

## Cellular Energy

### Objectives

- Describe the purpose of photosynthesis
- Describe the purpose of cellular respiration
- Explain how matter and energy flows between organisms that undergo photosynthesis and cellular respiration

### Key Terms

Autotroph  
Heterotroph  
Adenosine triphosphate  
Photosynthesis  
Cellular respiration

### Connect to Your World

How would the world be different if the sun stopped emitting light energy?

We know that all living things need food to produce energy for survival, but have you ever thought about how food provides organisms with the energy they need? The answer is complex and depends on the type of organisms and the food available.

Photosynthesis and cellular respiration are the chemical processes that allow organisms to transform matter and energy from the environment into usable forms. These two processes are essential to the function of all ecosystems by continuing to cycle matter and energy between organisms and the environment.

### Organisms, Energy, and Processes

There are two types of organisms we will be discussing—autotrophs and heterotrophs. The term **autotroph** breaks down into auto, meaning self, and troph, meaning nourishment. Autotrophs are able to provide their own nourishment or food, but this only happens with the help of the energy provided by the sun through the process of photosynthesis. **Heterotrophs**, on the other hand, are organisms that must gain nourishment from other sources, that is they must consume their nourishment.

Ecosystems are dependent upon many different types of energy. The law of conservation of energy states that energy cannot be created or destroyed but can be transformed. This is why the sun is considered to be the beginning source of all energy on Earth. Light energy from the sun may seem insignificant but it is vital for fueling the process of photosynthesis.

Organisms constantly need to convert energy in order to survive. Plants and animals have developed very different ways of addressing their energy requirements. However, all organisms rely on converting energy to a usable form.

# Cellular Energy

## Adenosine Triphosphate

ATP is a molecule that is made up of three parts: adenine, ribose, and three phosphate molecules. Figure 1 shows how the energy carried by ATP is made available when the bond between the second and third phosphate is broken. As a phosphate group is released, the molecule becomes adenosine diphosphate, or ADP. ADP is a lower-energy molecule that can easily store energy by adding an additional phosphate group. This back-and-forth process is a complex reaction that cells must carry out countless times a day to maintain the survival of the organism.

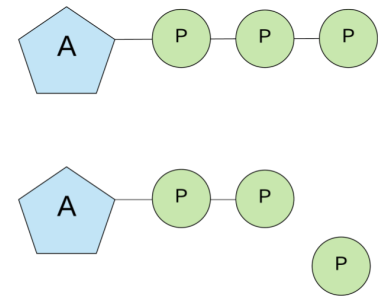


Figure 1

Remember that glucose, although considered a biomolecule for energy, is only the reactant to help our body produce the energy needed, ATP. Our diets are usually composed of a combination of carbohydrates, lipids, and proteins. Each of these biomolecules can be broken down into varying amounts of ATP. Carbohydrates are the molecules that can most easily be broken down to make ATP. Carbohydrates are polymers made of simple sugars, such as glucose. One glucose molecule can provide an organism with approximately 36 ATP molecules.

A small group of organisms can convert a different molecule into ATP to power their cellular processes. These organisms carry out a process called *chemosynthesis*. Chemosynthesis uses chemicals such as sulfides to produce ATP rather than using sunlight. Organisms that carry out chemosynthesis often live in places that receive little to no sunlight. These organisms are similar to plants in that they can make their own food; however, the inputs for the reaction are different.

We know that organisms use ATP as an energy currency to fuel cellular activity. But where does the ATP come from? First, plants convert energy from sunlight into chemical energy. Second, mitochondria in both plants and animals convert chemical energy into ATP. Let's look at both of these processes more closely.

## What is Photosynthesis?

**Photosynthesis** is a chemical process that autotrophs use to transform light energy into stored chemical energy in the form of glucose (see figure 2). Autotrophs are often called *producers* because they are able to produce their own food. The sun is the major source of light energy, however, many autotrophs can use artificial sources of light to perform photosynthesis as well. Plants and other photosynthetic organisms use carbon dioxide and water from the environment and light energy to synthesize glucose and oxygen. Either directly, or indirectly, all organisms in an ecosystem rely on the sun as an energy source.

## PHOTOSYNTHESIS

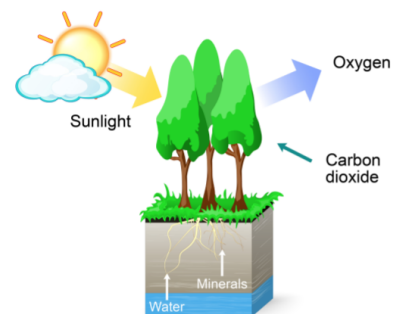
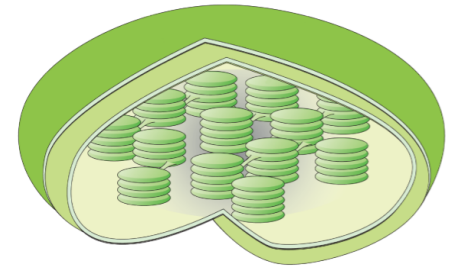


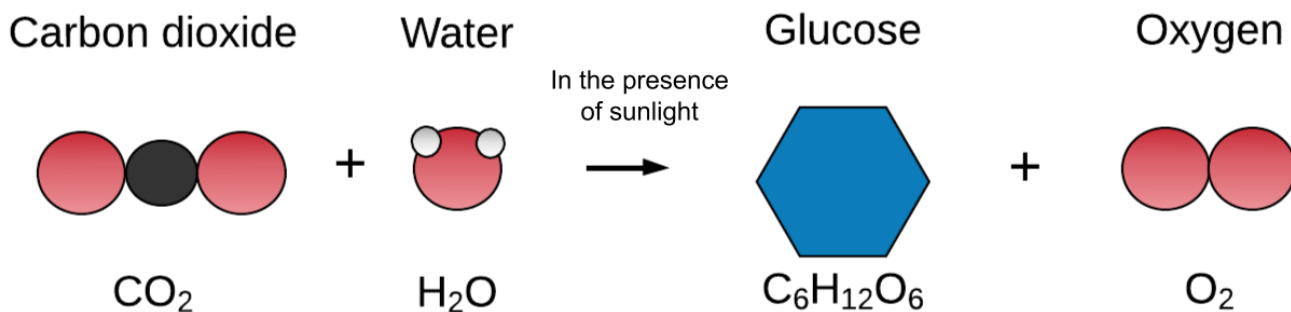
Figure 2

# Cellular Energy

Photosynthesis is a complex process that takes place within the chloroplast of plant cells (figure 3). The chloroplast is an organelle that contains chlorophyll, a pigment that absorbs light. Most chloroplasts are found in the leaves of plants which are best placed to gain maximum exposure to the sun. The process of photosynthesis requires carbon dioxide, light, and water. All these reactants are found in the plant's environment. Water is absorbed by the roots of the plant, and carbon dioxide enters the plants through small holes in the leaves called *stomata*. Light is absorbed by the chloroplasts in the leaves. When plants have these reactants they will produce glucose and oxygen. Plants store the glucose made by photosynthesis and release oxygen into the environment. The full chemical reaction for photosynthesis is below in figure 4.



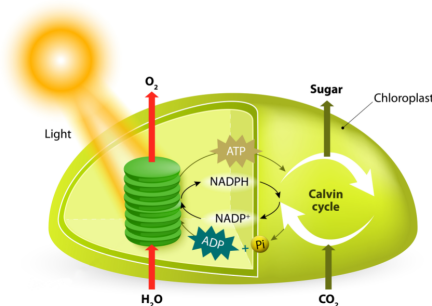
**Figure 3**



**Figure 4**

While the process of photosynthesis may seem very simple when you look at reactants and products, in actuality, it is a very complex process. Two different reactions are required for photosynthesis to be carried out: the light-dependent reaction and the light-independent reaction. This overall process can be seen in figure 5.

In light-dependent reactions, light photons (units of light energy) are absorbed and converted to ATP. This takes place in thylakoids, a series of flat, stacked disks located in chloroplasts. Thylakoids are bound inside a thylakoid membrane, along with the green pigment, chlorophyll.



**Figure 5**

Chlorophyll gives green plants their characteristic color. When light energy hits the thylakoid membrane, it is used to excite electrons in the photosystems and to split water. When the water molecules are split, the oxygen diffuses into the atmosphere. The electrons enter the electron transport chain, and the hydrogen ions exit the thylakoid membrane, where they are picked up and transported to the Calvin cycle on NADPH, a carrier protein molecule.

In the light-independent reactions, carbon dioxide and the products of the light-dependent reaction (ATP and NADPH) undergo a series of reactions known as the *Calvin cycle*. The Calvin cycle produces glucose as its end product. The combination of the light-dependent and light-independent reaction results in the overall equation for photosynthesis.

Now, glucose is available to be converted into the energy needed for cellular processes in the autotroph. Glucose contains chemical energy found in the bonds of the molecule. This energy can be released when these bonds are broken and new molecules are produced.

Glucose must now go through an additional process to release that stored energy into a usable form for the organism. This brings us to cellular respiration. It is important to remember that both autotrophs and heterotrophs use cellular respiration to create the necessary energy from glucose.

## The Nature of Science in Action

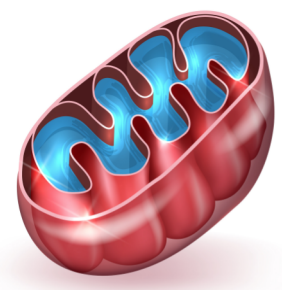
### Energy and Matter

Energy cannot be created or destroyed. It only moves between one place and another place, between objects and fields, or between systems.

The energy transferred from the sun cannot be destroyed, it can be transferred or transformed through chemical reactions such as photosynthesis.

## What is Cellular Respiration?

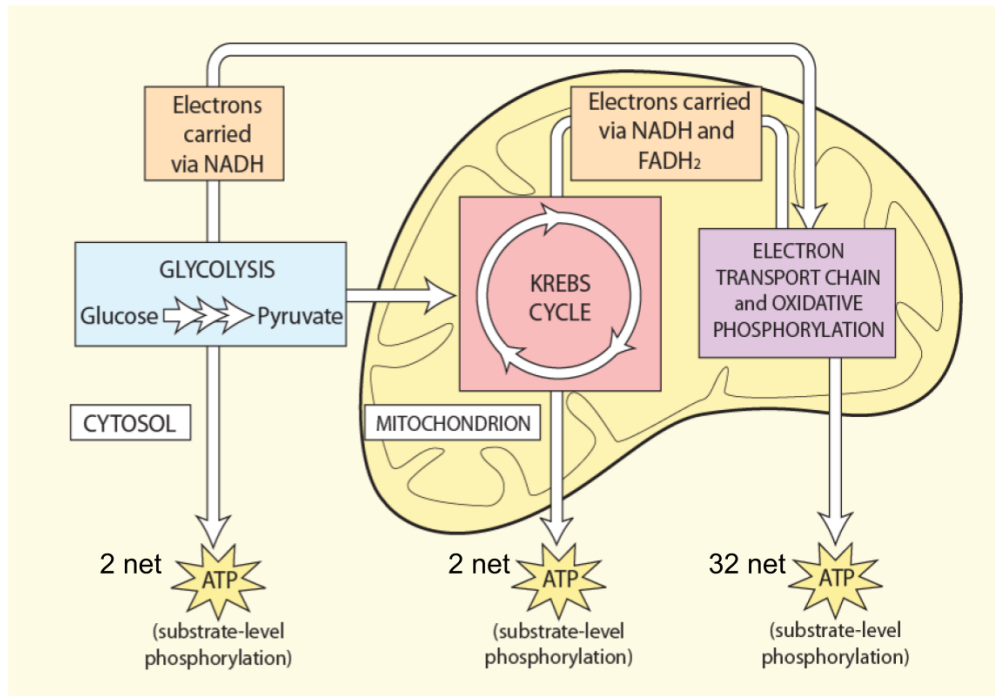
**Cellular respiration** is a chemical process used by autotrophs and heterotrophs to break down glucose molecules into **adenosine triphosphate**, or ATP. ATP is the main energy source for living organisms. This process occurs in the mitochondria of cells (figure 6). Cellular respiration can be aerobic or anaerobic. When oxygen is present, it is an aerobic process. This is the ideal process for organisms to access the most ATP from one glucose molecule.



**Figure 6**

Let's take a close look at aerobic cellular respiration. The inputs required are glucose and oxygen. These inputs, or reactants, will then be transformed into ATP, carbon dioxide, and water. One molecule of glucose can yield approximately 36 molecules of ATP.

Figure 7 below shows the overall chemical reaction for cellular respiration and the location of the processes.



**Figure 7**

## *Glycolysis*

The first step in aerobic respiration is known as glycolysis. During this process, glucose enters the cell. While in the cytoplasm, glucose is broken down into two three-carbon molecules called *pyruvate*. Although the cells uses some ATP to begin glycolysis, the overall process produces more ATP than was used to initiate it. For each molecule of glucose that enters glycolysis, a net of two ATP molecules are generated. After glycolysis, the remaining two steps of aerobic respiration take place in the mitochondria of eukaryotic cells.

## *Krebs cycle*

The two pyruvic acid molecules formed during glycolysis move into the mitochondria, where they initiate a series of enzymatic reactions that release electrons and hydrogen ions, and they produce carbon dioxide and two molecules of ATP. The carbon dioxide diffuses out of the mitochondria. The electrons and hydrogen ions are carried to the electron transport chain on NADH (a carrier protein molecule, similar to NADPH).

## Electron transport chain

Products from the Krebs cycle move across the inner membrane of the mitochondria. It is called the *electron transport chain* because electrons are shuttled back and forth across the inner mitochondrial membrane as part of this process. At the end of the electron transport chain, a process known as *oxidative phosphorylation* takes place. Here, the enzyme ATP synthase adds phosphate to ADP, creating approximately 32 ATP molecules per glucose in the process. With just one glucose molecule, aerobic respiration yields 36 net ATP molecules after the processes of glycolysis, the Krebs cycle, and the electron transport chain.

## The Cycling of Matter and Energy

The different levels of organization in living systems have varying energy needs, however, they all use energy and matter found within the environment and the biotic factors in an ecosystem. The processes of photosynthesis and cellular respiration keep matter cycling and energy flowing throughout the ecosystem.

### How does matter cycle in the ecosystem?

Beginning with the inputs of photosynthesis, the environment is a source of water and carbon dioxide that plants use to transform into glucose and oxygen. The oxygen is then released into the environment for other organisms to breathe or use to help power cellular respiration. Additionally, the glucose produced by plants is then consumed by heterotrophs and can be broken down into ATP, water, and carbon dioxide. Water and carbon dioxide are eliminated from the body and then released back into the environment for plants to use for photosynthesis. The cycle continues on and on, transforming matter into various molecules to sustain life. This is depicted in figure 8.

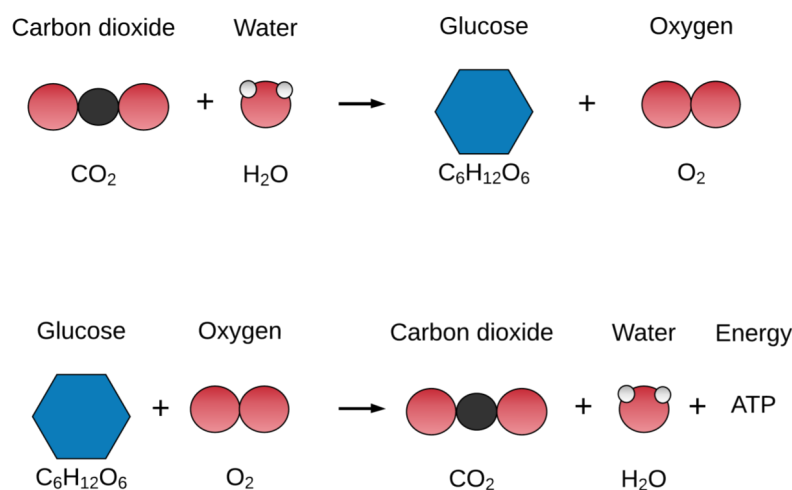


Figure 8



# Cellular Energy

## How does energy flow through the ecosystem?

Beginning with the energy from the sun, plants capture and use the light energy in photosynthesis. The light energy is transformed into chemical energy in the form of glucose. This chemical energy is then used by plants or passed onto animals as they consume plants. The process of cellular respiration will then break down the glucose to produce ATP. Organisms will then release heat to the ecosystem which is then used as thermal energy

As chemical bonds are broken and formed through chemical reactions such as photosynthesis and cellular respiration, energy can flow from autotrophs to heterotrophs and throughout the ecosystem. This is diagrammed in figure 9.

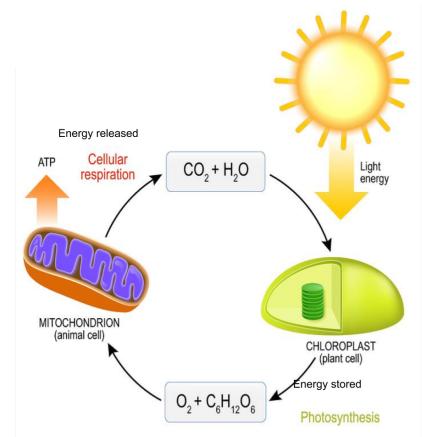


Figure 9

## The Nature of Science in Action

### Energy and Matter

Energy drives the cycling of matter within and between systems.

The light energy from the Sun drives the cycling of matter through plants to create chemical energy that organisms use to function and release heat into the ecosystem.

## Endergonic and exergonic reactions

The process of photosynthesis and cellular respiration both use and produce energy. The amount of energy produced is based on the amount of energy needed to break the initial bonds of the reactant compared to the amount of energy needed to form the bonds of the products. In the case of photosynthesis, this reaction would be considered *endergonic*. An endergonic reaction requires more energy needed to form the bonds of products than the amount of energy needed to break the bonds of the reactants. Endergonic reactions require energy to be “put into” the reaction. In this case, that is light energy.

Cellular respiration is considered an *exergonic* reaction. Exergonic reactions produce energy or require less energy to put products together compared to the amount of energy needed to break the bonds of the reactants.

# Cellular Energy

The cycling of matter and energy within an ecosystem is a very unique interaction. In this process, the matter occurs cyclically, meaning the main elements found in cellular respiration and photosynthesis are transferred between organisms as the different cycles occur. The glucose and oxygen from photosynthesis will be consumed during cellular respiration, and the water and carbon dioxide produced will be used by plants to make more glucose. This cycle will continue as long as organisms exist.

The energy that is used or produced on the other hand is more directional. Energy is needed for photosynthesis to occur and energy is produced when cellular respiration occurs. So is energy really transferred in ecosystems? The answer is yes, but it is not cyclical. The energy transfer will be more closely examined in the scope Flow of Matter and Energy in Ecosystems.

The relationship of matter and energy transfer is similar to that of a child blowing on a pinwheel as shown in figure 10. The air the child is blowing is energy and the pinwheel is matter in the ecosystem. This energy is moving one direction toward the pinwheel. When it contacts the pinwheel it will cause the pinwheel to turn but will keep going in the same direction. The pinwheel will continue to turn as long as energy is available. So the analogy helps us to see the important role that energy plays in the movement of matter in our ecosystem.



**Figure 10**

All living things require ATP to power their cellular processes. As photosynthesis uses sunlight, water, and carbon dioxide to produce glucose and oxygen, cellular respiration then uses glucose and oxygen as reactants to produce ATP, water, and carbon dioxide. The cell then uses the ATP for energy and plants can use the water and carbon dioxide to produce more glucose and oxygen. The reactants and products of each chemical process are cycled over and over throughout the interactions among organisms and their environments. The constant cycling of matter and flow of energy is essential to the health of individual organisms and the ecosystems they live in.



## Beyond the Classroom

Pollution is an important scientific and social issue today due to the detrimental impact on Earth and its inhabitants. Engineers and scientists have been working diligently to find solutions to mitigate the effects of pollution in the environment. Once such possible solution is called *bioremediation*.

Bioremediation is the process of using a living organism to help convert pollutants in the environment into materials previously present in that environment. *Remediate* means to solve a problem, and *bioremediate* means to use biological organisms to solve an environmental problem such as contaminated soil or groundwater.

In a non-polluted environment, bacteria, fungi, protists, and other microorganisms are constantly at work breaking down organic matter. What would occur if an organic pollutant such as oil contaminated this environment? Some of the microorganisms would die, while others capable of eating the organic pollution would survive. Bioremediation works by providing these pollution-eating organisms with fertilizer, oxygen, and other conditions that encourage their rapid growth. These organisms would then be able to break down the organic pollutant at a correspondingly faster rate. In fact, bioremediation is often used to help clean up oil spills.

Bioremediation of a contaminated site typically works in one of two ways. In the case described above, ways are found to enhance the growth of whatever pollution-eating microbes might already be living at the contaminated site. In the second, less common case, specialized microbes are added to degrade the contaminants.

Bioremediation provides a good cleanup strategy for some types of pollution, but as you might expect, it will not work for all. For example, bioremediation may not provide a feasible strategy at sites with high concentrations of chemicals that are toxic to most microorganisms. These chemicals include metals such as cadmium or lead and salts such as sodium chloride.

Nonetheless, bioremediation provides a technique for cleaning up pollution by enhancing the same biodegradation processes that occur in nature. Depending on the site and its contaminants, bioremediation may be safer and less expensive than alternative solutions such as incineration or disposing of the contaminated materials in landfills. It also has the advantage of treating the contamination in one place so that large quantities of soil, sediment, or water do not have to be dug up or pumped out of the ground for treatment.

Use a variety of internet resources to learn more about the process of bioremediation and where it has been successful. Then, write a one page news article highlighting the importance of this process and how it might be of future benefit to a local ecosystem.

## Cellular Energy Review

### Reviewing Key Terms

Use each of the following terms in a separate sentence.

1. Autotroph:
2. Heterotroph:
3. Adenosine Triphosphate:
4. Photosynthesis:
5. Cellular Respiration:

Use the correct key term to complete each of the following sentences.

1. \_\_\_\_\_ is the preferred form of energy cells use to power cellular processes.
2. Oxygen is an input for \_\_\_\_\_ where it is used to produce ATP and waste products.
3. \_\_\_\_\_ is a process that stores energy for later use by the organism.

### Reviewing Main Ideas

1. What are the three inputs of photosynthesis?
  - a. Water, carbon dioxide, and glucose
  - b. Water, oxygen, and sunlight
  - c. Water, carbon dioxide, and sunlight
  - d. Water, oxygen, and glucose
2. Where is the chemical energy stored in ATP?
  - a. In the chemical bonds between the first and second phosphate
  - b. In the chemical bonds between the second and third phosphate
  - c. In the chemical bonds between adenine and ribose
  - d. ATP does not store energy

3. What does cellular respiration produce?
  - a. Water, Carbon Dioxide, and ATP
  - b. Water, Oxygen, and ATP
  - c. Glucose and Oxygen
  - d. Glucose, water, and carbon dioxide

### Making Connections

1. Describe the relationship between photosynthesis and cellular respiration.
2. Explain how organisms and the environment cycle matter and energy through these processes.

### Open-Ended Response

1. Explain why autotrophs must undergo cellular respiration.
2. Explain why light energy must be transformed into chemical energy for organisms.
3. Describe the roles gases play in photosynthesis and cellular respiration.
4. Explain how the waste products of photosynthesis and cellular respiration are essential to the corresponding process.
5. Why is photosynthesis considered endergonic while cellular respiration is considered exergonic.
6. Use a diagram to model the relationship between photosynthesis and cellular respiration.