# Photosynthesis and Respiration: How cells make and use energy

In order for cells to do any work, they need energy! Where does this energy come from? How do they store it? How do they use it? The answers to these questions and more are found in the complementary processes of **photosynthesis** and **respiration**. In photosynthesis, energy is stored in chemical bonds, while in respiration, those same chemical bonds are broken and energy is released for use by the cell.

Before going into the details of photosynthesis and respiration, let's review a little bit about energy and light and how they are used by cells.

**Energy**

Energy can be stored in the form of covalent bonds between atoms. Remember that covalent bonds are bonds created when two atoms share a pair of electrons between them. When these bonds are broken by enzymes, the energy is released for the cell to use.

In photosynthesis, plants take energy from the sun and store it in the chemical bonds of **glucose**, a simple sugar. In respiration, the energy in the glucose bonds is released. The energy released from glucose through respiration is transferred to a molecule called **ATP**. Think of ATP as a kind of money used by the cell. ATP is used to power some cellular processes, like active transport or enzyme activity, that cost energy.

Only plants can photosynthesize, but all organisms carry out some form of cellular respiration because all organisms need to get energy for their cells to use.

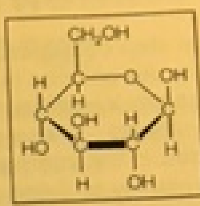
**Key point:**
All organisms, including plants, use cellular respiration to get energy from the chemical bonds in food.

**Light**

Light travels from the sun across *93 million miles* of space to get to use here on earth. That's pretty far, but it only takes 8 minutes for light to travel that distance! A single unit of light is called a photon, and it carries energy. It is the energy of light photons that is harnessed by the plant through photosynthesis.

stroma where the glucose-building step of photosynthesis, the Calvin cycle, occurs.

In the Calvin cycle, the solar energy in those electrons is used to combine carbon dioxide and hydrogen into glucose. The energy that was absorbed from solar photons has now been stored in the stable chemical bonds of a glucose molecule.




After glucose is synthesized, it is often processed into sucrose (a disaccharide) or starch (a polysaccharide) for long-term storage or transport to other parts of the plant.

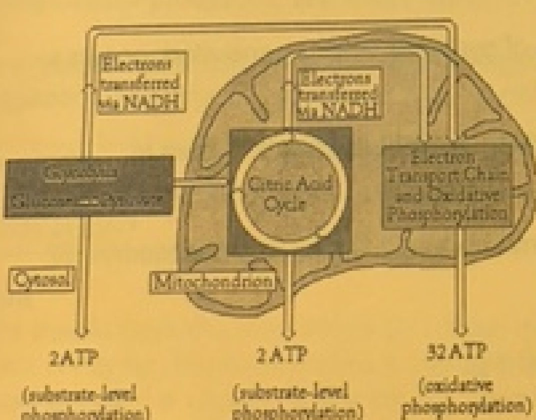
## Respiration

How do plants and animals use the energy stored in glucose? Cellular respiration! While only plants can photosynthesize, **all** organisms perform some kind of respiration. Respiration in eukaryotes is the breakdown of glucose in the presence of oxygen and can be summarized by the following equation:

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

glucose + oxygen → carbon dioxide + water + energy

Notice that oxygen is required for cellular respiration, which is why we breathe it in, and that carbon dioxide is one of the waste products. Notice also that this is the reverse of photosynthesis, where carbon dioxide is taken in and oxygen is a product. In other words, we exist in a beautiful mutualism with plants – they provide us with exactly what we need and vice versa!




Respiration consists of three main steps: **glycolysis**, **the Krebs cycle (a.k.a. the citric acid cycle)**, and **oxidative phosphorylation**. The end product of these three steps in 36 molecules of ATP, the cell's energy "money", per molecule of glucose.

Respiration mostly takes place in the mitochondria, but the first step in the breakdown of glucose, **glycolysis**, actually occurs out in the cytoplasm. In glycolysis, enzymes split a molecule of glucose, which has 6 carbon atoms, into two 3-carbon molecules called pyruvate. A small amount of energy is released in glycolysis, and two molecules of ATP are created.

After glucose is split into pyruvate, the pyruvate is transferred to the inside of a mitochondrion, where the **Krebs cycle** is carried out. In the Krebs cycle, pyruvate is

# Photosynthesis

The production of glucose in photosynthesis can be summarized by the following equation:

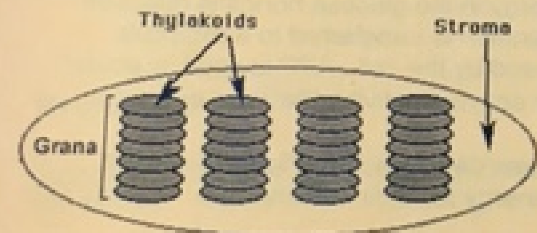
$$6\ CO_2 + 12\ H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

carbon dioxide + water + light energy → glucose + oxygen gas + water

Let's break this equation down a little bit. On the left side of the equation, where does the **carbon dioxide** come from? It is present in the air, and is brought into the plant through tiny pores in the leaf called stomata. How about **water**, where does it come from? It comes from the soil, and is drawn in by the roots. And, as mentioned above, the light comes from the sun, and provides the energy for the chemical reaction between carbon dioxide and water.

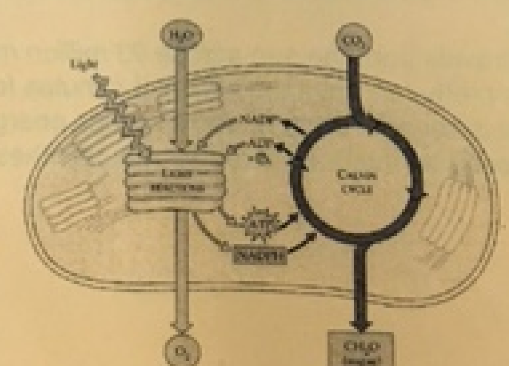
On the right side of the equation, notice that photosynthesis gives off **oxygen**, the very substance we need to breathe. As we will see later, oxygen is a necessary component of cellular respiration. This is why the word 'respiration' is used for both breathing and for the release of energy from glucose molecules.

Photosynthesis takes place in the chloroplasts of plant cells. In most plant chloroplasts are most abundant in the leaves and give them their green color. Therefore the leaves are the major site of photosynthesis in most plants. Inside the chloroplasts, there are a number of flattened structures that look like stacks of green pancakes. A single "pancake" is called a **thylakoid**, and the whole stack is called a **granum**. The **chlorophyll** pigment, which is very important in photosynthesis, is located in the thylakoid membranes. The rest of the space inside the chloroplast is called the **stroma**.



Chloroplast

The process of photosynthesis can be divided into two main parts: the **light-dependent reaction** and the **Calvin cycle**. The light-dependent reaction is the energy-capture part of photosynthesis, while the Calvin cycle uses that energy to build sugar molecules.



In the light-dependent reaction, which takes place in the thylakoid membrane, electrons in a chlorophyll molecule directly absorb the energy in a photon from the sun. These high-energy electrons are carried from the thylakoid to the stroma on special carrier molecules. It is in the further broken down by enzymes into carbon dioxide and water and 2 more molecules of ATP are generated.

The final step of respiration, **oxidative phosphorylation**, is where the big payoff in ATP happens. As glucose is broken down in glycolysis and the Krebs cycle, high-energy electrons are transferred to special electron carriers very similar to the ones found photosynthesis. These electrons are passed to **electron transport proteins** embedded in the internal membrane of the mitochondrion. These proteins are able to use the energy of these protons to make ATP molecules. In this final stage of respiration, 32 molecules of ATP are generated for each molecule of glucose that we started with. The cell now has a big supply of energy money to spend on whatever activities it wants!

# Summary:

**Photosynthesis**:

light-dependent reaction – energy from sunlight is harvested, water is split into H and $O_2$, occurs in thylakoid membrane

Calvin cycle – glucose is created from $CO_2$ and H, energy is stored chemically, occurs in stroma

**Respiration:**

glycolysis – glucose is split into 2 molecules of pyruvate, 2 ATP generated, occurs in cytoplasm

Krebs cycle – pyruvate is broken down into $CO_2$, 2 ATP generated, occurs in mitochondria

electron transport – electrons transferred to membrane proteins in mitochondria, 32 ATP generated, $O_2$ required