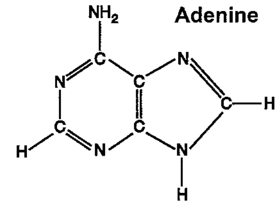
Cellular Energy

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.

ATP Molecule

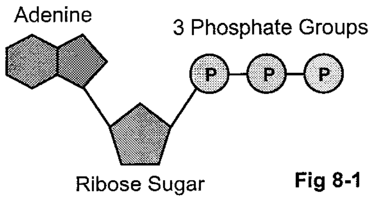


Fig 8-1

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).

Forming ATP from ADP

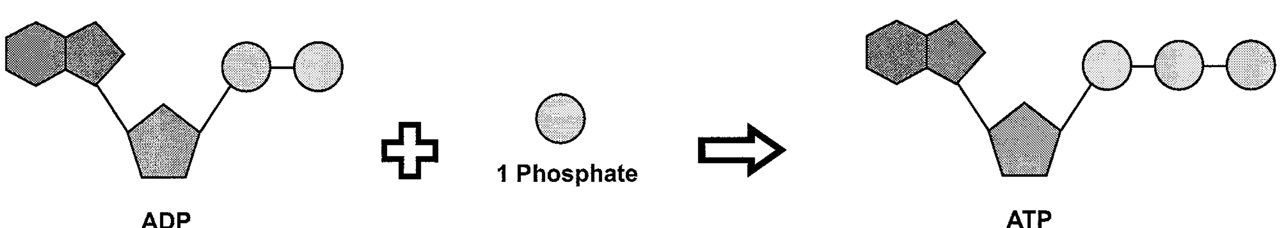


Fig. 8-2

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.

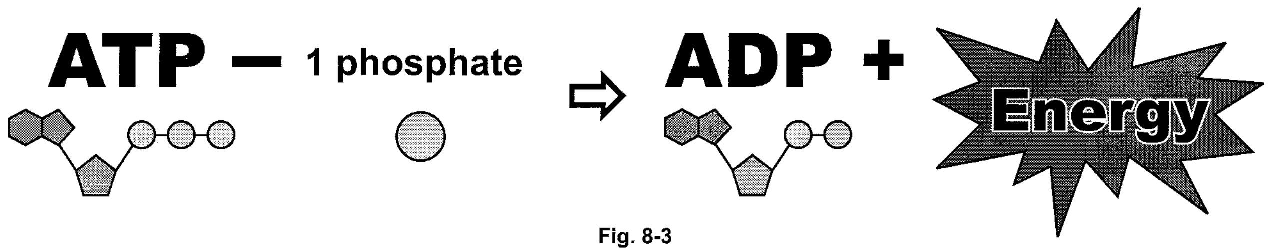


Fig. 8-3

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.

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

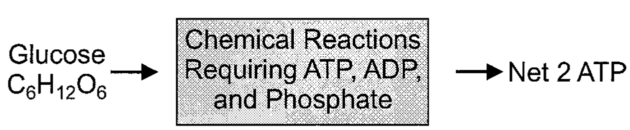


Fig. 8-4

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.

Aerobic versus Anaerobic Respiration Pathways

Is oxygen present?

YES	NO
AEROBIC RESPIRATION	**ANAEROBIC RESPIRATION**
• must have oxygen to occur • takes place in mitochondria • produces a net of 36 ATP molecules from one glucose molecule	• no oxygen needed • takes place in cytoplasm • produces 2 ATP molecules from one glucose molecule

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.

Aerobic Respiration Summary
(Including Glycolysis)

Glucose $C_6H_{12}O_6$ → Chemical Reactions Requiring ADP, ATP, Phosphate, and Oxygen → Net 36 ATP (plus carbon dioxide and water)

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.

Aerobic Respiration (Net Reaction)

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \xrightarrow{\text{enzymes}} \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{energy}}{ATP}$$

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.

Anaerobic Respiration Summary
(Including Glycolysis)

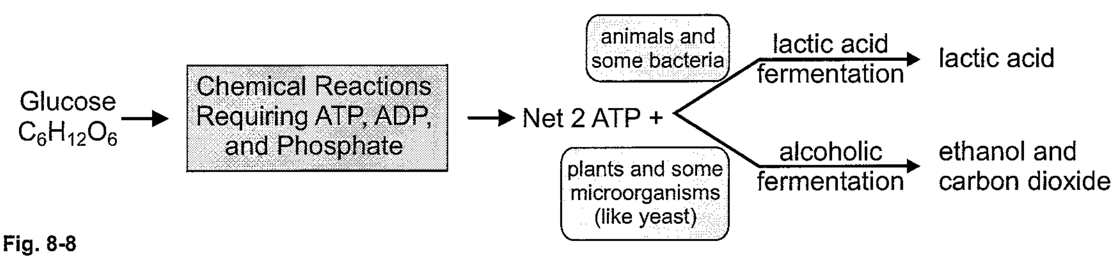


Fig. 8-8

Anaerobic Respiration (Net Reactions)

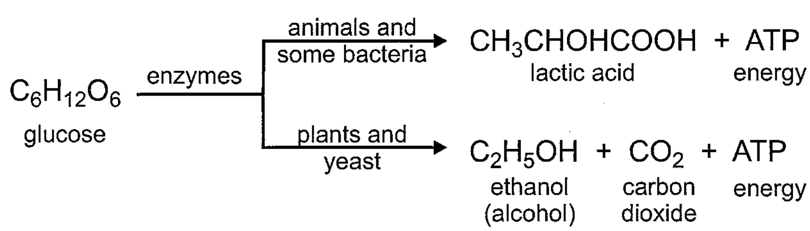
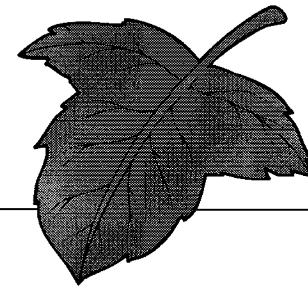


Fig. 8-9

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:

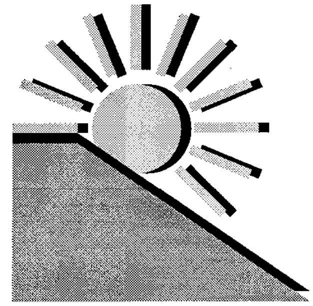
Photosynthesis

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

$6CO_2$	$6H_2O$		$C_6H_{12}O_6$	$6O_2$
carbon dioxide	water	light energy / enzymes and chlorophyll	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.

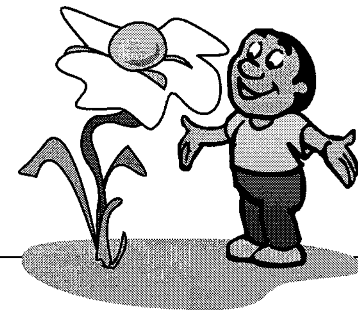
$$CO_2 + H^+ \xrightarrow[\text{and ATP}]{\text{enzymes}} C_6H_{12}O_6$$

carbon dioxide + hydrogen ions → glucose

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.

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.

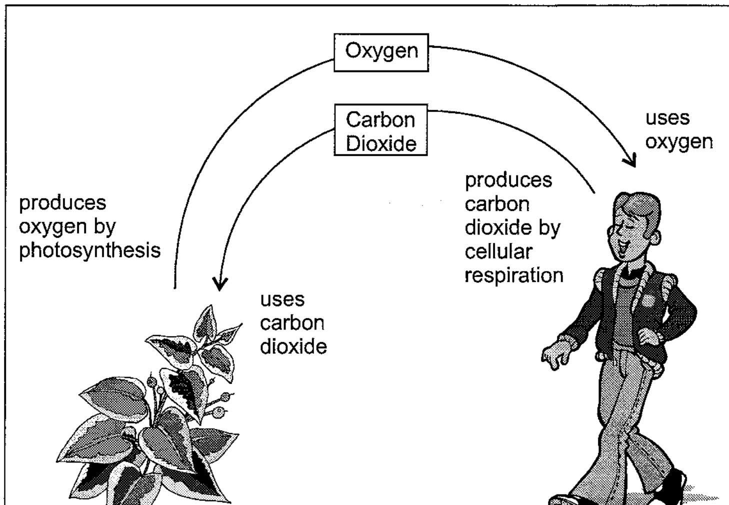


Fig. 8-12

Section 8.4, continued
Relationship Between Cellular Respiration and Photosynthesis

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