of oxygen, it will convert glucose into what?

A. lactic acid
B. starch
C. ethanol
D. cellulose

Ⓐ Ⓑ Ⓒ Ⓓ 8. Which of the following processes does NOT release carbon dioxide?

A. aerobic respiration
B. alcoholic fermentation
C. lactic acid fermentation
D. all anaerobic respiration

Ⓐ Ⓑ Ⓒ Ⓓ 9. How many net ATP molecules are produced from one glucose molecule during the entire process of aerobic respiration?

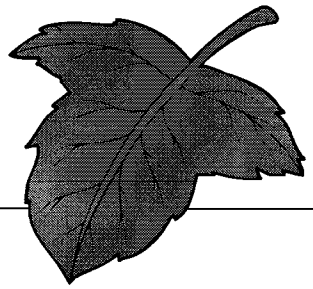
A. 2
B. 8
C. 16
D. 36

Ⓐ Ⓑ Ⓒ Ⓓ 10. How many net ATP molecules are produced from one glucose molecule if a cell undergoes anaerobic respiration?

A. 2
B. 8
C. 16
D. 36

Cellular Energy

Section 8.3
Photosynthesis



Pre-View 8.3

- **Heterotrophs** (also called ***consumers***) – organisms, such as animals, that obtain energy by consuming plants and other animals
- **Autotrophs** (also called ***producers***) – organisms, such as plants, that usually use energy directly from the sun to produce glucose and other carbohydrates
- **Carbon fixation** – the process of converting the inorganic carbon found in carbon dioxide to organic carbon in glucose
- **Photosynthesis** – process used by autotrophs that uses the sun's energy to convert water and carbon dioxide to glucose (simple sugar) and oxygen
- **Chlorophyll** – the green pigment found in the chloroplasts of plant cells that absorbs energy from the sun and uses that energy in the first stage of photosynthesis
- **Calvin cycle** – the stage of photosynthesis that does not require light

You know that all living things need energy, but where does that energy come from? In Sections 8.1 and 8.2, we discussed how energy comes from converting glucose (or simple sugar) into ATP, but where does the glucose come from? The sun is actually the main source of energy for living organisms although many organisms can't use that energy in its original form. All living organisms live by releasing energy found in chemical compounds such as glucose, but some can also use energy directly from the sun to make glucose.

Living organisms can be divided into two main groups: autotrophs and heterotrophs. **Heterotrophs** are organisms, such as animals, that get energy from the sun indirectly by consuming foods that have energy stored in them. Heterotrophs are also called ***consumers*** since they must consume food for energy. **Autotrophs** are organisms, such as plants, that can directly use the sun's energy to produce energy-containing chemical compounds such as glucose and other carbohydrates. Autotrophs are also called ***producers*** since they can produce their own food.

Through the process of **photosynthesis**, most autotrophs use the energy in sunlight to change water and carbon dioxide (CO_2) into glucose and oxygen. The net equation for photosynthesis is shown in figure 8-10 below:

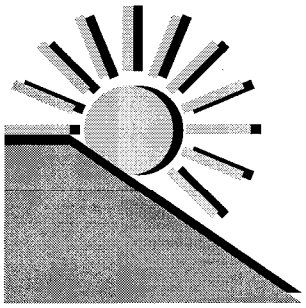
Photosynthesis

$$6CO_2 + 6H_2O \xrightarrow[\text{enzymes and chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$$

carbon dioxide | water | glucose (simple sugar) | oxygen

Fig. 8-10

Do you remember the difference between organic and inorganic compounds that you saw in Section 4.1? You may remember that carbon dioxide is an inorganic compound even though it contains carbon. Glucose, on the other hand, is an organic compound. So photosynthesis converts carbon from an inorganic compound into an organic one. This conversion is called **carbon fixation**. (Hint: Carbon dioxide cannot be used as food for us as humans. Once plants convert it into glucose, it is "fixed" into food that we can eat. The glucose made by photosynthesis helps to make up the potatoes, apples, lettuce, wheat, etc. that we eat.)



How do plants use chlorophyll and light energy to produce glucose? Photosynthesis has two main parts: the light dependent reactions and the light independent reactions. Let's start with the light dependent reactions.

Light Dependent Reactions

As the name implies, the light dependent reactions must have light for the reactions to occur. **Chlorophyll** is a green pigment found in the chloroplasts of plant cells. When the chlorophyll absorbs sunlight, some of the energy is also absorbed. This energy goes to the electrons in the chlorophyll. Through a series of steps, the energy from the electrons is used to convert ADP to ATP.

As light energy from the sun is converted to chemical energy stored in ATP, water molecules are split. Splitting water molecules releases oxygen back into the environment and produces hydrogen ions and electrons. The hydrogen ions from the water attach to a carrier molecule to be used in later steps of photosynthesis. (The carrier molecule is a coenzyme called NADP. When a hydrogen ion attaches to it, the NADP becomes NADPH.)

Summary of Light Dependent Stage of Photosynthesis

- This stage requires light.
- Electrons in the chlorophyll absorb the light energy.
- Energy from electrons converts ADP to ATP.
- Water molecules are split to form oxygen, hydrogen ions, and electrons.
- Hydrogen ions attach to carrier molecules to be used in later steps of photosynthesis. (The carrier molecule NADP becomes NADPH.)

Light Independent Reactions/The Calvin Cycle

The second part of photosynthesis is the **Calvin cycle**, or the light independent reactions. Light is not needed for this part of photosynthesis. In the Calvin cycle, enzymes combine carbon dioxide from the atmosphere with the hydrogen ions, which were formed in the light dependent stage, to form glucose. These reactions convert the energy stored in ATP (also formed in the light dependent stage) to energy stored in the chemical bonds of glucose. If more glucose is made than the plant can use, then it is stored as complex carbohydrates, such as cellulose and starch.

Summary of the Calvin Cycle (Light Independent Stage of Photosynthesis)

- This stage does NOT require light.
- Carbon dioxide and hydrogen ions combine to form simple sugars.
- Simple sugars can be stored as complex carbohydrates, such as cellulose and starch.

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{hydrogen ions}}{H^+} \xrightarrow[\text{and ATP}]{\text{enzymes}} \underset{\text{glucose}}{C_6H_{12}O_6}$$

Plants use the glucose made in photosynthesis to get energy. They also convert the glucose to larger, more complex carbohydrates, such as starch and cellulose, that are needed for development and growth. If another organism eats a plant, the organism breaks the chemical bonds holding the carbohydrate molecules together (through the process of cellular respiration). The stored energy is then released for the organism's own use.

Practice

Answer the following questions on photosynthesis.

Ⓐ Ⓑ Ⓒ Ⓓ 1. Which of the following is an example of an autotroph?

A. an oak tree
B. a butterfly
C. a mushroom
D. a dog

Ⓐ Ⓑ Ⓒ Ⓓ 2. Which of the following is a characteristic of a heterotroph?

A. uses energy directly from the sun
B. uses chlorophyll to absorb energy
C. undergoes photosynthesis to create glucose
D. obtains energy by consuming other organisms

Ⓐ Ⓑ Ⓒ Ⓓ 3. Which of the following chemical reactions correctly summarizes photosynthesis?

A. $4CO_2 + 6H_2O + 2O_2 \rightarrow C_6H_{12}O_6$
B. $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
C. $6H_2O + 6H_2 \rightarrow C_6H_{12}O_6$
D. $6CO_2 + 6H_2O + 6O_2 \rightarrow C_6H_{12}O_6 + O_2$

Ⓐ Ⓑ Ⓒ Ⓓ 4. Which of these does NOT occur during the light dependent reactions of photosynthesis?

A. Chlorophyll absorbs energy from the sun.
B. Carbon dioxide combines with hydrogen ions to form sugar.
C. Water molecules are split.
D. ATP is produced.

Ⓐ Ⓑ Ⓒ Ⓓ 5. Which of the following is true about the energy used in the light independent reactions?

A. It comes directly from the sun.
B. It comes from molecules stored in the roots of the plant.
C. It is produced during the Calvin cycle.
D. It is produced in the light dependent reactions.

Ⓐ Ⓑ Ⓒ Ⓓ 6. In photosynthesis, energy from the sun is converted to (and stored in) which of the following?

A. chemical bonds in carbohydrates
B. enzymes in the chloroplasts
C. carbon dioxide and water
D. chlorophyll

Ⓐ Ⓑ Ⓒ Ⓓ 7. What kind of molecule is responsible for absorbing energy from the sun?

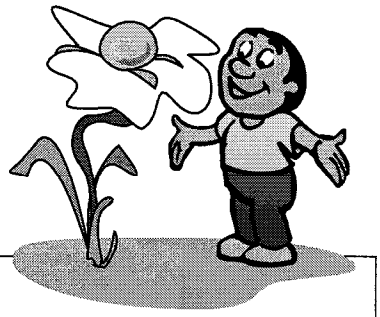
A. ATP
B. ADP
C. chlorophyll
D. mitochondria

Ⓐ Ⓑ Ⓒ Ⓓ 8. Which of the following is a product of photosynthesis?

A. carbon dioxide
B. light energy
C. oxygen
D. carbon monoxide

Cellular Energy

Section 8.4
Relationship Between Cellular Respiration and Photosynthesis



Pre-View 8.4

- **Cellular respiration** – process that converts glucose and oxygen into carbon dioxide and water and releases energy as ATP
- **Photosynthesis** – process that uses light energy to convert carbon dioxide and water into glucose and oxygen

Have you noticed that the same terms used to describe cellular respiration are also used to describe photosynthesis? What is their relationship? Look at the reaction summaries below in figure 8-11.

Cellular Respiration (Aerobic) vs. Photosynthesis

cellular respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

glucose oxygen → carbon dioxide water

photosynthesis: $6CO_2 + 6H_2O \xrightarrow{\text{light energy}} C_6H_{12}O_6 + 6O_2$

carbon dioxide water → glucose oxygen

Fig. 8-11

You should notice that the reactions are nearly opposites. The reactants of cellular respiration, glucose and oxygen, are the products of photosynthesis. The products of cellular respiration, carbon dioxide and water, are the reactants of photosynthesis!

The relationship between photosynthesis and cellular respiration can also be summarized in figure 8-12. Plants use carbon dioxide to produce oxygen by the process of photosynthesis. Humans and animals use oxygen and produce carbon dioxide by cellular respiration. The processes of photosynthesis and cellular respiration cycle carbon between the atmosphere and living organisms. Photosynthesis converts the inorganic carbon in carbon dioxide to organic carbon found in glucose. Cellular respiration converts the organic carbon in glucose to inorganic carbon in carbon dioxide. These two process are also part of the oxygen cycle. You'll see more about these cycles in Section 18.

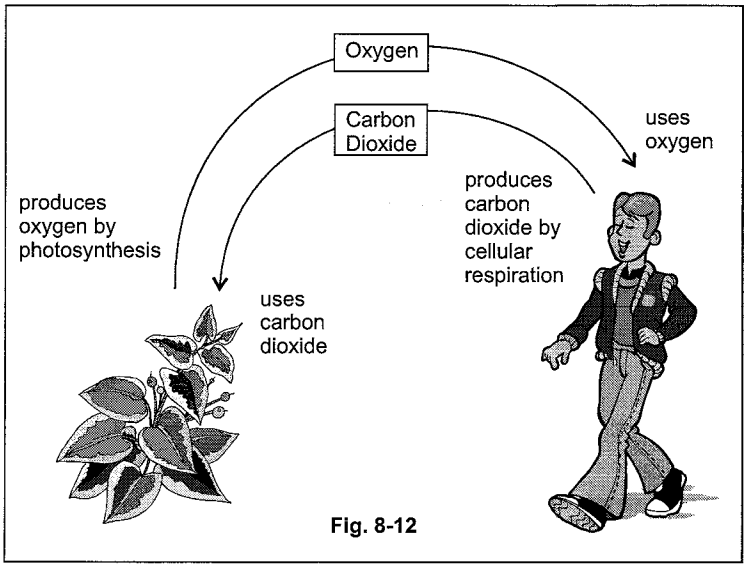


Fig. 8-12

The following chart summarizes each process. Notice how they are alike and how they are different.

Cellular Respiration Versus Photosynthesis

	CELLULAR RESPIRATION	PHOTOSYNTHESIS
Takes place where?	all cells	cells with chlorophyll (such as in the leaf cells of plants)
Occurs when?	all of the time	in the presence of light
What goes in? (the reactants)	glucose and oxygen	carbon dioxide and water
What comes out? (the products)	carbon dioxide and water	glucose and oxygen
Energy source?	chemical bonds in glucose	light
Result?	energy is stored as ATP	energy is stored as glucose

Practice

Answer the following questions.

Ⓐ Ⓑ Ⓒ Ⓓ 1. Which of the following is a TRUE statement about cellular respiration?

A. Cellular respiration converts the energy directly from the sun into energy stored in chemical bonds.
B. Cellular respiration cannot occur without sunlight.
C. Cellular respiration occurs in plant cells and in animal cells.
D. Cellular respiration converts carbon dioxide and water into carbohydrates and glucose.

Ⓐ Ⓑ Ⓒ Ⓓ 2. Which of the following is a TRUE statement about photosynthesis?

A. Photosynthesis occurs only in cells that contain chlorophyll.
B. Photosynthesis converts the chemical energy stored in carbohydrate bonds to light energy.
C. Photosynthesis converts carbohydrates and oxygen into carbon dioxide and water.
D. Photosynthesis occurs when light energy is not available.

Ⓐ Ⓑ Ⓒ Ⓓ 3. Which of the following is NOT true about the relationship between cellular respiration and photosynthesis?

A. Photosynthesis and cellular respiration cycle carbon between living organisms and the atmosphere.
B. The chemical reactions in cellular respiration use glucose and oxygen to produce carbon dioxide and water. The chemical reactions for photosynthesis do the opposite.
C. Cellular respiration is needed in all cells and takes place all the time, but photosynthesis only occurs in certain plant cells when light is available.
D. The source of energy for cellular respiration is light, but the source of energy for photosynthesis is the chemical bonds in carbohydrate molecules.

Cellular Energy
Section 8 Review

Answer the following questions on cellular energy.

1. Both ADP and ATP contains which of these sugars?

A adenine
B ribose
C glucose
D guanine

Ⓐ Ⓑ Ⓒ Ⓓ

2. ATP releases energy when a bond is broken between which of the following?

F two phosphate groups
G adenine and ribose
H adenine and a phosphate group
J ribose and a phosphate group

Ⓕ Ⓖ Ⓗ Ⓙ

3. Why do cells tend to have more ADP molecules than ATP molecules?

A ADP stores more energy.
B ATP is used only by plant cells.
C ADP is a smaller molecule than ATP, so more ADP molecules can fit into a cell.
D ATP does not store long-term energy.

Ⓐ Ⓑ Ⓒ Ⓓ

4. Which of the following is NOT true about ATP?

F ATP consists of adenine, ribose, and phosphate.
G When ATP releases energy, ADP is formed.
H ATP provides energy for cells to function.
J Used ATP is discarded by the cell as waste.

Ⓕ Ⓖ Ⓗ Ⓙ

5. Which of the following processes does NOT use ATP for energy?

A muscle contraction
B nerve transmission
C osmosis
D exocytosis

Ⓐ Ⓑ Ⓒ Ⓓ

6. Which of these is NOT part of aerobic cellular respiration?

F photosynthesis
G electron transport
H Krebs cycle
J glycolysis

Ⓕ Ⓖ Ⓗ Ⓙ

7. What is the main purpose of cellular respiration in cells?

A to obtain energy to use in other processes
B to form glucose and store energy in its chemical bonds
C to produce lactic acid in animals or to produce alcohol in plants
D to create carbon dioxide and water

Ⓐ Ⓑ Ⓒ Ⓓ

8. What does cellular respiration always release?

F oxygen
G carbon monoxide
H energy
J lactic acid

Ⓕ Ⓖ Ⓗ Ⓙ

9. Which of the following is needed for aerobic respiration?

A carbon dioxide
B oxygen
C chlorophyll
D magnesium

Ⓐ Ⓑ Ⓒ Ⓓ

10. Which of these is broken down during cellular respiration to release energy?

F glucose
G ADP
H water
J carbon dioxide

Ⓕ Ⓖ Ⓗ Ⓙ

11. Which of the following processes produces the most ATP?

A aerobic respiration
B glycolysis
C lactic acid fermentation
D alcoholic fermentation

Ⓐ Ⓑ Ⓒ Ⓓ

12. Which of these occurs in the cytoplasm of a cell?

F glycolysis
G electron transport
H Krebs cycle
J photosynthesis

Ⓕ Ⓖ Ⓗ Ⓙ

13. Where can lactic acid fermentation be found to occur?

A in bread that is rising
B in any environment without oxygen
C in muscle cells
D in mitochondria

Ⓐ Ⓑ Ⓒ Ⓓ

14. Which of the following correctly summarizes aerobic cellular respiration?

F $6O_2 + C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$
G $6O_2 + C_6H_{12}O_6 + \text{Energy} \rightarrow 6CO_2 + 6H_2O$
H $6CO_2 + 6H_2O \rightarrow 6O_2 + C_6H_6O_6 + \text{Energy}$
J $6CO_2 + 6H_2O + \text{Energy} \rightarrow 6O_2 + C_6H_{12}O_6$

Ⓕ Ⓖ Ⓗ Ⓙ

15. When oxygen is present, what follows glycolysis?

A photosynthesis
B lactic acid fermentation
C alcohol fermentation
D the Krebs cycle

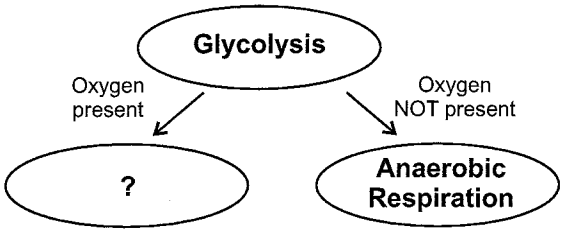
Ⓐ Ⓑ Ⓒ Ⓓ

16. Which of the following is a true statement about how energy is stored in living organisms?

F Energy is stored when a third phosphate group breaks off from an ADP molecule.
G Energy is stored when cells break down sucrose to form glucose and fructose.
H Energy is stored when a third phosphate group is bonded to an ADP molecule to form ATP.
J Energy is stored when minerals are released into the bloodstream.

Ⓕ Ⓖ Ⓗ Ⓙ

17. Study the diagram below.



Which process is represented by the question mark?

A photosynthesis
B fermentation
C aerobic respiration
D chemosynthesis

Ⓐ Ⓑ Ⓒ Ⓓ

18. What is the most important purpose of photosynthesis to plants?

F to create oxygen
G to store energy in the chemical bonds of glucose
H to break down glucose into carbon dioxide and water
J to create sunlight

Ⓕ Ⓖ Ⓗ Ⓙ

19. Which of the following best summarizes the process of photosynthesis?

A $C + O_2 + H_2O + \text{energy} \rightarrow CO_2 + H_2O$
B $6CO_2 + 6H_2O + \text{energy} \rightarrow C_6H_{12}O_6 + 6O_2$
C $C_{12}H_6O_6 \rightarrow 6CO_2 + 6H_2O + \text{energy}$
D $6CO + 6H_2O \rightarrow C_6H_{12}O_6 + \text{energy}$

Ⓐ Ⓑ Ⓒ Ⓓ

20. Consider the following chemical reaction that can take place in plants and yeast.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{ethanol (alcohol)}}{C_2H_5OH} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{energy}}{ATP}$$

Which process is represented by this reaction?

F photosynthesis
G fermentation
H aerobic respiration
J glycolysis

Ⓕ Ⓖ Ⓗ Ⓙ

21. What is the green pigment that traps energy from sunlight called?

A chloroplasts
B ATP
C chlorophyll
D thylakoid membranes

Ⓐ Ⓑ Ⓒ Ⓓ

22. Plants take in the sun's energy by absorbing what?

F high-energy carbohydrates
G chlorophyll
H chloroplasts
J sunlight

Ⓕ Ⓖ Ⓗ Ⓙ

23. Which of the following is produced by the Calvin cycle?

A oxygen gas
B ADP
C high-energy sugar
D carbon dioxide

Ⓐ Ⓑ Ⓒ Ⓓ

24. During photosynthesis, what occurs in the light dependent reactions?

F Carbon dioxide is released.
G Oxygen is released.
H Water molecules are created from hydrogen and oxygen.
J NADP is produced.

Ⓕ Ⓖ Ⓗ Ⓙ

25. During the light dependent reactions of photosynthesis, which of the following is NOT produced?

A oxygen
B ATP
C NADPH
D glucose

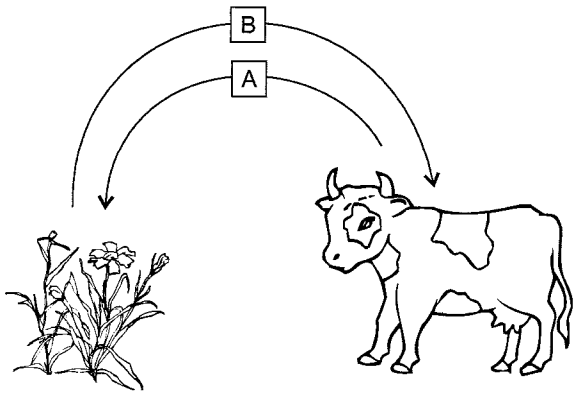
Ⓐ Ⓑ Ⓒ Ⓓ

26. Photosynthesis and cellular respiration cycle which of the following between the atmosphere and living organisms?

F ADP and ATP
G water and hydrogen
H carbon and oxygen
J glucose and starch

Ⓕ Ⓖ Ⓗ Ⓙ

27. The diagram below represents the relationship between photosynthesis and cellular respiration.



What does the arrow labeled A represent?

A water
B glucose
C oxygen
D carbon dioxide

Ⓐ Ⓑ Ⓒ Ⓓ

28. In the diagram above, what does the arrow labeled B represent?

F water
G glucose
H oxygen
J carbon dioxide

Ⓕ Ⓖ Ⓗ Ⓙ