Chapter 4

Photosynthesis and Cellular Respiration

Energy in Living Systems

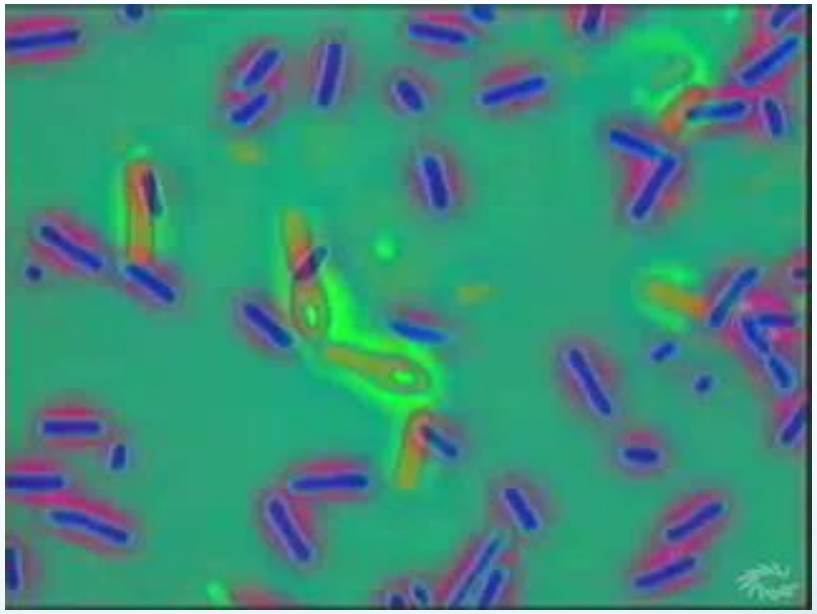
- Directly or indirectly, almost all of the energy in living systems needed for metabolism comes from the sun.

Building Molecules That Store Energy

- **Metabolism** involves either using energy to build molecules or breaking down molecules in which energy is stored.
- **Photosynthesis** is the process by which light energy is converted to chemical energy.
- Organisms that use energy from sunlight or from chemical bonds in inorganic substances to make organic compounds are called **autotrophs.**

Breaking Down Food for Energy

- The chemical energy in organic compounds can be transferred to other organic compounds or to organisms that consume food.
- Organisms that must get energy from food instead of directly from sunlight or inorganic substances are called Heterotrophs.
- Cellular respiration is a metabolic process similar to burning fuel.



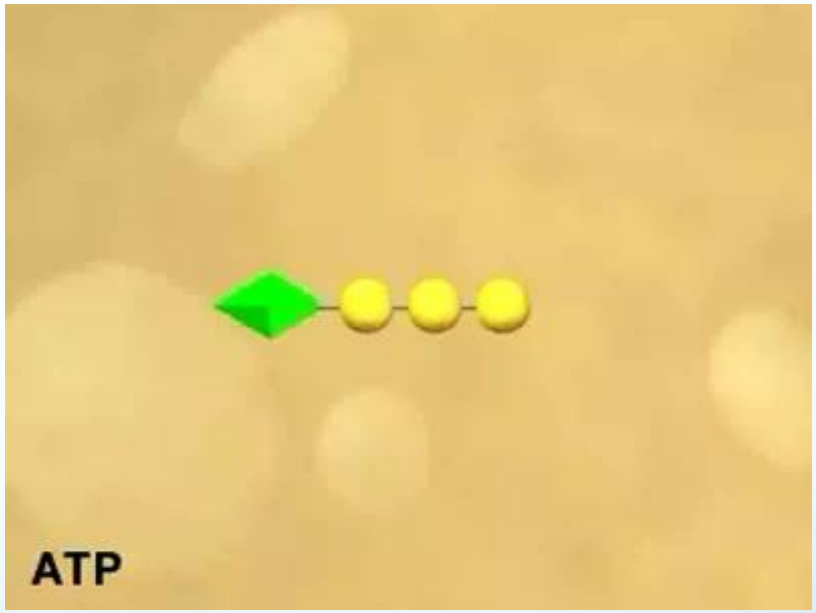
Transfer of Energy to ATP

- When cells break down food molecules, some of the energy in the molecules is released as heat. Much of the remaining energy is stored temporarily in molecules of ATP.
- Like money, ATP is a portable form of energy “currency” inside cells. ATP delivers energy wherever energy is needed in a cell.

ATP

- ATP (adenosine triphosphate) is a nucleotide with two extra energy-storing phosphate groups.
- Energy is released when the bonds that hold the phosphate groups together are broken.
- The removal of a phosphate group from ATP produces adenosine diphosphate, or ADP:

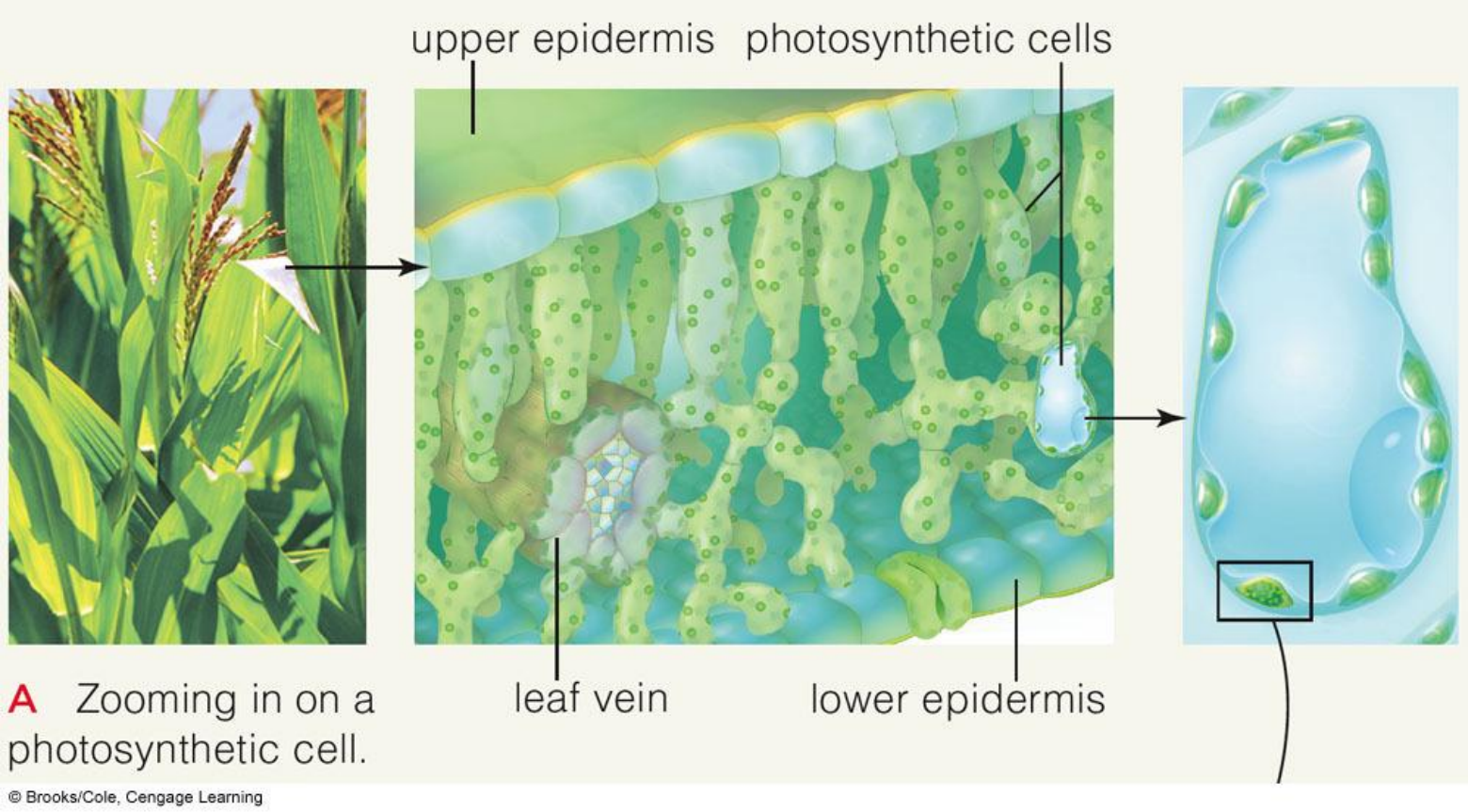
$H_2O + ATP \rightarrow ADP + P + energy$



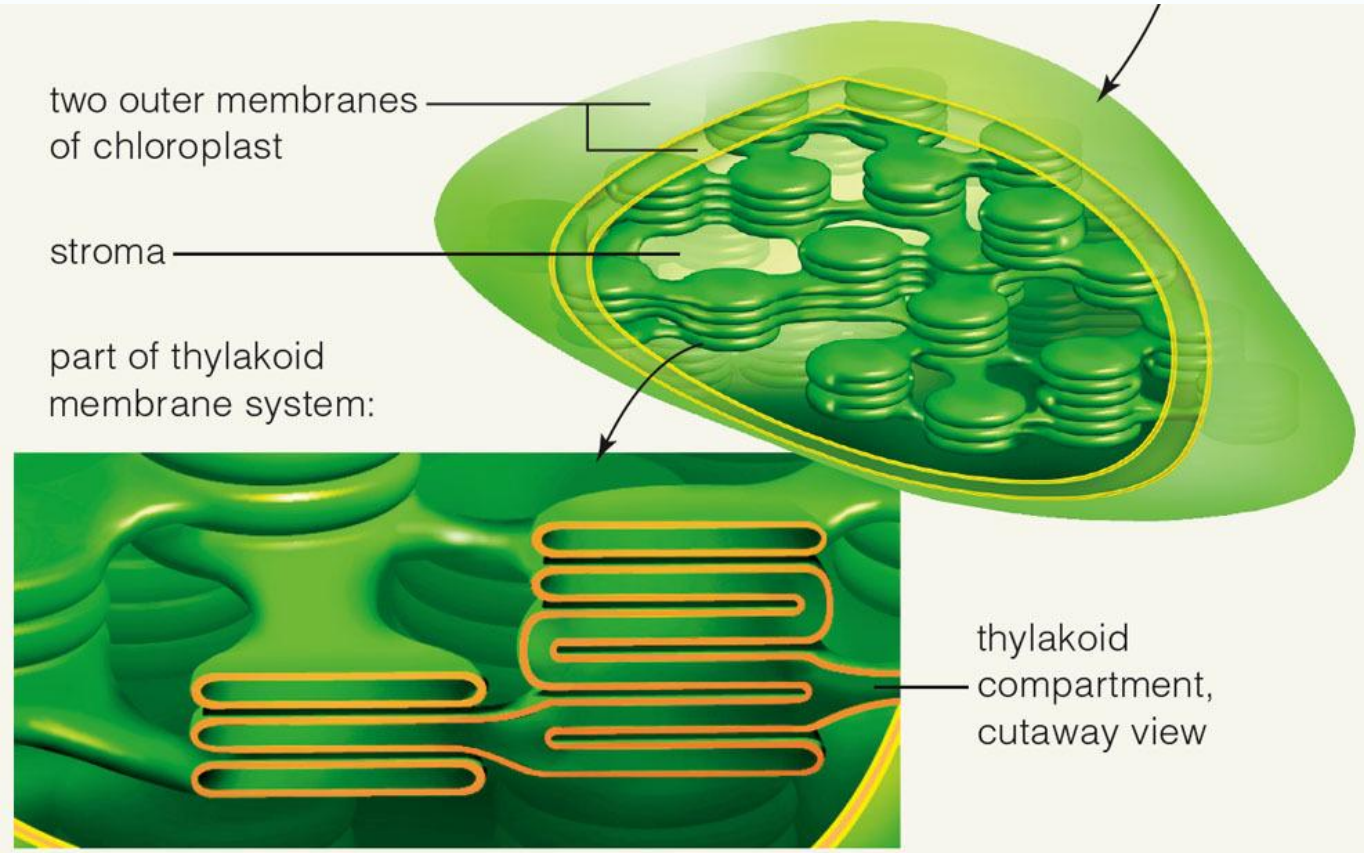
Example Problem

- Organisms that can make their own food using the energy of the sun are called _____.
- Organisms that obtain their energy by eating other organisms are called _____.
- Draw a diagram of energy flowing from the sun to a human.

Structure of a Leaf



Chloroplast



B Chloroplast structure. No matter how highly folded, its thylakoid membrane system forms a single, continuous compartment in the stroma.

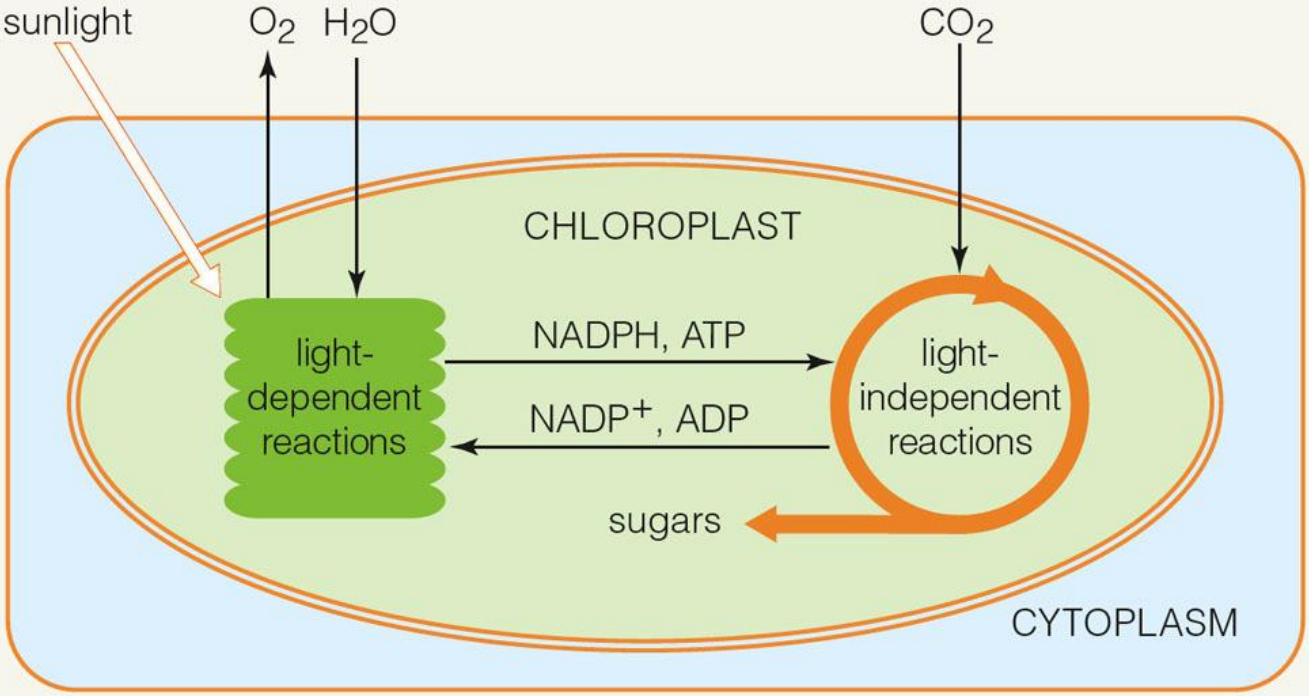
The Stages of Photosynthesis

- **Stage 1** Energy is captured from sunlight.
- **Stage 2** Light energy is converted to chemical energy, which is temporarily stored in ATP and the energy carrier molecule NADPH.
- **Stage 3** The chemical energy stored in ATP and NADPH powers the formation of organic compounds, using carbon dioxide, CO_2.
- Photosynthesis can be summarized by the following equation:

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

Carbon dioxide water sugars oxygen gas

Overview Photosynthesis

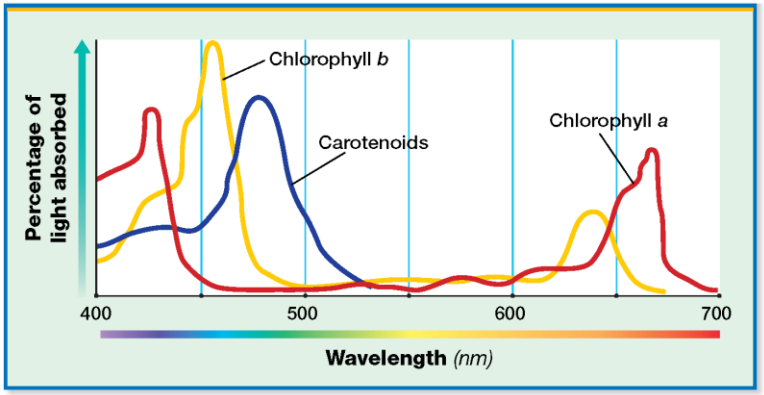


C In chloroplasts, ATP and NADPH form in the light-dependent stage of photosynthesis, which occurs at the thylakoid membrane. The second stage, which produces sugars and other carbohydrates, proceeds in the stroma.

Stage One: Absorption of Light Energy

- Sunlight contains a mixture of all the wavelengths (colors) of visible light. When sunlight passes through a prism, the prism separates the light into different colors.

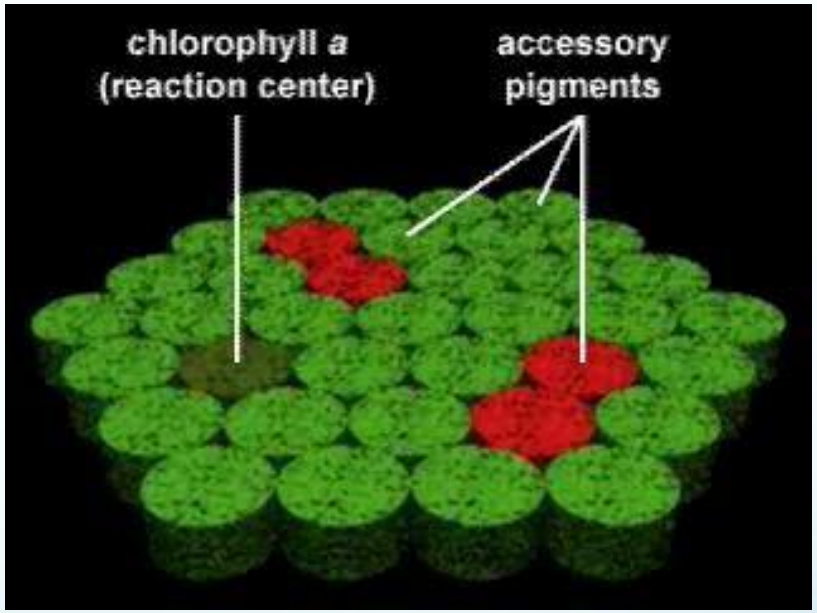
Pigments



- How does a human eye or a leaf absorb light? These structures contain light-absorbing substances called **pigments.**
- **Chlorophyll** the primary pigment involved in photosynthesis, absorbs mostly blue and red light and reflects green and yellow light.
- Plants contain two types of chlorophyll, chlorophyll *a* and chlorophyll *b.*
- The pigments that produce yellow and orange fall leaf colors, as well as the colors of many fruits, vegetables, and flowers, are called **carotenoids.**
- Carotenoids absorb wavelengths of light different from those absorbed by chlorophyll, so having both pigments enables plants to absorb more light energy during photosynthesis.

Production of Oxygen

- Clusters of pigments are embedded in the membranes of disk-shaped structures called **thylakoids.**
- When light strikes a thylakoid in a chloroplast, energy is transferred to electrons in chlorophyll.
- This energy transfer causes the electrons to jump to a higher energy level. This is how plants first capture energy from sunlight.
- The excited electrons that leave chlorophyll molecules must be replaced by other electrons.
- Plants get these replacement electrons from water molecules, which are split by thylakoid.
- The oxygen atoms, O, from the disassembled water molecules combine to form oxygen gas, O_2.



Stage Two: Conversion of Light Energy

- Excited electrons that leave chlorophyll molecules are used to produce new molecules that temporarily store chemical energy.
- First an excited electron jumps to a nearby molecule in the thylakoid membrane. Then the electron is passed through a series of molecules along the thylakoid membrane.
- The series of molecules through which excited electrons are passed along a thylakoid membrane are called **electron transport chains.**

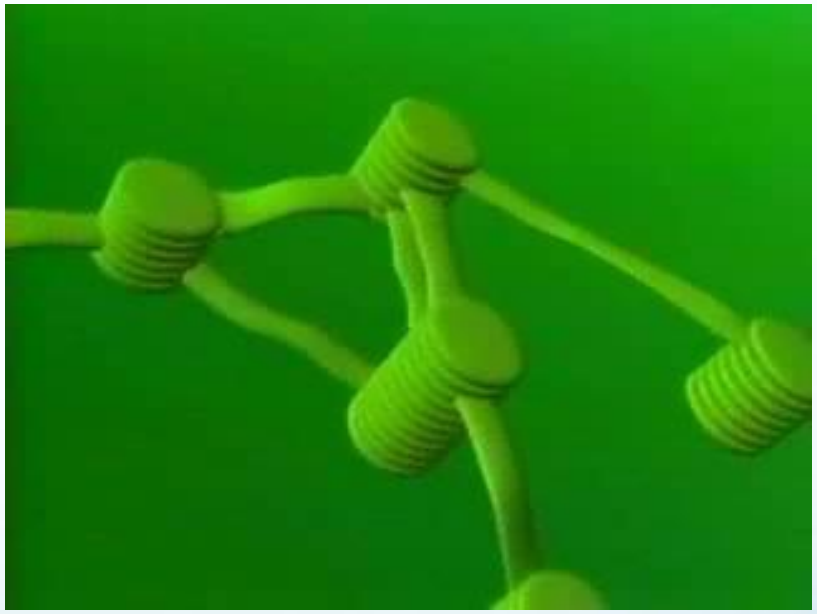
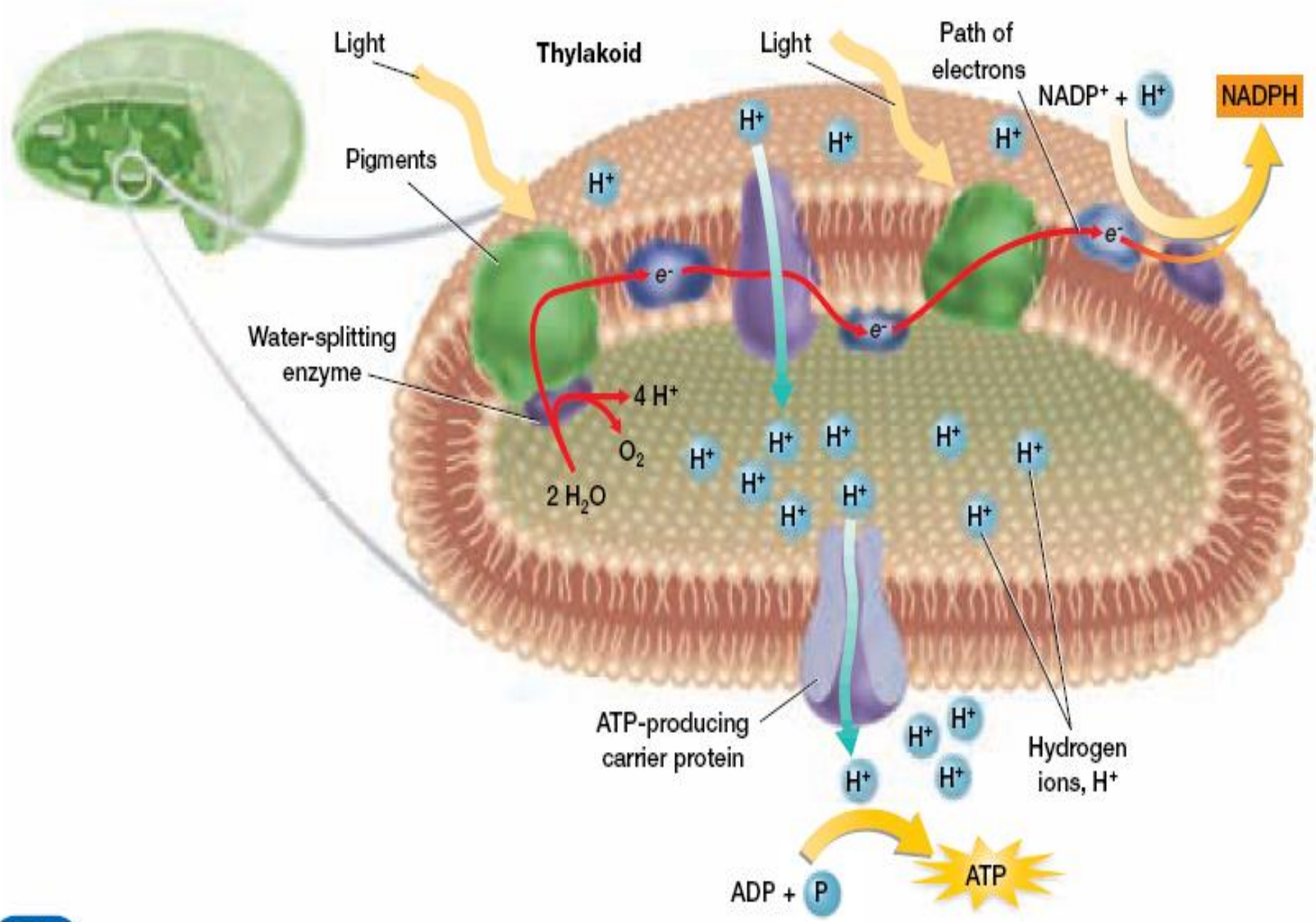


Figure 8 Electron transport chains of photosynthesis

Electron transport chains (represented by the red lines) convert light energy to chemical energy.



Stage Three: Storage of Energy

- In the third (final) stage of photosynthesis, carbon atoms from carbon dioxide in the atmosphere are used to make organic compounds in which chemical energy is stored.

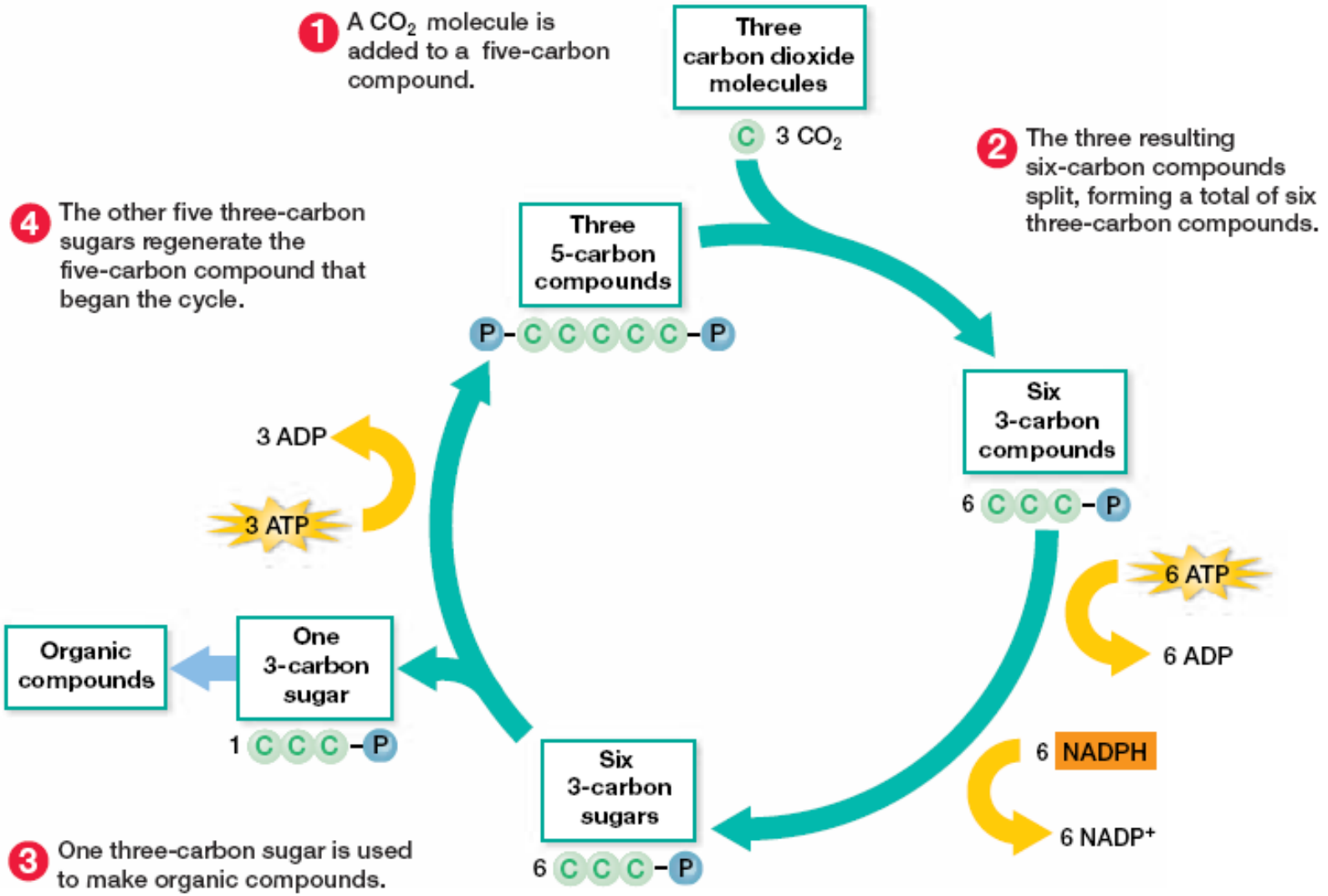
- The transfer of carbon dioxide to organic compounds is called **carbon dioxide fixation.**

Figure 9

BIO graphic

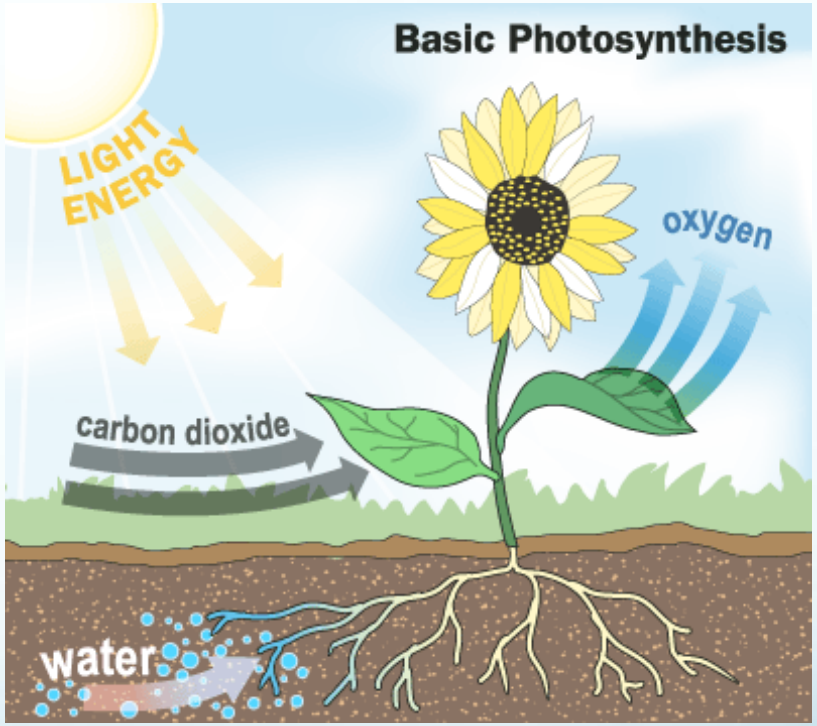
Calvin Cycle

The Calvin cycle is a common method of carbon dioxide fixation.



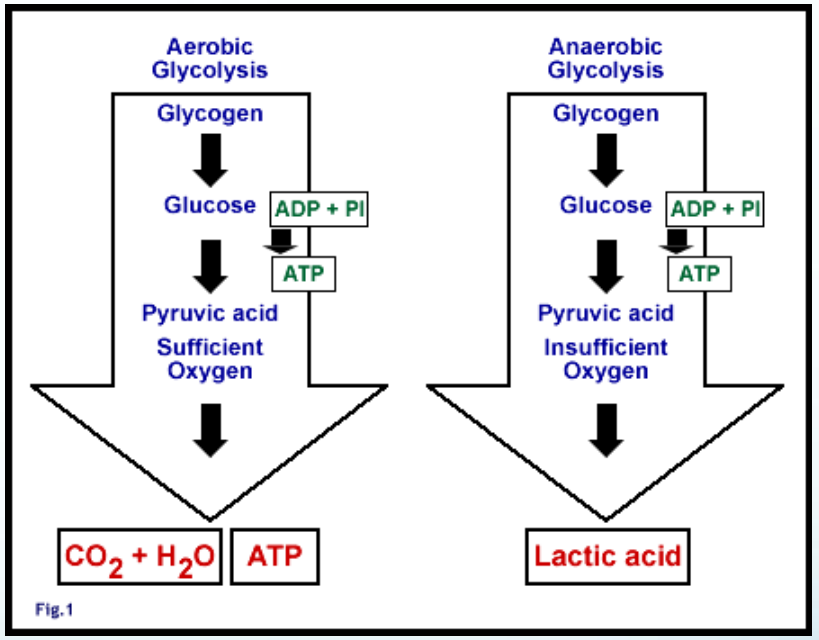
Factors that Affect Photosynthesis

- Photosynthesis is directly affected by various environmental factors.
- In general, the rate of photosynthesis increases as light intensity increases until all the pigments are being used.
- Photosynthesis is most efficient within a certain range of temperatures.

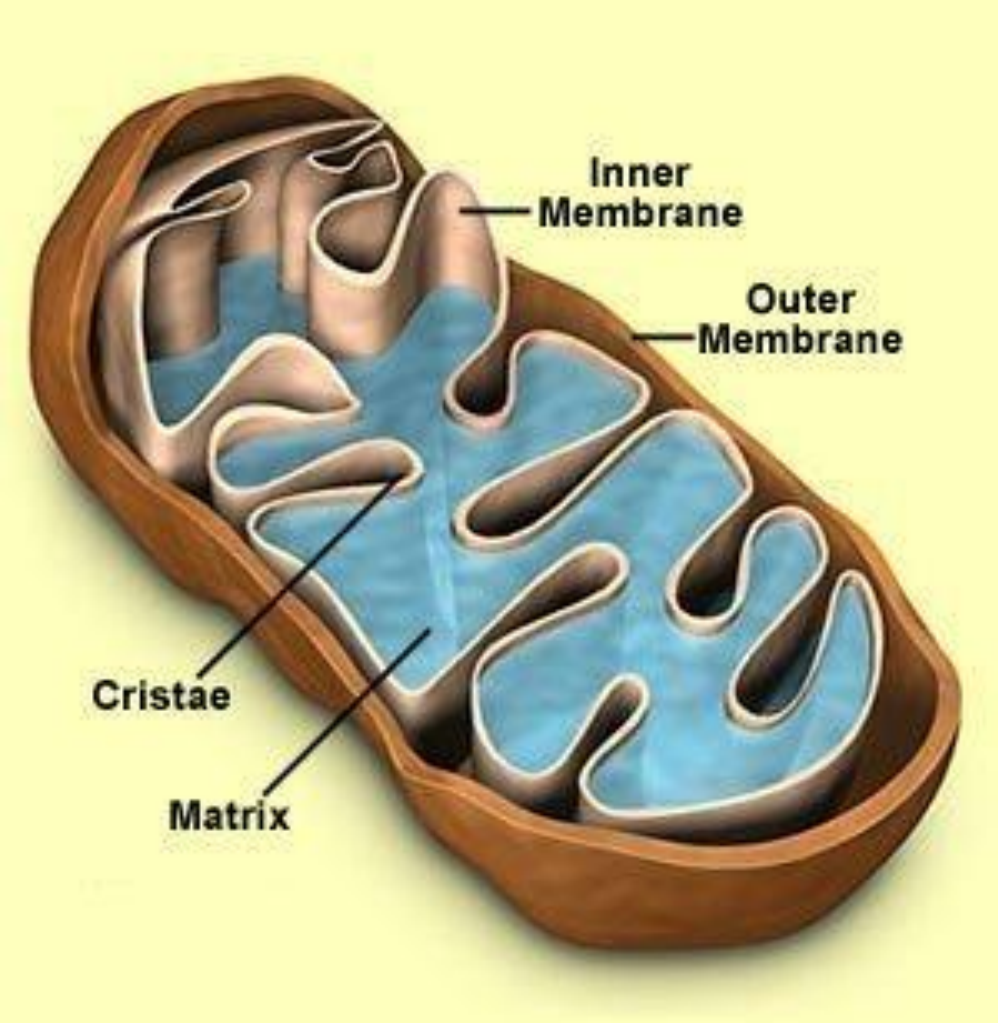


Cellular Energy

- Oxygen in the air you breathe makes the production of ATP more efficient, although some ATP is made without oxygen.
- Metabolic processes that require oxygen are called **aerobic.**
- Metabolic processes that do not require oxygen are called **anaerobic,** which means “without air.



Mitochondria



The Stages of Cellular Respiration

- Cellular respiration is the process cells use to harvest the energy in organic compounds, particularly glucose.
- The breakdown of glucose during cellular respiration can be summarized by the following equation:

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

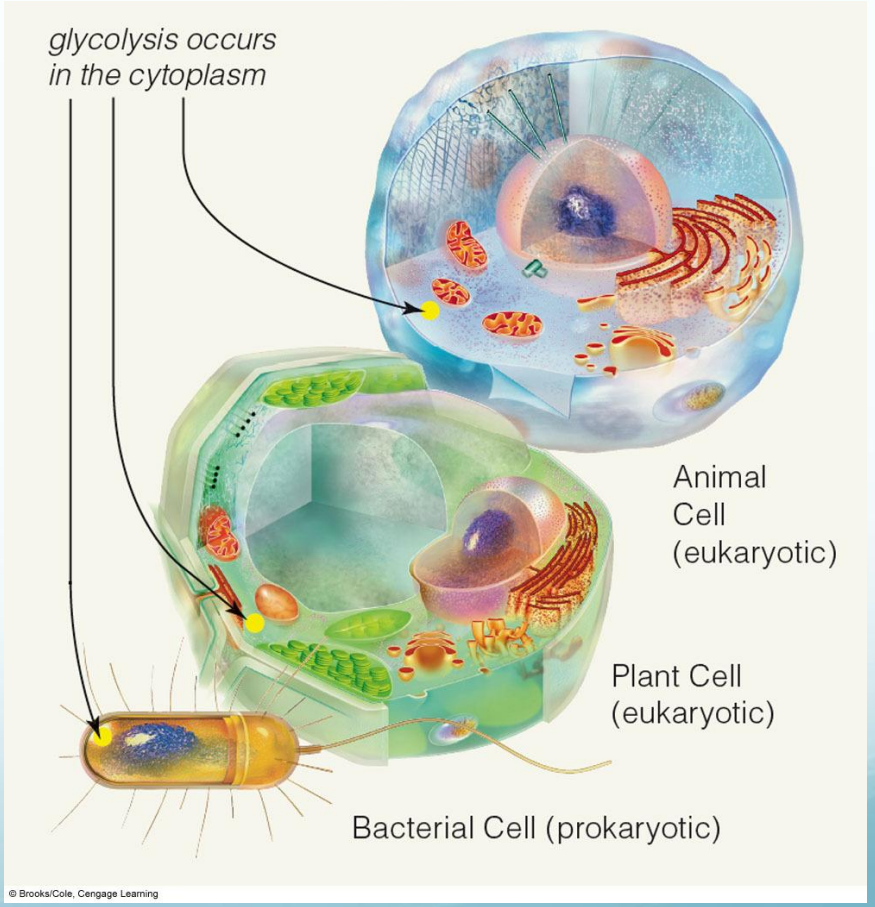
glucose oxygen gas carbon dioxide water ATP

- **Stage 1** Glucose is converted to pyruvate, producing a small amount of ATP and NADH.
- **Stage 2** When oxygen is present, pyruvate and NADH are used to make a large amount of ATP. When oxygen is not present, pyruvate is converted to either lactate or ethanol and carbon dioxide.

Glycolysis

- In the first stage of cellular respiration, glucose is broken down in the cytoplasm during a process called **glycolysis.**

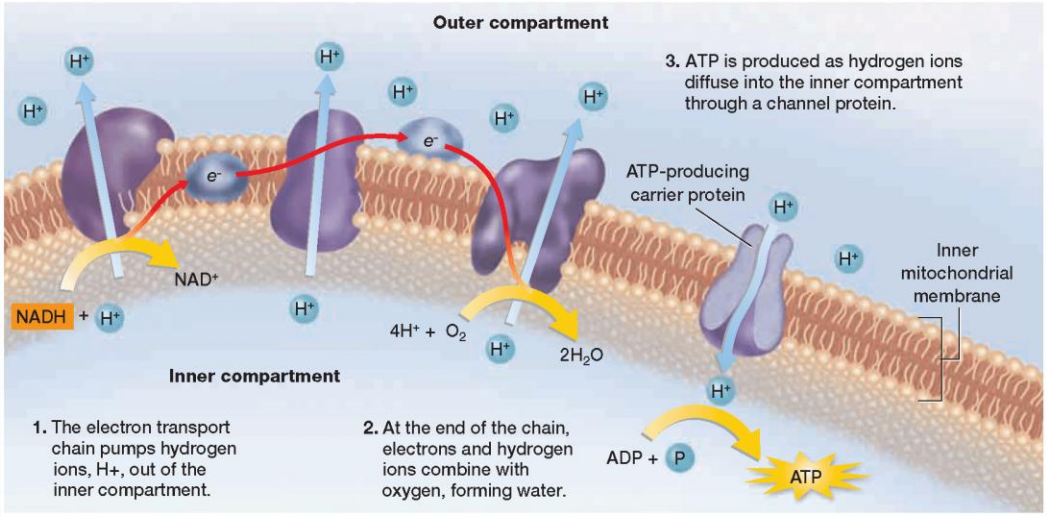
- As glucose is broken down, some of its hydrogen atoms are transferred to an electron acceptor called NAD^+. This forms an electron carrier called **NADH.**



Stage Two: Production of ATP

- When oxygen is present, pyruvate produced during glycolysis enters a mitochondrion and is converted to a two-carbon compound.
- This reaction produces one carbon dioxide molecule, one NADH molecule, and one two-carbon acetyl group.
- The acetyl group is attached to a molecule called coenzyme A (CoA), forming a compound called acetyl-CoA.

Electron Transport Train



- In aerobic respiration, electrons donated by NADH and $FADH_2$ pass through an electron transport chain.
- In eukaryotic cells, the electron transport chain is located in the inner membranes of mitochondria.
- At the end of the electron transport chain, hydrogen ions and spent electrons combine with oxygen molecules forming water molecules.

A Carbohydrate breakdown pathways start in the cytoplasm, with glycolysis.

B Fermentation pathways are completed in the semi-fluid matrix of the cytoplasm.

C In eukaryotes, aerobic respiration is completed inside mitochondria.

Fig. 8-2b, p. 124

Respiration in the Absence of Oxygen

- When oxygen is not present, NAD^+ is recycled in another way. Under anaerobic conditions, electrons carried by NADH are transferred to pyruvate produced during glycolysis.
- This process recycles NAD^+ needed to continue making ATP through glycolysis.
- The recycling of NAD^+ using an organic hydrogen acceptor is called **fermentation.**

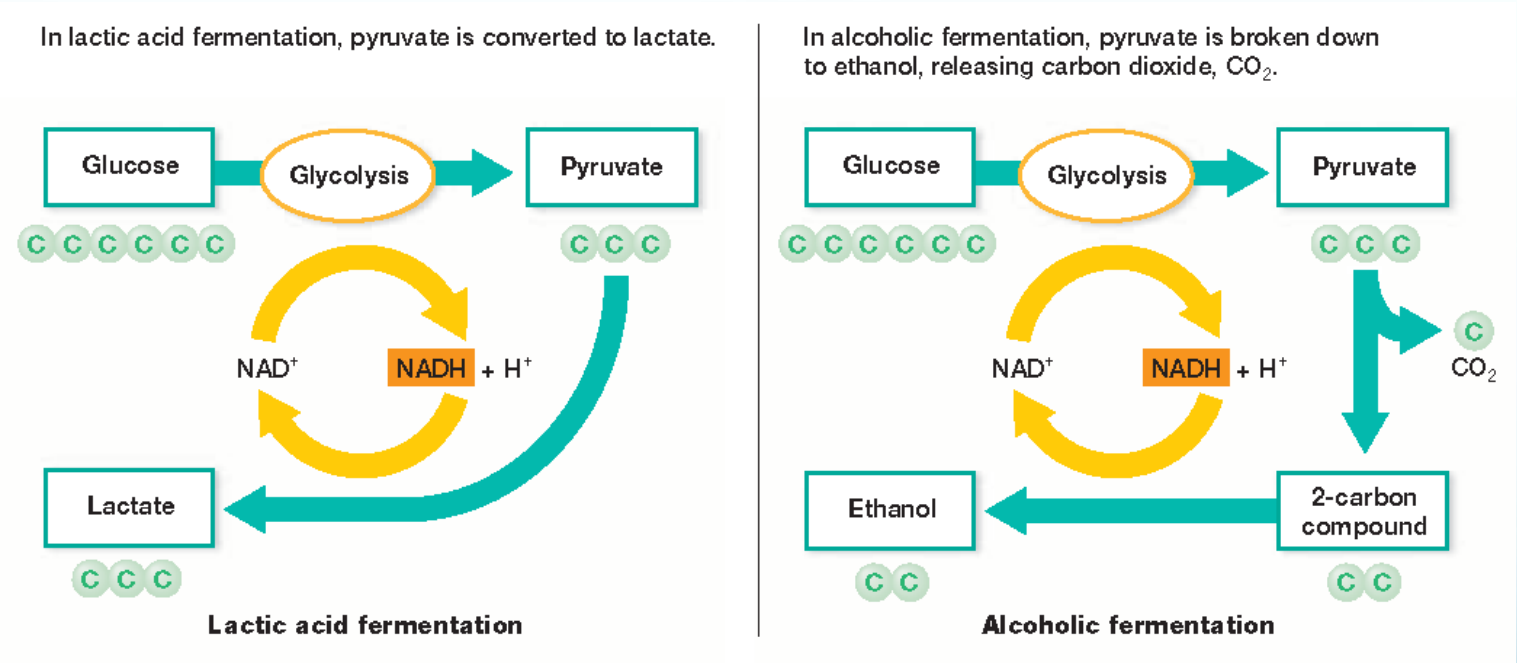
Lactic Acid Fermentation

- In some organisms, a three-carbon pyruvate is converted to a three-carbon lactate through lactic acid fermentation.
- Fermentation enables glycolysis to continue producing ATP in muscles as long as the glucose supply lasts.

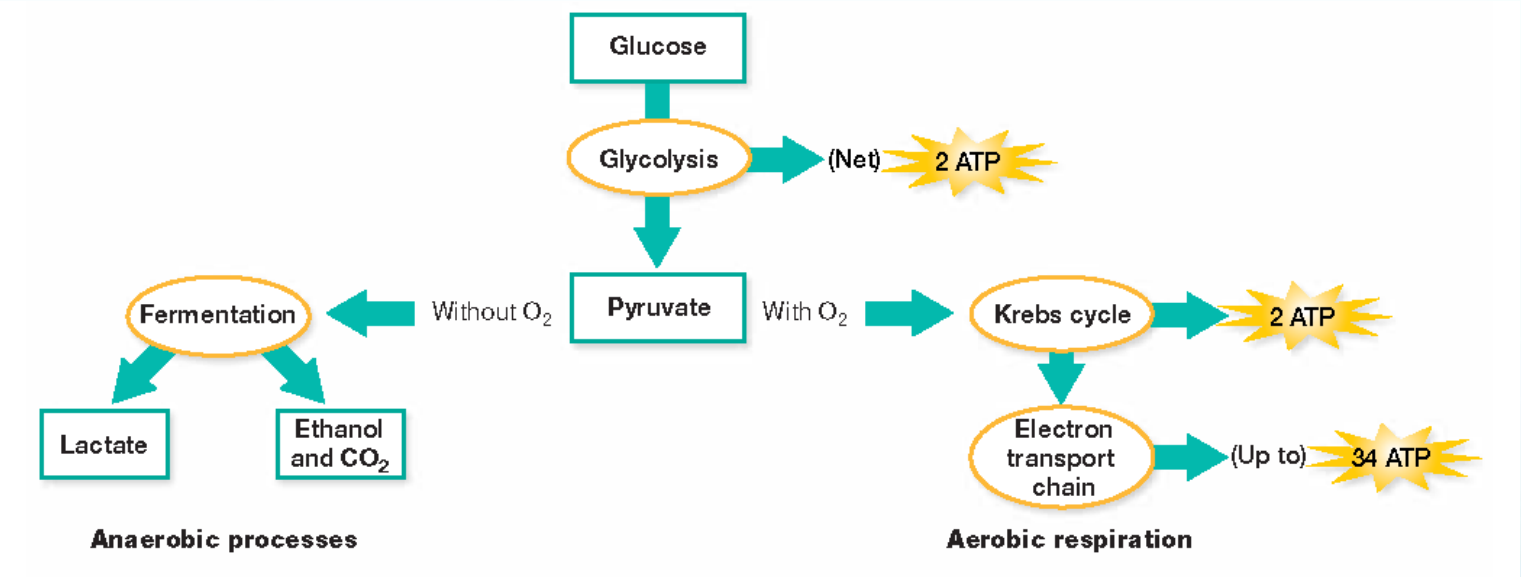
Alcoholic Fermentation

- In some organisms, the three-carbon pyruvate is broken down to ethanol (ethyl alcohol), a two-carbon compound, through alcoholic fermentation.
- As in lactic acid fermentation, NAD^+ is recycled, and glycolysis can continue to produce ATP.

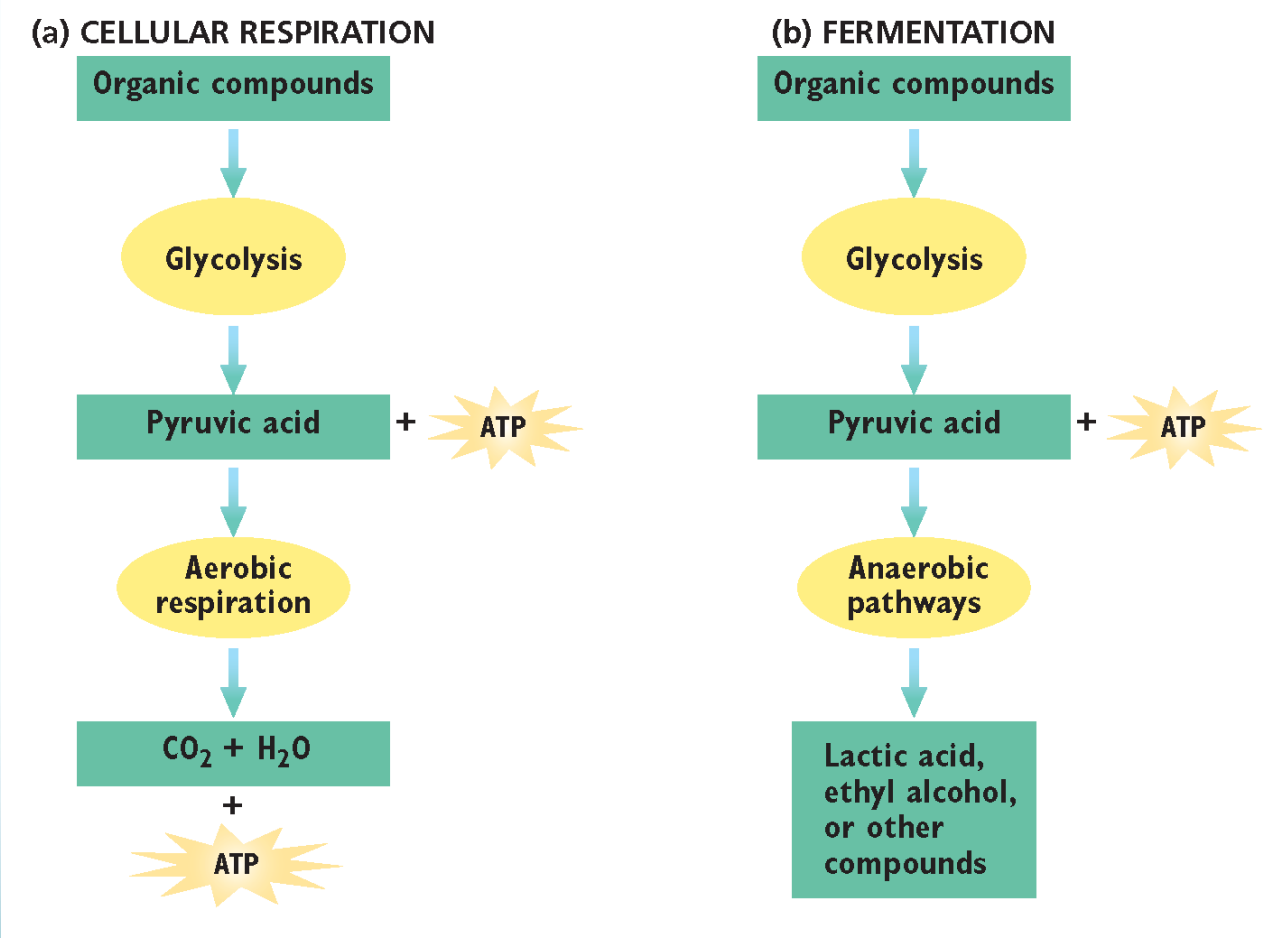
Lactic Acid and Alcoholic Fermentation



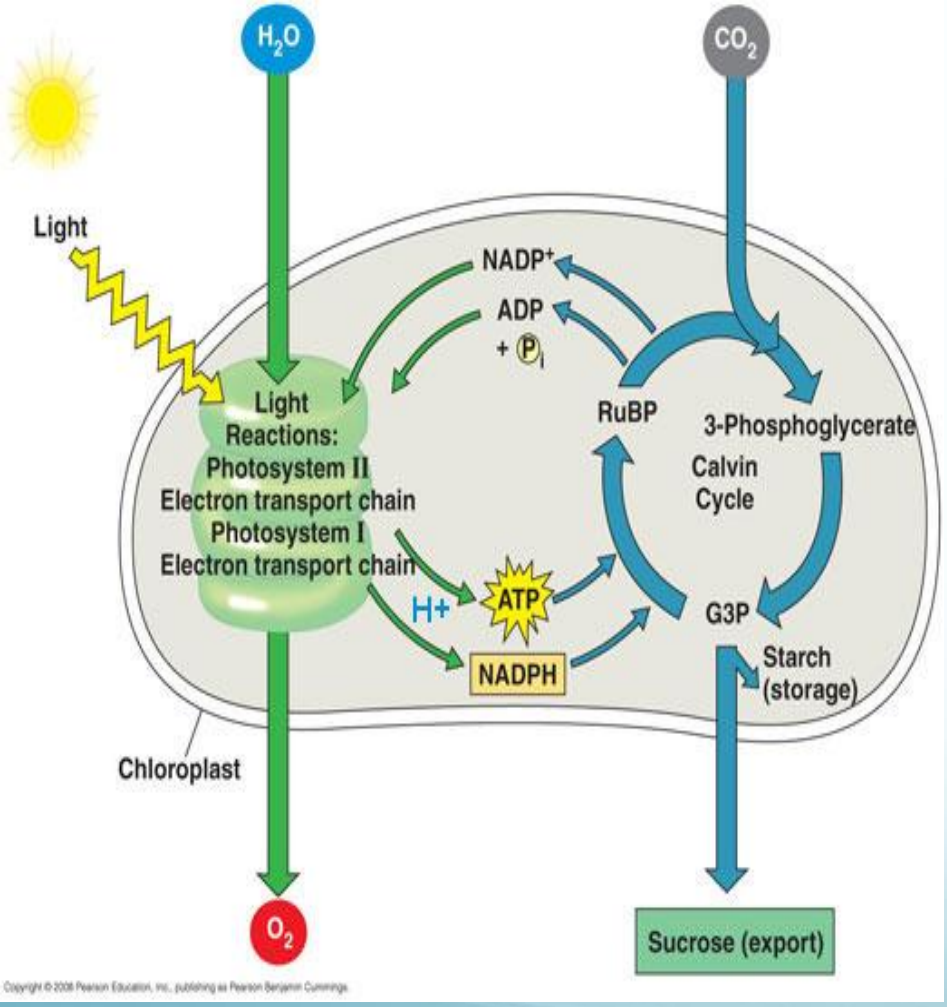
Hetrotrophs

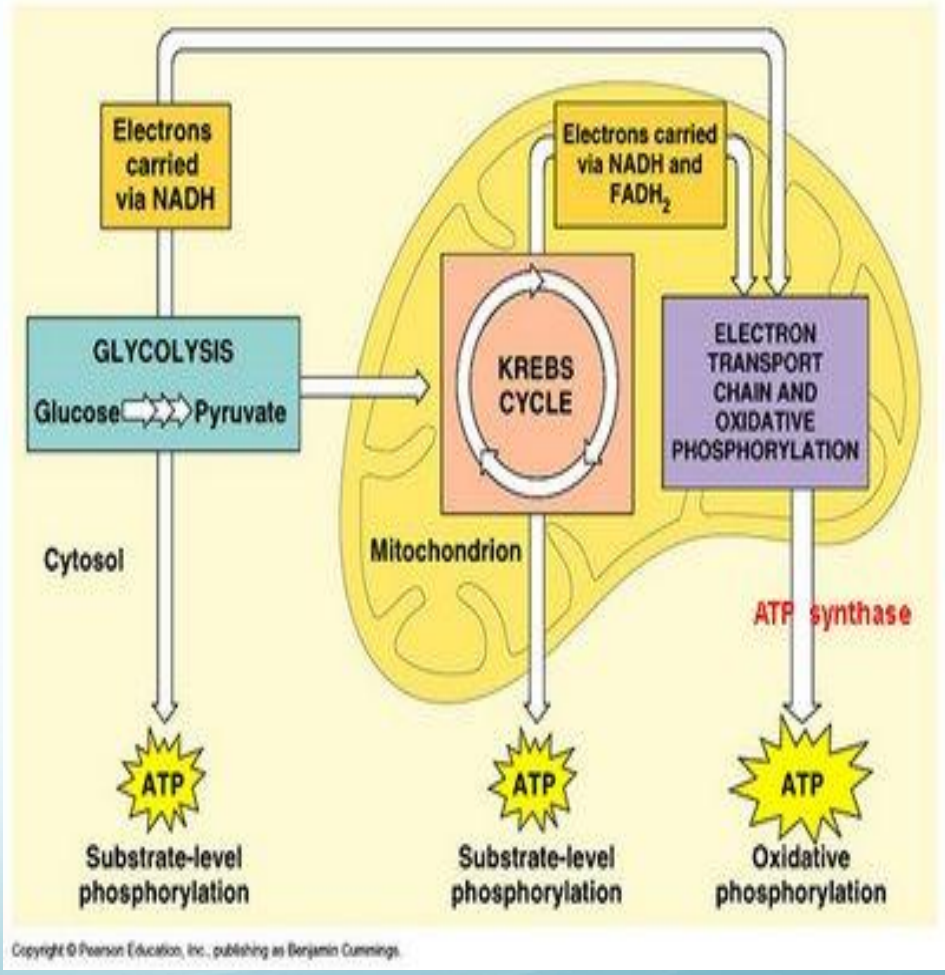


Cellular Respiration vs. Fermentation



Comparing Photosynthesis and Cellular Respiration





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