

8-3 The Reactions of Photosynthesis



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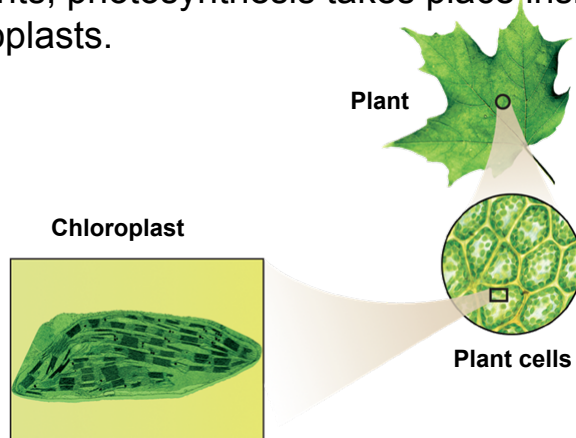
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8-3 The Reactions of Photosynthesis → Inside a Chloroplast

Inside a Chloroplast

In plants, photosynthesis takes place inside chloroplasts.



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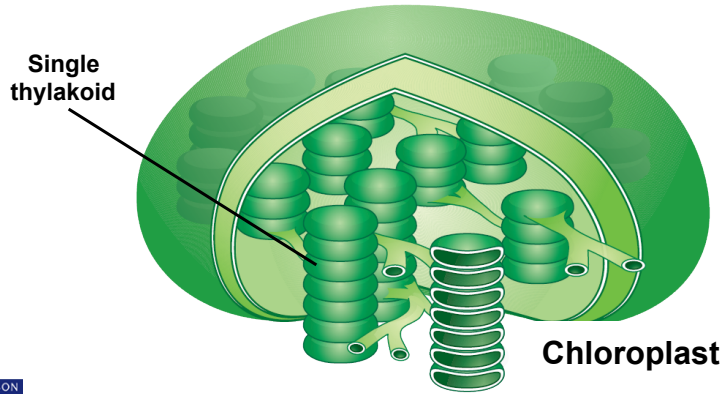
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8-3 The Reactions of Photosynthesis → Inside a Chloroplast

Chloroplasts contain **thylakoids**—sac-like photosynthetic membranes.



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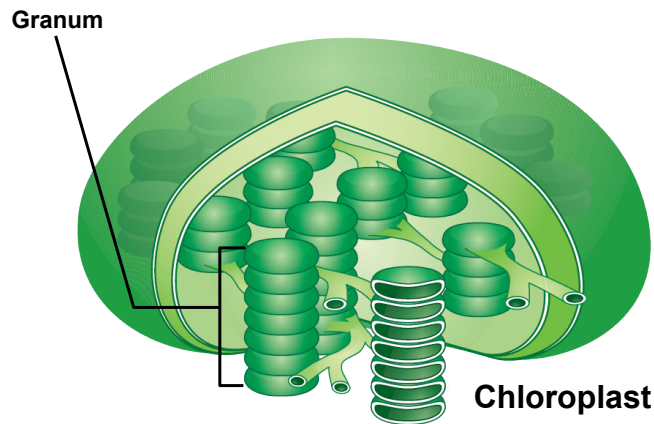
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8-3 The Reactions of Photosynthesis → Inside a Chloroplast

Thylakoids are arranged in stacks known as grana. A singular stack is called a granum.



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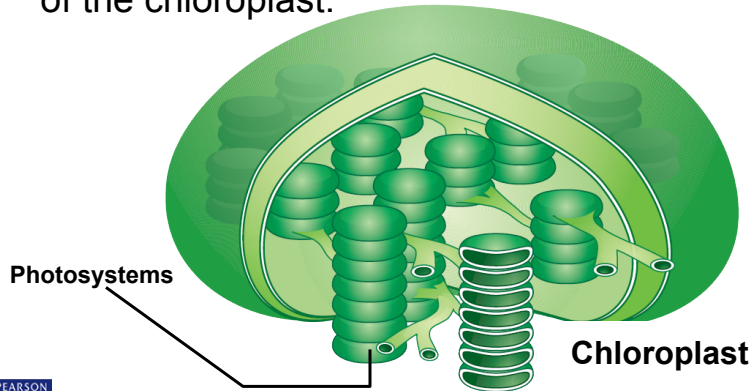
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8-3 The Reactions of Photosynthesis → Inside a Chloroplast

Proteins in the thylakoid membrane organize chlorophyll and other pigments into clusters called **photosystems**, which are the light-collecting units of the chloroplast.



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8-3 The Reactions of Photosynthesis → Inside a Chloroplast

The reactions of photosystems include: the light-dependent reactions and the light-independent reactions, or Calvin cycle.

The light-dependent reactions take place within the thylakoid membranes.

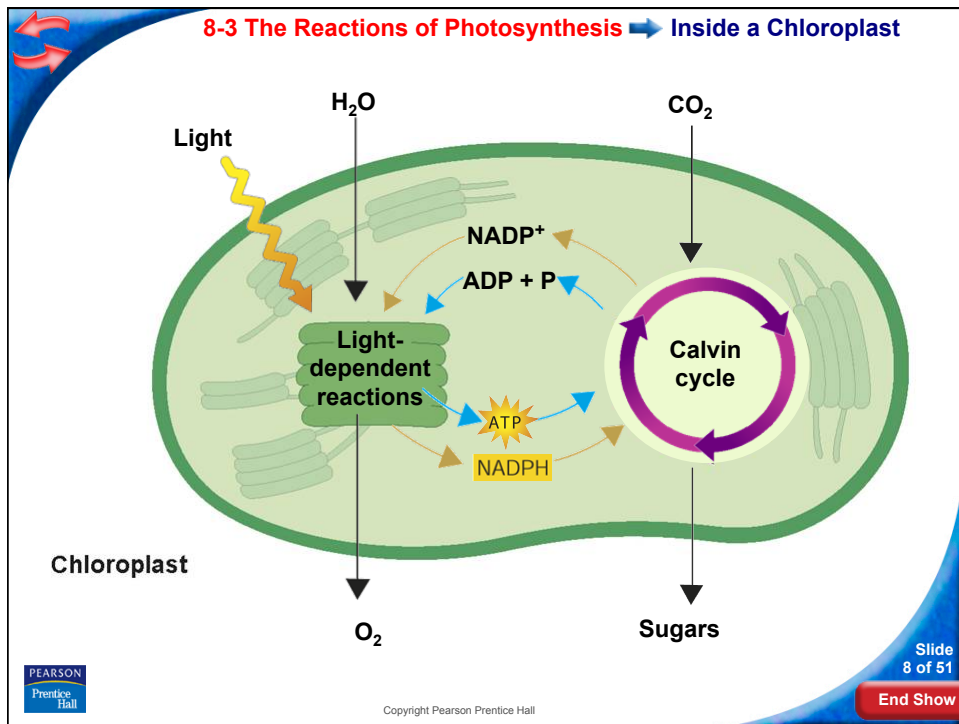
The Calvin cycle takes place in the **stroma**, which is the region outside the thylakoid membranes.

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8-3 The Reactions of Photosynthesis → **Electron Carriers**

Electron Carriers

When electrons in chlorophyll absorb sunlight, the electrons gain a great deal of energy.

Cells use electron carriers to transport these high-energy electrons from chlorophyll to other molecules.

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8-3 The Reactions of Photosynthesis → Electron Carriers

One carrier molecule is **NADP⁺**.

Electron carriers, such as NADP⁺, transport electrons.

NADP⁺ accepts and holds 2 high-energy electrons along with a hydrogen ion (H⁺). This converts the NADP⁺ into NADPH.



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8-3 The Reactions of Photosynthesis → Electron Carriers

The conversion of NADP⁺ into NADPH is one way some of the energy of sunlight can be trapped in chemical form.

The NADPH carries high-energy electrons to chemical reactions elsewhere in the cell.

These high-energy electrons are used to help build a variety of molecules the cell needs, including carbohydrates like glucose.



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What happens in the light-dependent reactions?

Light-Dependent Reactions

The light-dependent reactions require light.



The light-dependent reactions produce oxygen gas and convert ADP and NADP⁺ into the energy carriers ATP and NADPH.

8-3 The Reactions of Photosynthesis → **Light-Dependent Reactions**

movie
click to start

The diagram shows a cross-section of a thylakoid membrane, represented by a phospholipid bilayer of grey spheres. Several protein complexes are embedded in the membrane, shown as blue and green spheres. A red structure, resembling a photosynthetic reaction center, is also present. A green shaded area above the membrane indicates the stroma.

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8-3 The Reactions of Photosynthesis → **Light-Dependent Reactions**

Photosynthesis begins when pigments in photosystem II absorb light, increasing their energy level.

Photosystem II

The diagram is similar to the previous one, but a yellow lightning bolt symbol, representing light energy, is shown striking a green pigment molecule. A black arrow points from the label 'Photosystem II' to this green molecule. Two red curved arrows in the top left corner indicate a transition or continuation.

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8-3 The Reactions of Photosynthesis → **Light-Dependent Reactions**

These high-energy electrons are passed on to the electron transport chain.

Photosystem II

High-energy electron

Electron carriers

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8-3 The Reactions of Photosynthesis → **Light-Dependent Reactions**

Enzymes on the thylakoid membrane break water molecules into:

Photosystem II

$2\text{H}_2\text{O}$

High-energy electron

Electron carriers

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

- hydrogen ions
- oxygen atoms
- energized electrons

Photosystem II

$2\text{H}_2\text{O}$

H^+ + O_2

e^-

High-energy electron

Electron carriers

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

The energized electrons from water replace the high-energy electrons that chlorophyll lost to the electron transport chain.

Photosystem II

$2\text{H}_2\text{O}$

H^+ + O_2

e^-

High-energy electron

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As plants remove electrons from water, oxygen is left behind and is released into the air.

Photosystem II

$2\text{H}_2\text{O}$

H^+ + O_2

e^-

High-energy electron

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

The hydrogen ions left behind when water is broken apart are released inside the thylakoid membrane.

Photosystem II

$2\text{H}_2\text{O}$

H^+ + O_2

e^-

High-energy electron

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Energy from the electrons is used to transport H^+ ions from the stroma into the inner thylakoid space.

Photosystem II

$2H_2O \rightarrow O_2 + 2H^+$

e^-

H^+

H^+

H^+

H^+

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

High-energy electrons move through the electron transport chain from photosystem II to photosystem I.

Photosystem II

$2H_2O \rightarrow O_2 + 2H^+$

e^-

H^+

H^+

H^+

H^+

Photosystem I

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Pigments in photosystem I use energy from light to re-energize the electrons.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

NADP⁺ then picks up these high-energy electrons, along with H⁺ ions, and becomes NADPH.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

As electrons are passed from chlorophyll to NADP^+ , more H^+ ions are pumped across the membrane.

The diagram illustrates the light-dependent reactions of photosynthesis occurring across a membrane. Light energy (represented by yellow lightning bolts) is absorbed by chlorophyll (green spheres). This energy is used to split water ($2\text{H}_2\text{O}$) into oxygen (O_2) and protons (H^+). Electrons (e^-) are transferred from chlorophyll to a series of electron carriers (blue and green spheres). As electrons move through these carriers, protons (H^+) are pumped from the stroma (bottom) to the thylakoid space (top). Finally, electrons are transferred to 2NADP^+ , which combines with 2H^+ to form 2NADPH . The membrane is shown as a phospholipid bilayer with a red cylindrical structure on the right.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

Soon, the inside of the membrane fills up with positively charged hydrogen ions, which makes the outside of the membrane negatively charged.

This diagram is similar to the previous one, showing the light-dependent reactions of photosynthesis. It illustrates the same process of light energy being used to split water and transfer electrons through a series of carriers, resulting in the pumping of protons across the membrane and the formation of NADPH. The key difference is that the thylakoid space (top) is now filled with a higher concentration of protons (H^+), indicating the establishment of a proton gradient across the membrane.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

The difference in charges across the membrane provides the energy to make ATP

The diagram illustrates the light-dependent reactions of photosynthesis occurring across a membrane. Light energy (represented by yellow lightning bolts) is absorbed by photosystem II (green sphere), which splits water ($2\text{H}_2\text{O}$) into oxygen (O_2) and protons (H^+). Electrons (e^-) are transferred through a series of electron carriers (blue spheres) to photosystem I (green sphere). At photosystem I, light energy again excites electrons, which are then passed to NADP⁺, reducing it to NADPH. Simultaneously, protons (H^+) are pumped from the stroma (bottom) into the thylakoid space (top) by the electron transport chain. This creates a proton gradient across the membrane. ATP synthase (red structure) is shown embedded in the membrane, ready to harness the energy from the proton gradient to synthesize ATP.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

H^+ ions cannot cross the membrane directly.

This diagram is similar to the previous one but highlights the role of ATP synthase. It shows that protons (H^+) cannot cross the membrane directly. Instead, they flow back from the thylakoid space to the stroma through ATP synthase. This flow drives the synthesis of ATP from ADP and inorganic phosphate (Pi). The electron transport chain and NADP⁺ reduction to NADPH are also shown, as in the previous slide.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

The cell membrane contains a protein called **ATP synthase** that allows H^+ ions to pass through it

Diagram illustrating the light-dependent reactions of photosynthesis. Light energy (represented by yellow lightning bolts) is absorbed by photosystems (green and blue spheres) embedded in a cell membrane. Water ($2H_2O$) is split into oxygen (O_2) and protons (H^+). Electrons (e^-) are transferred to $2 NADP^+$ + $2 H^+$ to form $2 NADPH$. Protons (H^+) are pumped across the membrane by the photosystems. ATP synthase is embedded in the membrane, allowing protons (H^+) to pass through it.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

As H^+ ions pass through ATP synthase, the protein rotates.

Diagram illustrating the light-dependent reactions of photosynthesis. Light energy (represented by yellow lightning bolts) is absorbed by photosystems (green and blue spheres) embedded in a cell membrane. Water ($2H_2O$) is split into oxygen (O_2) and protons (H^+). Electrons (e^-) are transferred to $2 NADP^+$ + $2 H^+$ to form $2 NADPH$. Protons (H^+) are pumped across the membrane by the photosystems. ATP synthase is embedded in the membrane, and its rotation is shown as protons (H^+) flow through it.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

As it rotates, ATP synthase binds ADP and a phosphate group together to produce ATP.

The diagram illustrates the light-dependent reactions of photosynthesis. Light energy (represented by yellow lightning bolts) is absorbed by photosystem II, where water ($2\text{H}_2\text{O}$) is split into oxygen (O_2) and protons (H^+). Electrons (e^-) are transferred through a series of photosystems (green and blue spheres) and electron carriers. This process pumps protons from the stroma into the thylakoid space, creating a proton gradient. At photosystem I, light energy again excites electrons, which are then passed to NADP⁺, reducing it to NADPH. The resulting proton gradient drives ATP synthase, which rotates as protons flow back into the stroma, synthesizing ATP from ADP and inorganic phosphate.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

Because of this system, light-dependent electron transport produces not only high-energy electrons but ATP as well.

This diagram is identical to the one on slide 32, showing the light-dependent reactions of photosynthesis. It details the absorption of light energy, the splitting of water into oxygen and protons, the transport of electrons through photosystems and carriers to produce NADPH, and the use of the resulting proton gradient to drive ATP synthase, which produces ATP from ADP and phosphate.

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8-3 The Reactions of Photosynthesis → Light-Dependent Reactions

The light-dependent reactions use water, ADP, and NADP⁺.

The light-dependent reactions produce oxygen, ATP, and NADPH.

These compounds provide the energy to build energy-containing sugars from low-energy compounds.



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8-3 The Reactions of Photosynthesis → The Calvin Cycle



What is the Calvin cycle?



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The Calvin Cycle

ATP and NADPH formed by the light-dependent reactions contain an abundance of chemical energy, but they are not stable enough to store that energy for more than a few minutes.

During the **Calvin cycle** plants use the energy that ATP and NADPH contain to build high-energy compounds that can be stored for a long time.



The Calvin cycle uses ATP and NADPH from the light-dependent reactions to produce high-energy sugars.

Because the Calvin cycle does not require light, these reactions are also called the light-independent reactions.

8-3 The Reactions of Photosynthesis → **The Calvin Cycle**

Six carbon dioxide molecules enter the cycle from the atmosphere and combine with six 5-carbon molecules.

CO₂ Enters the Cycle

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8-3 The Reactions of Photosynthesis → **The Calvin Cycle**

The result is twelve 3-carbon molecules, which are then converted into higher-energy forms.

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8-3 The Reactions of Photosynthesis → **The Calvin Cycle**

The energy for this conversion comes from ATP and high-energy electrons from NADPH.

Diagram illustrating the first step of the Calvin Cycle: 6 molecules of 6-carbon CO_2 are converted into 12 molecules of 3-carbon molecules. This process requires energy input from 12 ATP (which become 12 ADP) and 12 NADPH (which become 12 NADP^+).

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8-3 The Reactions of Photosynthesis → **The Calvin Cycle**

Two of twelve 3-carbon molecules are removed from the cycle.

Diagram illustrating the second step of the Calvin Cycle: 12 molecules of 3-carbon molecules are produced. Two of these 3-carbon molecules are removed from the cycle, while the remaining 10 continue the cycle. The process still requires energy input from 12 ATP (which become 12 ADP) and 12 NADPH (which become 12 NADP^+).

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8-3 The Reactions of Photosynthesis → **The Calvin Cycle**

The molecules are used to produce sugars, lipids, amino acids and other compounds.

The diagram illustrates the Calvin Cycle as a circular pathway. At the top, 6 molecules of CO_2 (each with a '6 C' label) enter the cycle. An arrow points to 12 molecules of a 3-carbon intermediate (labeled '12 C C C'). From here, an arrow points to 12 molecules of a 3-carbon sugar (labeled '12 C C C'). This step is associated with the conversion of 12 ATP to 12 ADP (indicated by a blue arrow) and 12 NADPH to 12 NADP⁺ (indicated by a yellow arrow). From the 12 3-carbon sugars, an arrow points to 10 molecules of a 3-carbon sugar (labeled '10 C C C') and 2 molecules of a 3-carbon sugar (labeled '2 C C C'). The 2 3-carbon sugars are shown combining to form a 6-carbon sugar (labeled 'C C C C C C') and are collectively labeled 'Sugars and other compounds'. The 10 3-carbon sugars are labeled '6-Carbon sugar produced'. The cycle then returns to the starting point with 6 molecules of a 5-carbon sugar (labeled '6 C C C C C').

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8-3 The Reactions of Photosynthesis → **The Calvin Cycle**

The 10 remaining 3-carbon molecules are converted back into six 5-carbon molecules, which are used to begin the next cycle.

The diagram illustrates the Calvin Cycle as a circular pathway. At the top, 6 molecules of CO_2 (each with a '6 C' label) enter the cycle. An arrow points to 12 molecules of a 3-carbon intermediate (labeled '12 C C C'). From here, an arrow points to 12 molecules of a 3-carbon sugar (labeled '12 C C C'). This step is associated with the conversion of 12 ATP to 12 ADP (indicated by a blue arrow) and 12 NADPH to 12 NADP⁺ (indicated by a yellow arrow). From the 12 3-carbon sugars, an arrow points to 10 molecules of a 3-carbon sugar (labeled '10 C C C') and 2 molecules of a 3-carbon sugar (labeled '2 C C C'). The 2 3-carbon sugars are shown combining to form a 6-carbon sugar (labeled 'C C C C C C') and are collectively labeled 'Sugars and other compounds'. The 10 3-carbon sugars are labeled '5-Carbon Molecules Regenerated'. The cycle then returns to the starting point with 6 molecules of a 5-carbon sugar (labeled '6 C C C C C').

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The two sets of photosynthetic reactions work together.

- The light-dependent reactions trap sunlight energy in chemical form.
- The light-independent reactions use that chemical energy to produce stable, high-energy sugars from carbon dioxide and water.

Factors Affecting Photosynthesis

Many factors affect the rate of photosynthesis, including:

- Water
- Temperature
- Intensity of light