BIOLOGY 111

- **CHAPTER 4: Energy and Life**
- ***Part 2 - Photosynthesis***

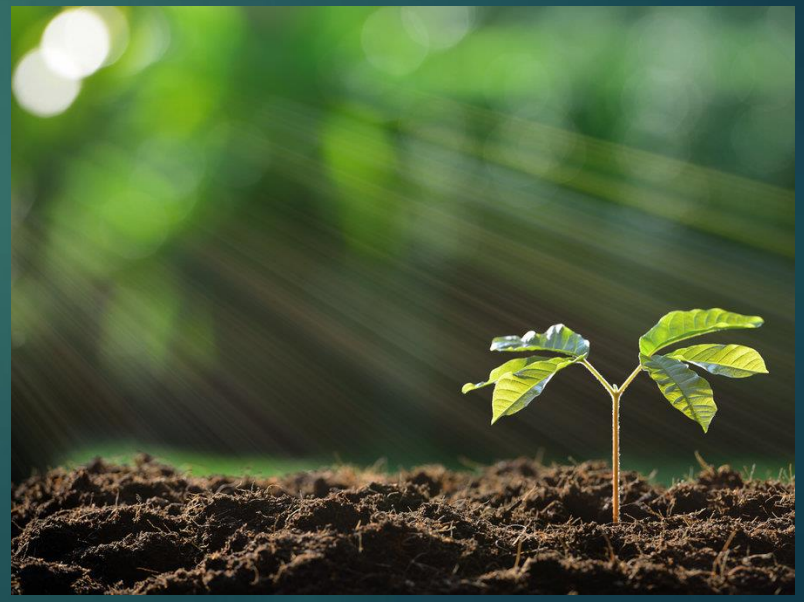
Energy and Life

Learning Outcomes

4.3 Describe the overall process of photosynthesis. *(Modules 4.3–4.6)*

4.4 Name the cellular structures and locations involved in photosynthesis. *(Module 4.3)*

4.5 Describe the two sets of reactions involved in photosynthesis, including the molecules that are used to bridge them. *(Modules 4.4–4.6)*



In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

4.3: Within chloroplasts, the energy of sunlight is used to produce sugars.

CORE IDEA: Photosynthesis uses CO_2 (obtained via stomata on leaves), H_2O (obtained via the roots), and *light energy* (absorbed by the pigment *chlorophyll*, found in the thylakoid membranes of chloroplasts) to produce sugars (used by the plant) and O_2 gas (released via the stomata).

A. Within chloroplasts, the energy of sunlight is used to produce sugars.
B. Where and how photosynthesis occurs
C. Chlorophyll

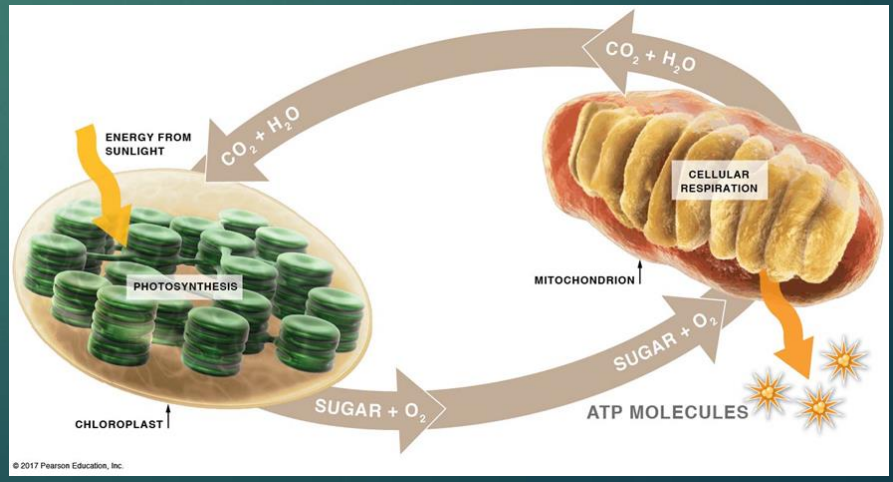
In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

4.3: Within chloroplasts, the energy of sunlight is used to produce sugars.

CORE IDEA: Photosynthesis uses CO_2 (obtained via stomata on leaves), H_2O (obtained via the roots), and *light energy* (absorbed by the pigment *chlorophyll*, found in the thylakoid membranes of chloroplasts) to produce sugars (used by the plant) and O_2 gas (released via the stomata).

A. Within chloroplasts, the energy of sunlight is used to produce sugars.
B. Where and how photosynthesis occurs
C. Chlorophyll



In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.

1. Photosynthesis uses *CO_2*, *H_2O*, and light *energy* to produce *sugars*.

   i. **H_20** enters through roots

In chloroplasts, the energy of sunlight is used to produce sugars:

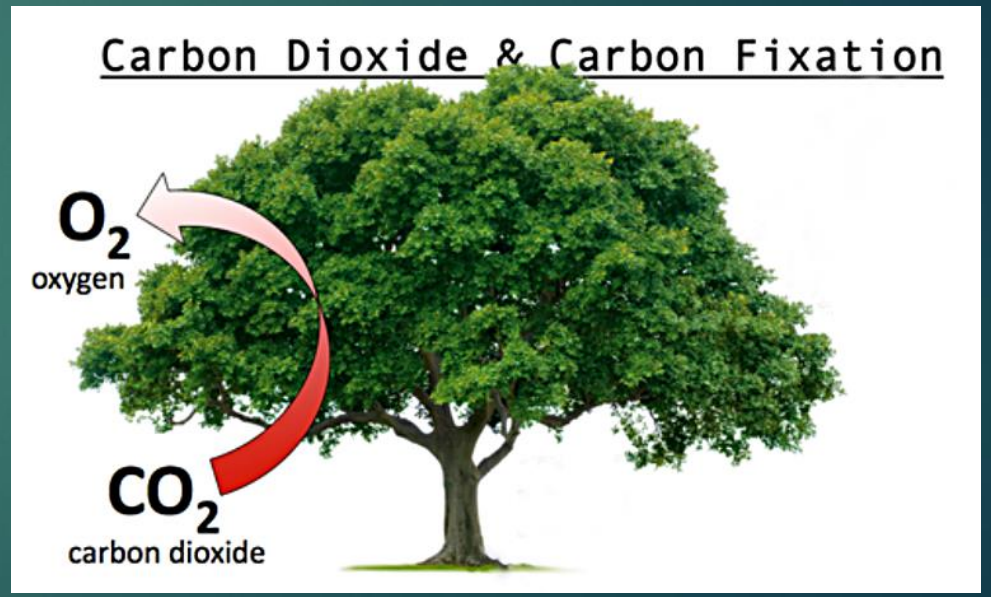
Within chloroplasts, the energy of sunlight is used to produce sugars

A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.

1. Photosynthesis uses *CO_2*, *H_2O*, and light *energy* to produce *sugars*.

   i. **H_20** enters through roots

   ii. **CO_2** comes from the atmosphere



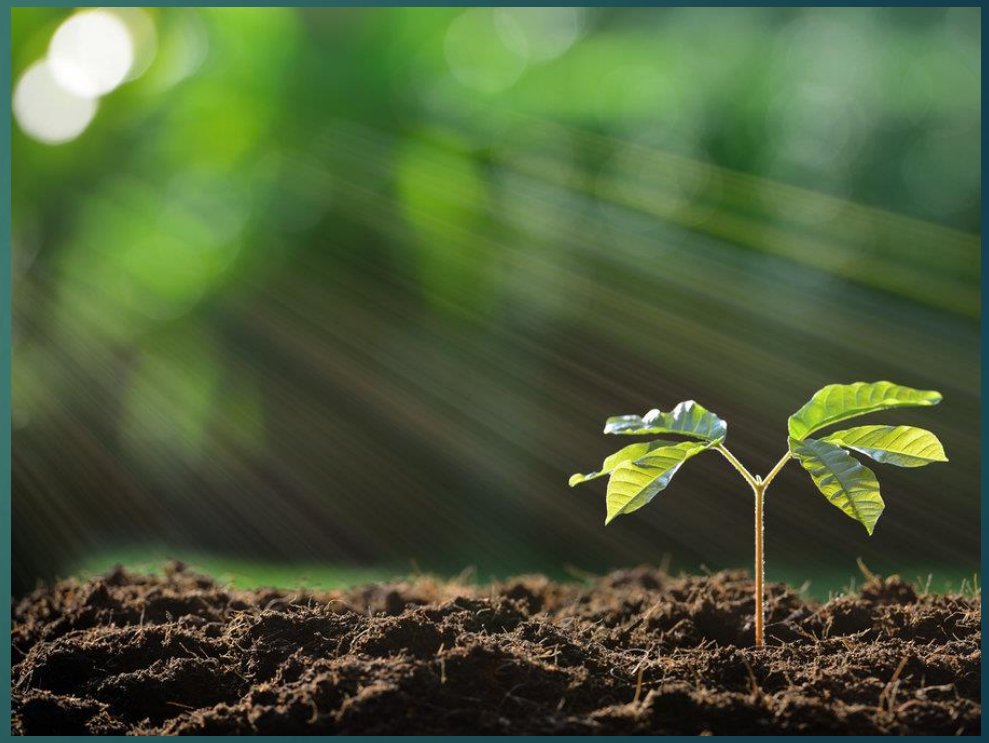
In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.

1. Photosynthesis uses *CO_2*, *H_2O*, and light *energy* to produce *sugars*.

   i. **H_20** enters through roots
   ii. **CO_2** comes from the atmosphere
   iii. **Energy** comes from sunlight



In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.

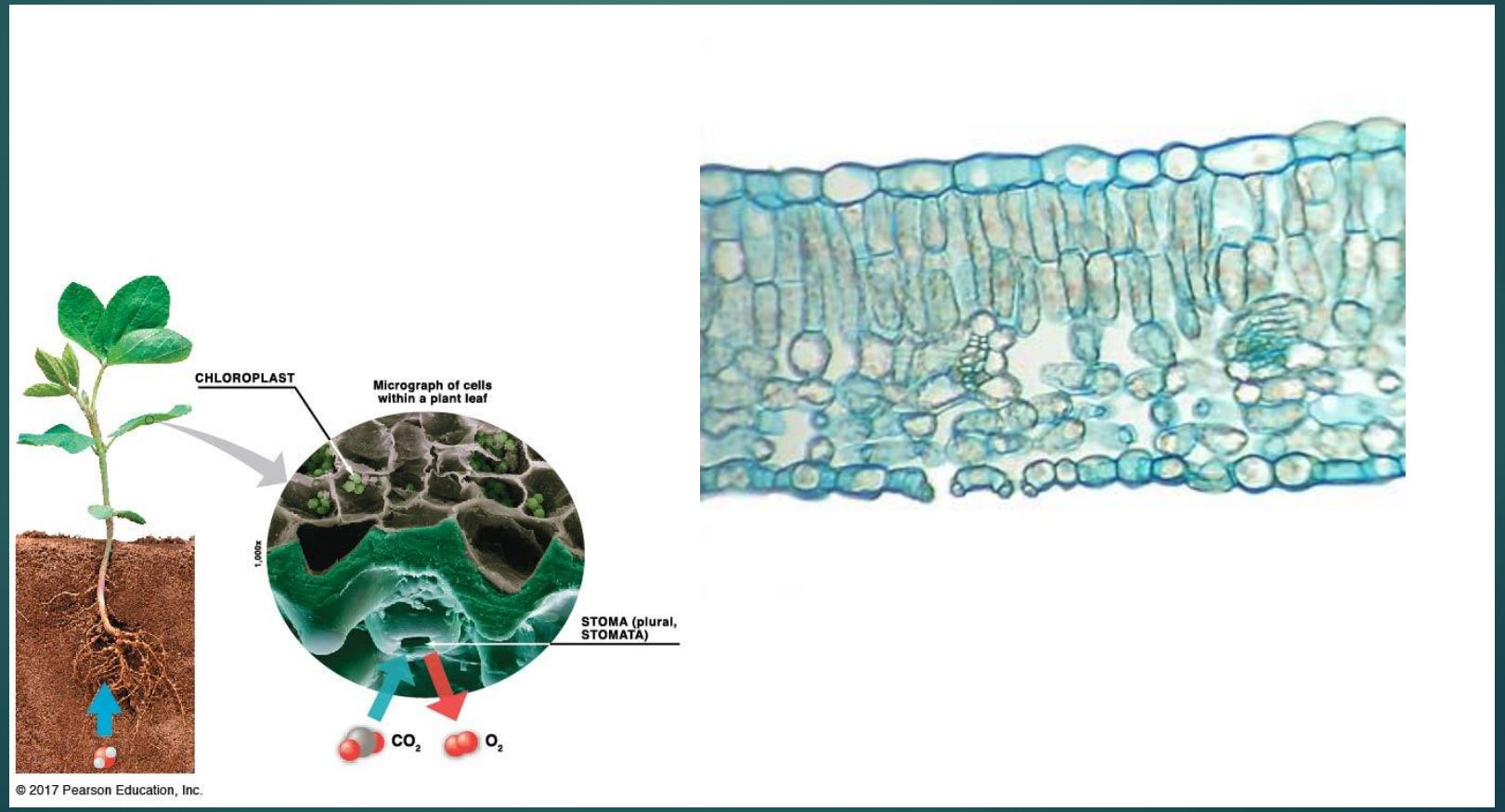
1. Photosynthesis uses *CO_2*, *H_2O*, and light *energy* to produce *sugars*.

2. Photosynthesis occurs in *chloroplasts*.

In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

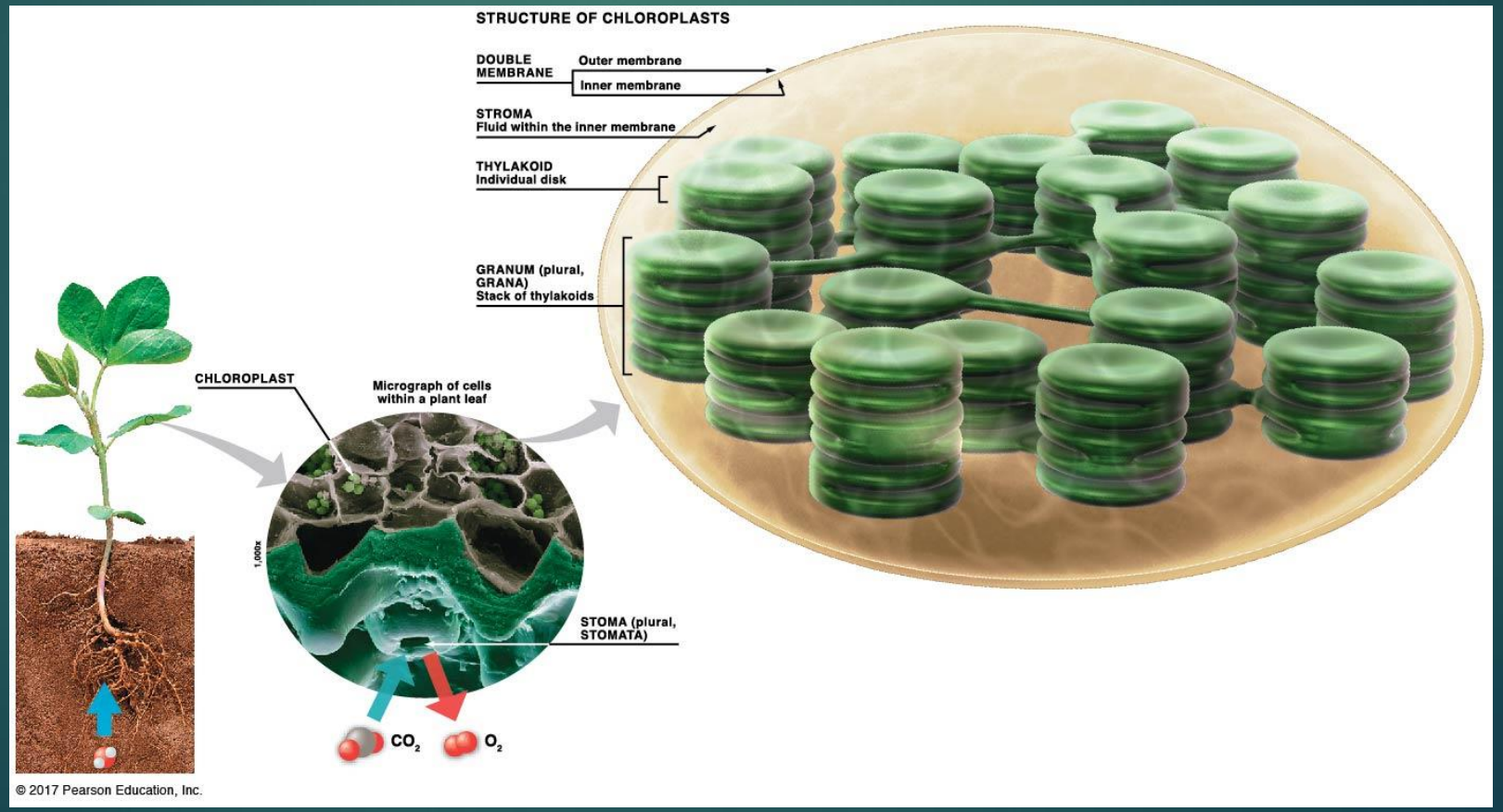
A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.



In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

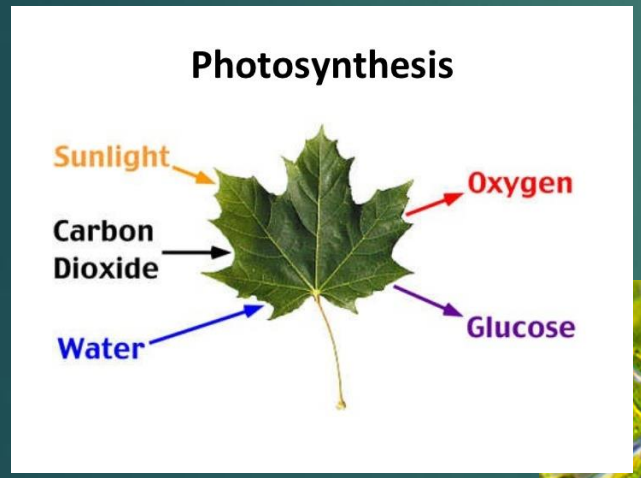
A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.

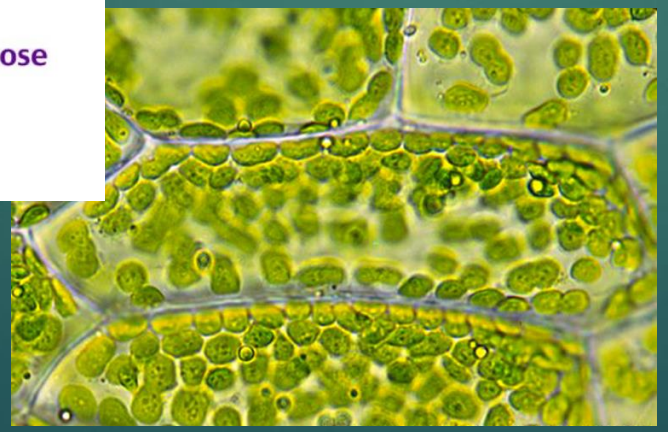


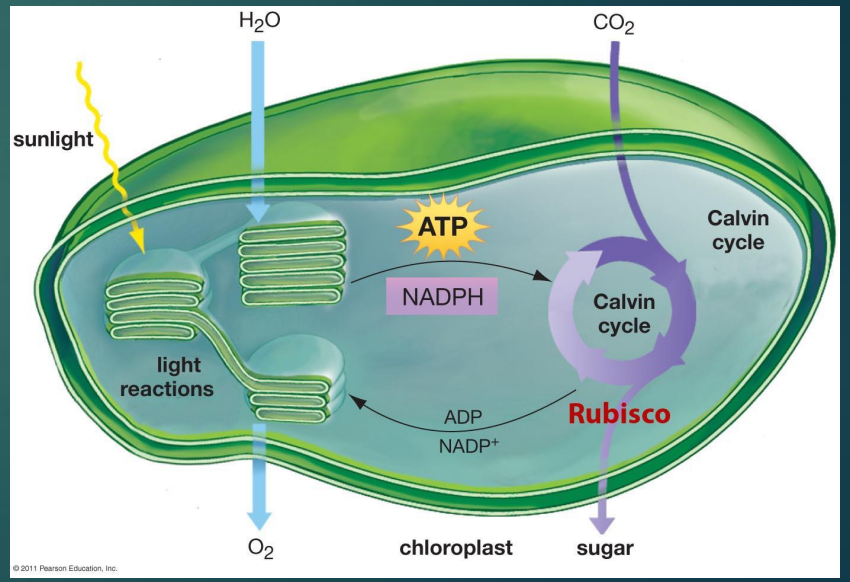
In chloroplasts, the energy of sunlight is used to produce sugars:

Within chloroplasts, the energy of sunlight is used to produce sugars

A. Within chloroplasts, the energy of *sunlight is used to produce sugars*.





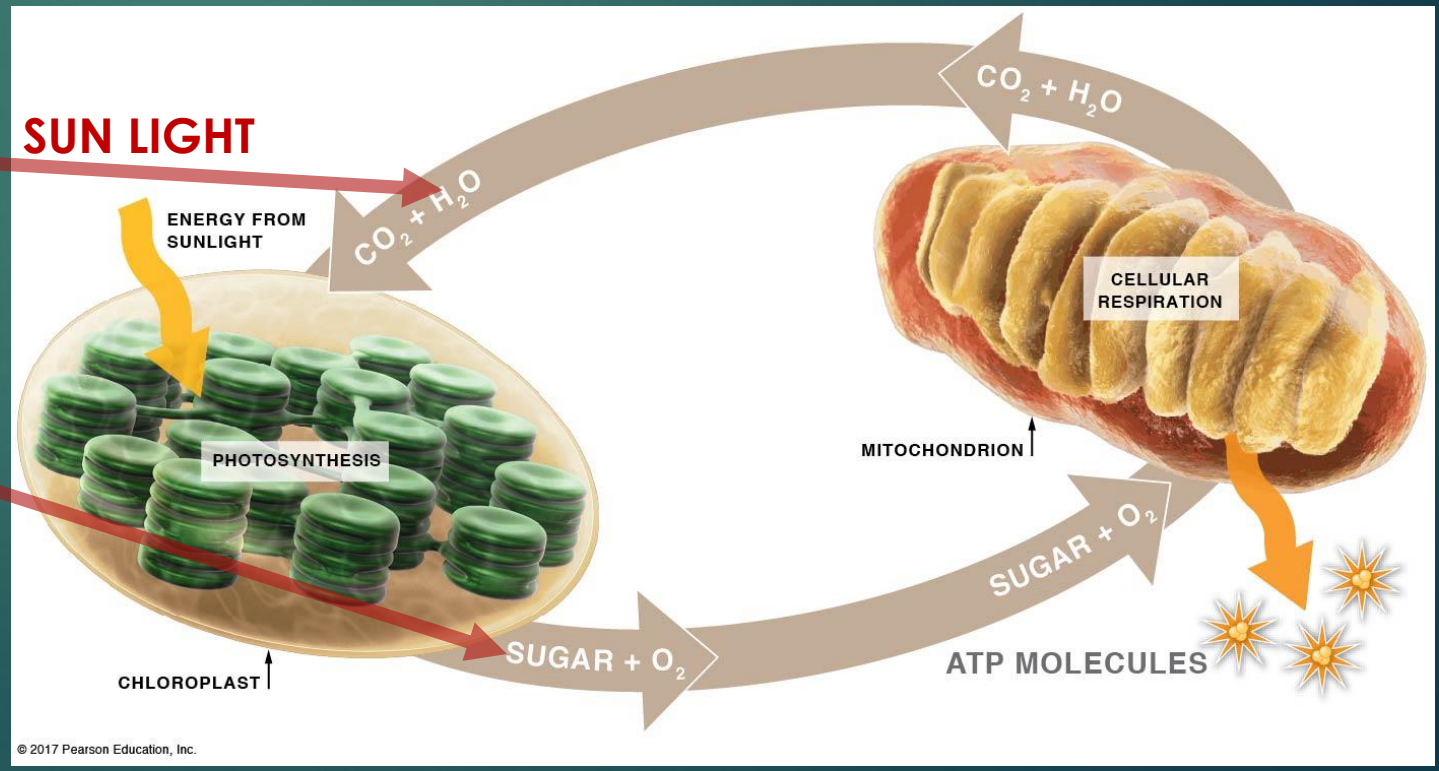


In chloroplasts, the energy of sunlight is used to produce sugars:

Photosynthesis: Following electrons and energy

A. Photosynthesis *starts with low energy electrons* and ends with high energy electrons

1. Low energy electrons come from water
2. High energy electrons end up in sugars (like glucose)

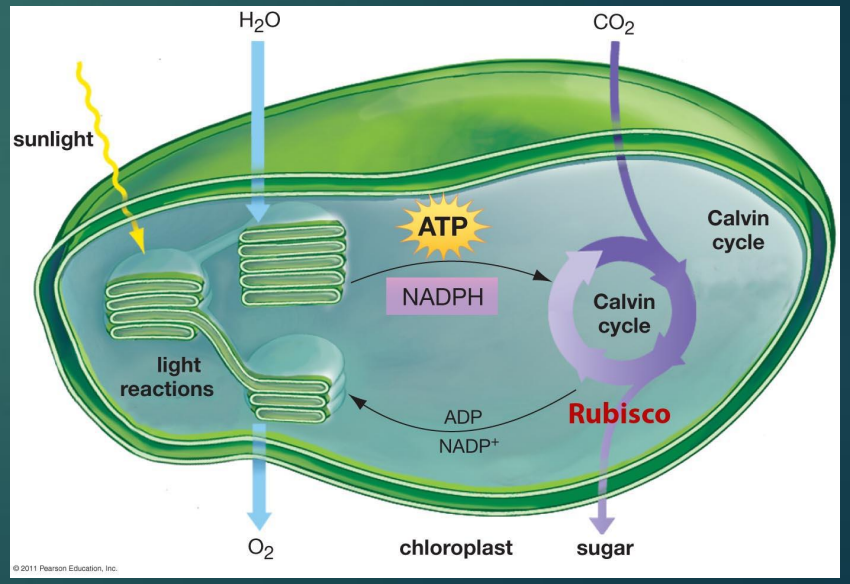


In chloroplasts, the energy of sunlight is used to produce sugars:

Where and how photosynthesis occurs

B. Where and how photosynthesis occurs

1. *Structure* of chloroplasts
   a. Inside each chloroplast is an extensive inner *framework of membranes*.

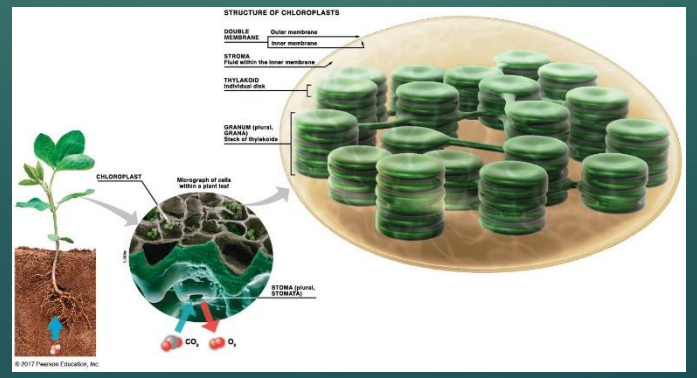


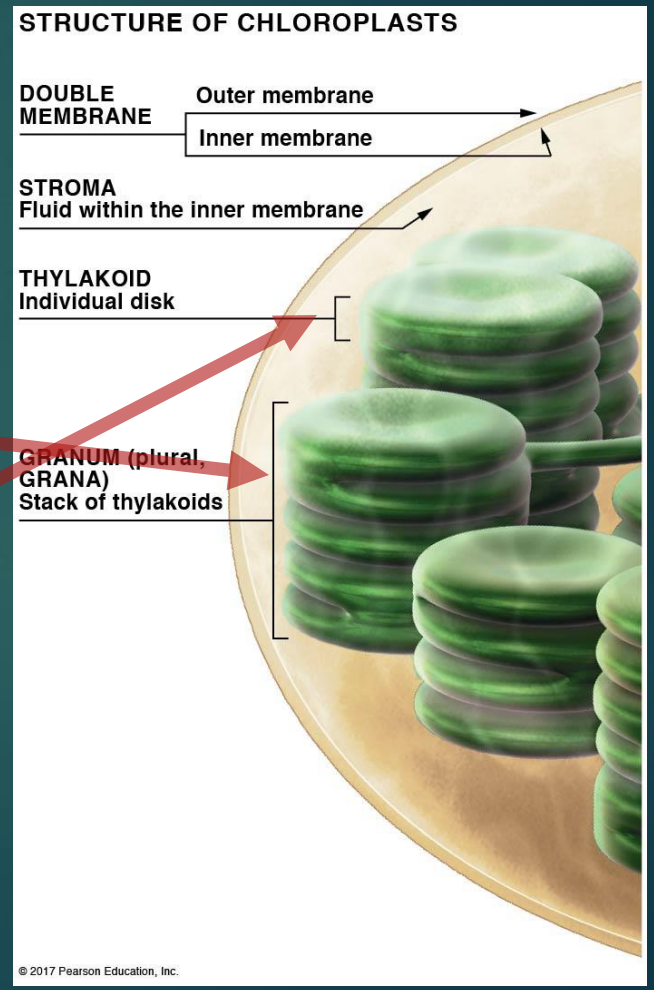
In chloroplasts, the energy of sunlight is used to produce sugars:

Where and how photosynthesis occurs

B. Where and how photosynthesis occurs

1. *Structure* of chloroplasts
   a. Inside each chloroplast is an extensive inner *framework of membranes*.
   b. Grana are stacks of disks made from this membrane.
   c. Each individual disk in a grana is a thylakoid.





In chloroplasts, the energy of sunlight is used to produce sugars:

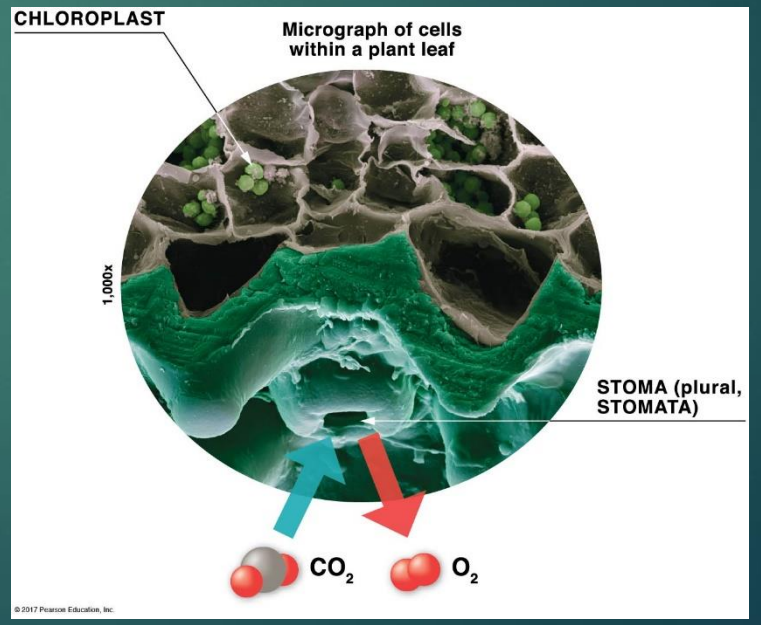
Where and how photosynthesis occurs

2. *How* photosynthesis works
   a. Photosynthesis *requires* water (H_2O) and carbon dioxide (CO_2).
   b. Water is absorbed by the *roots* and transported to cells.

In chloroplasts, the energy of sunlight is used to produce sugars:

Where and how photosynthesis occurs

2. *How* photosynthesis works
   a. Photosynthesis requires water (H_2O) and carbon dioxide (CO_2).
   b. Water is absorbed by the roots and transported to cells.
   c. CO_2 enters a leaf through stomata.
      i. O_2 gas is released as a by-product and exits through the same pores.

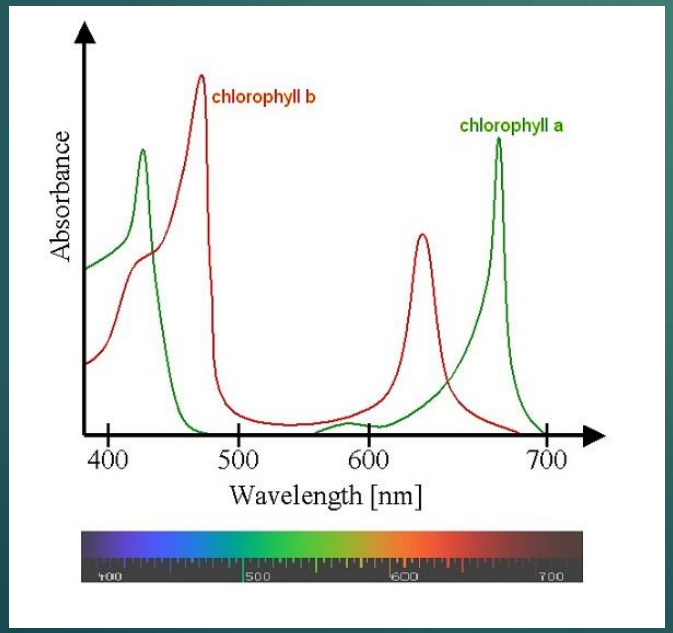


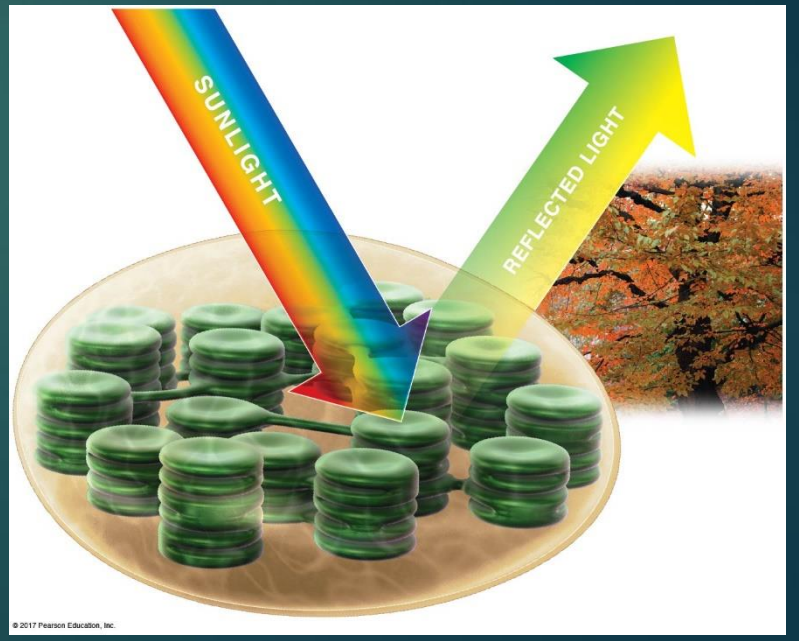
In chloroplasts, the energy of sunlight is used to produce sugars:

Chlorophyll

C. Chlorophyll

1. Chlorophyll is the *primary pigment* in chloroplasts.
2. Molecules of chlorophyll are located with the *thylakoid* membrane.
3. Chlorophyll *selectively absorbs* blue/violet and orange/red ranges of *light*.



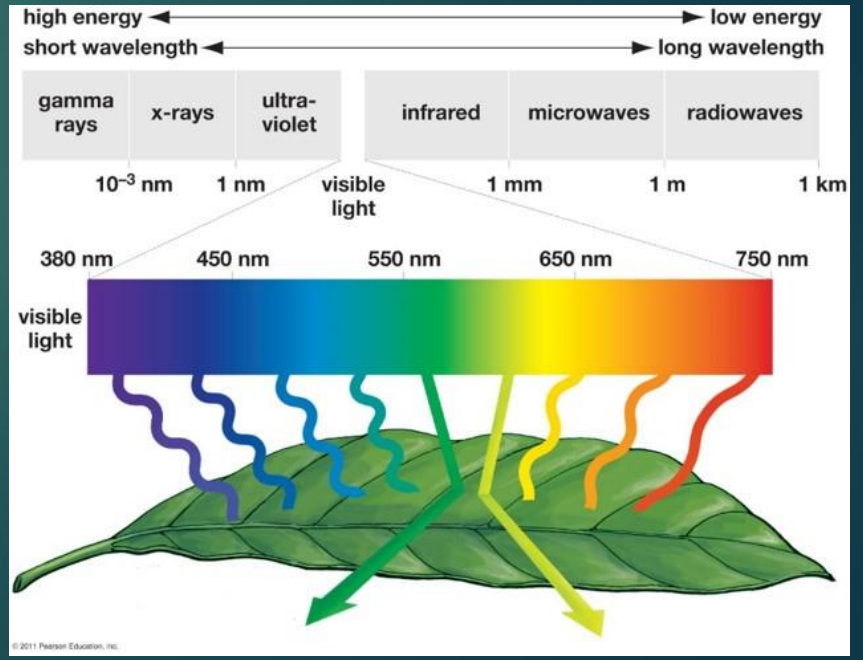


In chloroplasts, the energy of sunlight is used to produce sugars:

Chlorophyll

C. Chlorophyll

1. Chlorophyll is the *primary pigment* in chloroplasts.
2. Molecules of chlorophyll are located with the *thylakoid* membrane.
3. Chlorophyll selectively *absorbs* blue/violet and orange/red ranges of *light*.
4. A plant appears *green* because that color *(wavelength)* of light is reflected.
   a. Reflected light is *not absorbed* for use in photosynthesis



Photosynthesis occurs in two linked stages:

Stage 1 The light reactions: capturing energy

4.4) Photosynthesis occurs in two linked stages.

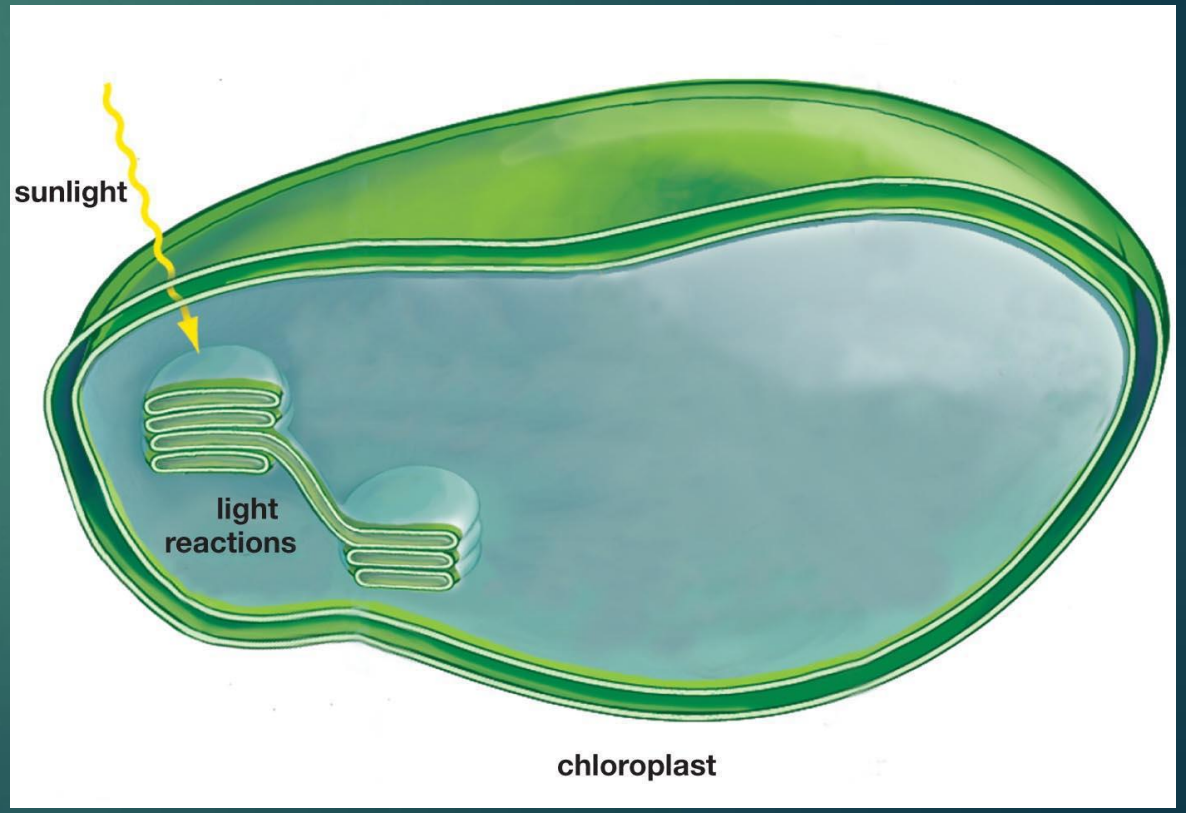
CORE IDEA: The overall process of photosynthesis is broken down into two main stages: (1) *The light Reactions* capture the energy in sunlight and store it as chemical energy, and (2) *The Calvin Cycle* uses that chemical energy to produce sugar.

A. Stage 1 The light reactions: capturing energy
B. Stage 2 The Calvin cycle: making sugar

Photosynthesis occurs in two linked stages:

Stage 1 The light reactions: capturing energy

A. Stage 1 **The light reactions**: *<u>capturing energy</u>*
   1. Within thylakoids, energy from sunlight is absorbed by chlorophyll.



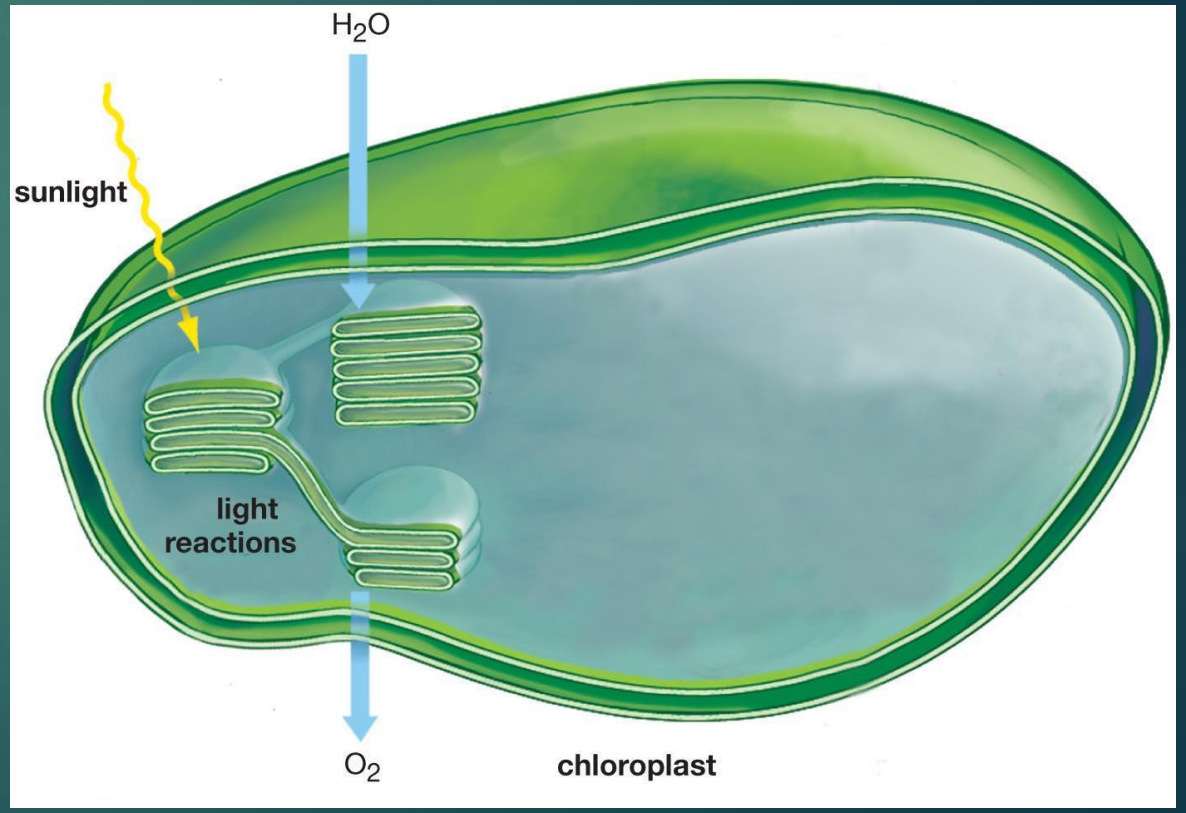
Photosynthesis occurs in two linked stages:

Stage 1 The light reactions: capturing energy

A. Stage 1 **The light reactions**: *capturing energy*

1. Within thylakoids, energy from sunlight is absorbed by chlorophyll.

2. This *energy* is used to split water, producing O_2 and *high-energy electrons*.

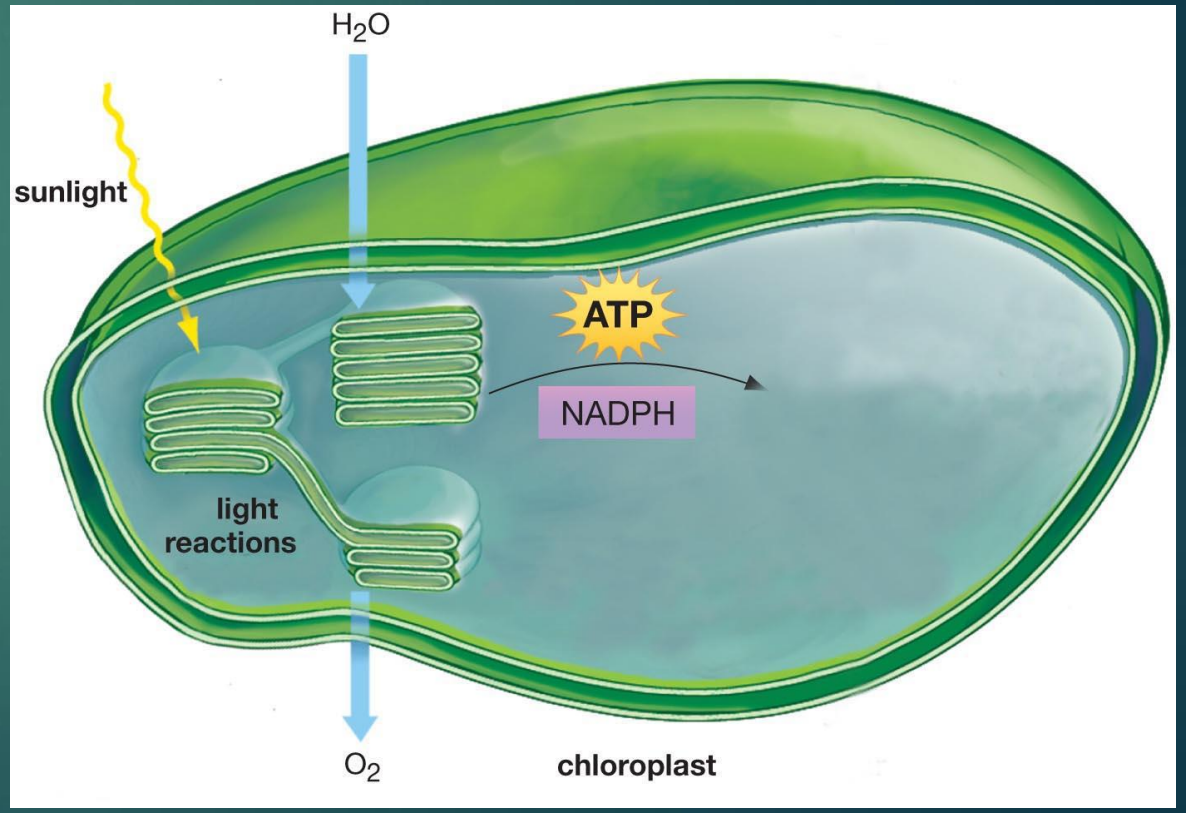


Photosynthesis occurs in two linked stages:

Stage 1 The light reactions: capturing energy

A. Stage 1 **The light reactions**: *capturing energy*

1. Within thylakoids, energy from sunlight is absorbed by chlorophyll.
2. This *energy* is used to split water, producing O_2 and *high-energy electrons*.
3. A bit of energy is used to make ATP. *(needed for the next step)*
4. The high-energy electrons are stored in molecules of NADPH



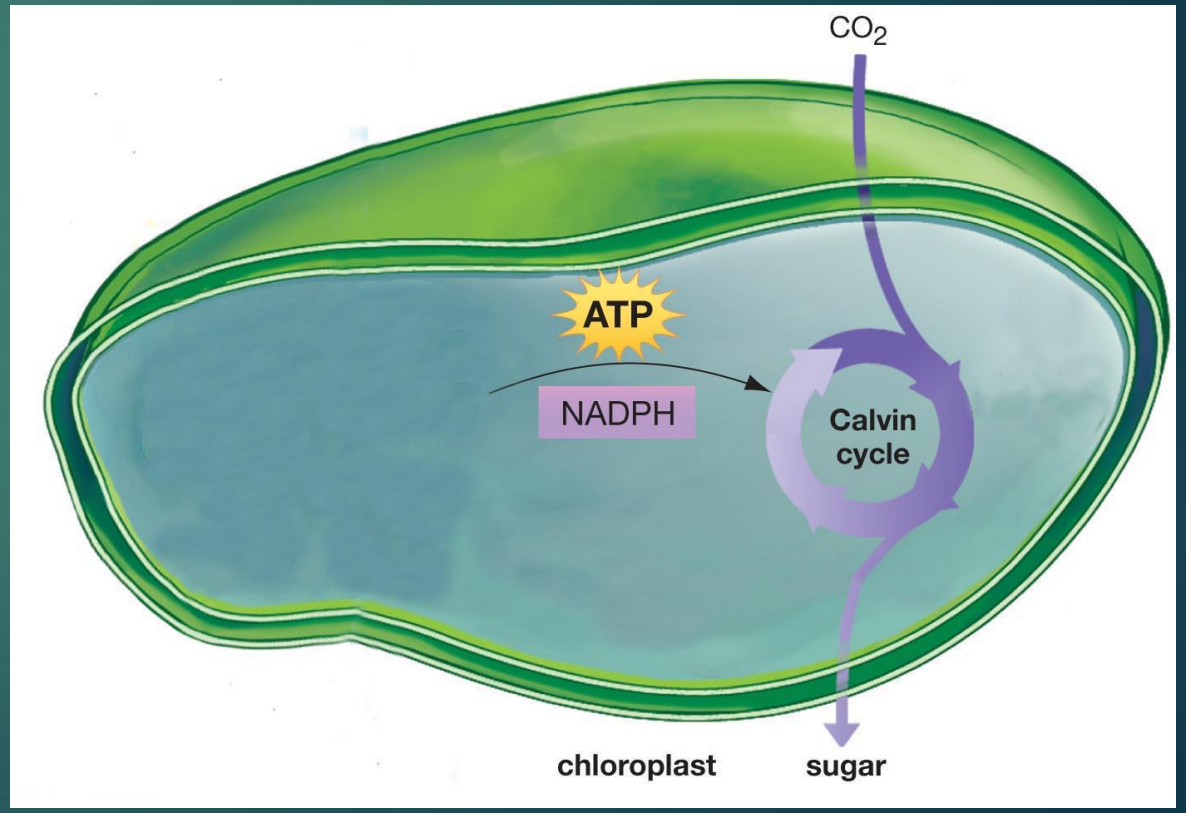
Photosynthesis occurs in two linked stages:

Stage 2 The Calvin cycle: making sugar

B. Stage 2 **The Calvin cycle**: *making sugar*

1. NADPH (high energy electrons) is combined with CO_2 to make *sugar*

2. A bit of ATP is needed for this process

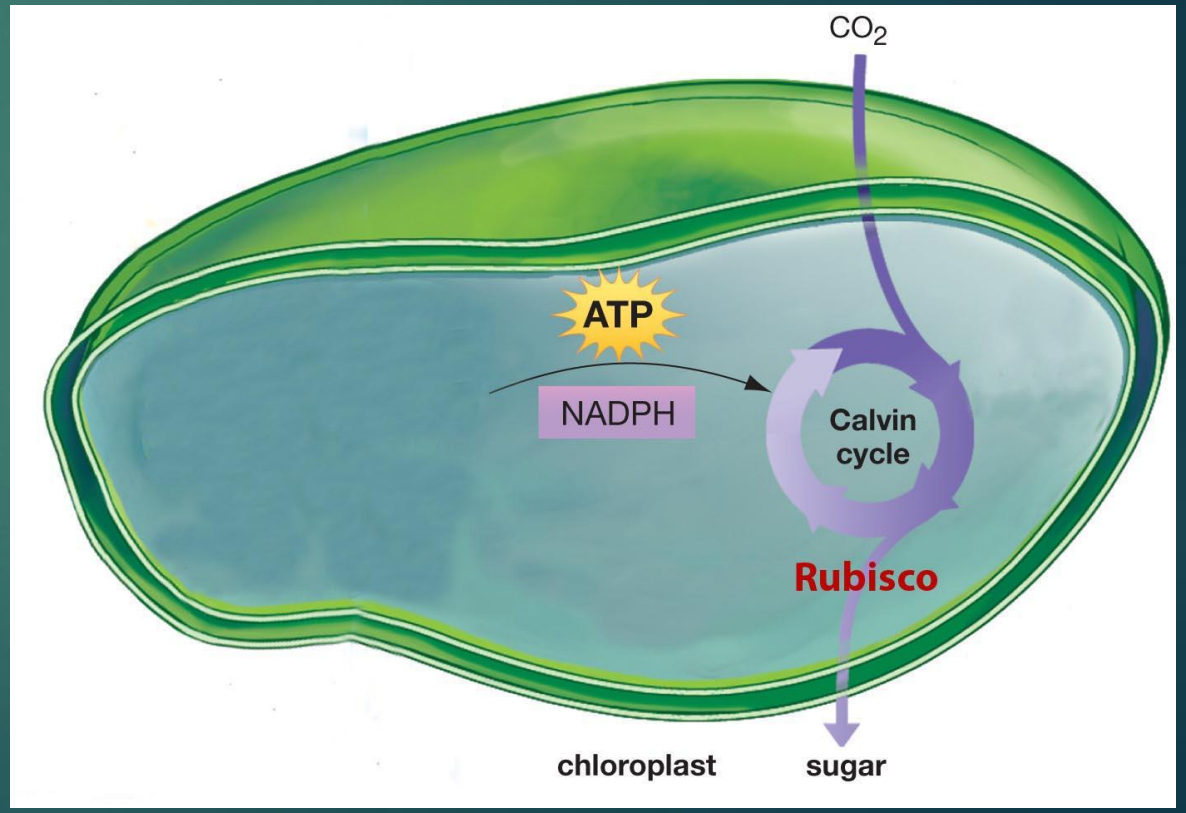


Photosynthesis occurs in two linked stages:

Stage 2 The Calvin cycle: making sugar

B. Stage 2 **The Calvin cycle**: *making sugar*

1. NADPH (high energy electrons) is combined with CO_2 to make *sugar*
2. A bit of ATP is needed for this process
3. The *enzyme* Rubisco speeds this process along
4. This occurs in the stroma, the fluid inside the chloroplast.



In the light reactions, the energy of sunlight is captured as chemical energy:

The energy of sunlight is captured as chemical energy

4.5) In the light reactions, the energy of sunlight is captured as chemical energy.

CORE IDEA: Sunlight drives the light reactions of *photosynthesis* by exciting electrons. As the excited electrons return to their original state, released energy is stored in the high-energy molecules of *ATP* and *NADPH*, which are later used by the *Calvin cycle* to produce sugar.

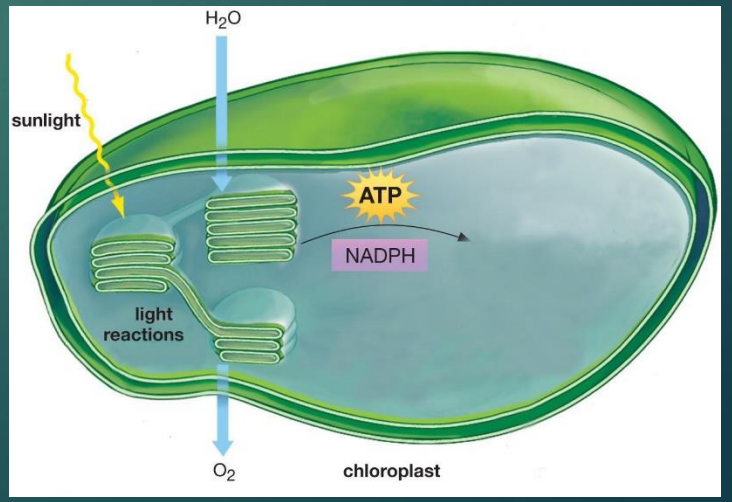
A. In the light reactions, the energy of sunlight is captured as chemical energy.
B. Photosystems
C. The light reactions

In the light reactions, the energy of sunlight is captured as chemical energy:

The energy of sunlight is captured as chemical energy

A. In the light reactions, the energy of sunlight is captured as chemical energy.

1. Two stages of photosynthesis:
   a. **First stage**—*light reactions*—the energy of sunlight is added to electrons stripped from water to produce ATP and NADPH.

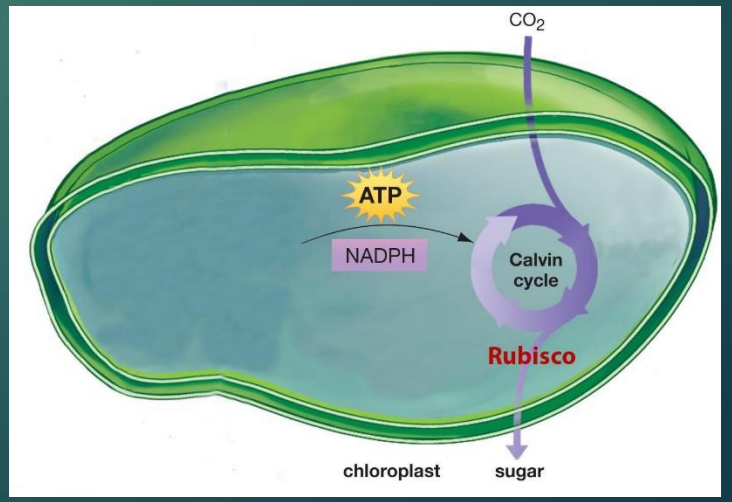


In the light reactions, the energy of sunlight is captured as chemical energy:

The energy of sunlight is captured as chemical energy

A. In the light reactions, the energy of sunlight is captured as chemical energy.

1. Two stages of photosynthesis:
   a. **First stage**—*light reactions*—the energy of sunlight is added to electrons stripped from water to produce ATP and NADPH.
   b. **Second stage**—*Calvin cycle*—ATP and NADPH are combined with CO_2 to produce sugars.



In the Calvin cycle, high-energy molecules are used to make sugar:

High-energy molecules are used to make sugar

4.6) In the Calvin cycle, high-energy molecules are used to make sugar.

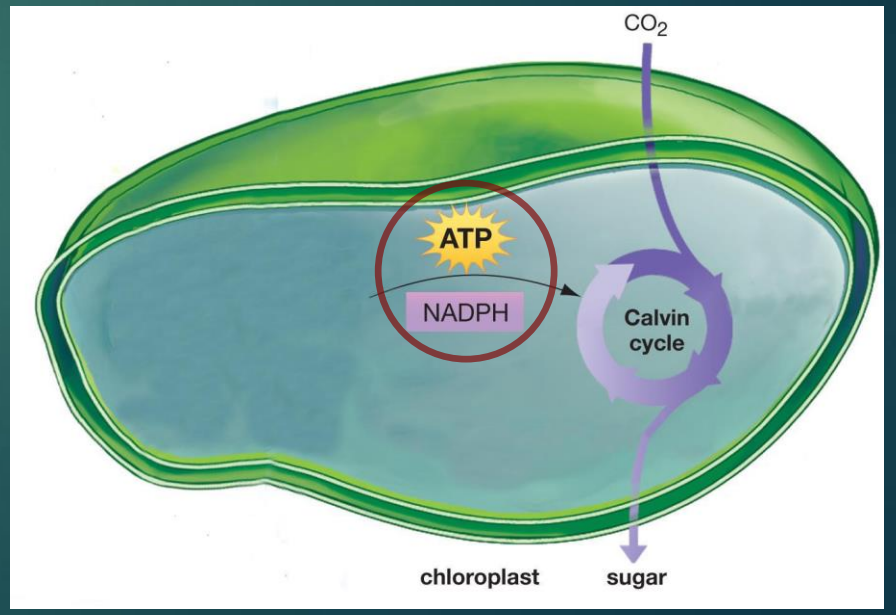
CORE IDEA: The *Calvin cycle* uses high-energy molecules (provided by the light reactions) and CO_2 (from the air) to construct *sugars*, the ultimate product of photosynthesis. These sugars can then be used in a variety of ways by the plant.

A. In the Calvin cycle, high-energy molecules are used to make sugar.
B. Inputs of the Calvin cycle
C. Outputs from the Calvin cycle

In the Calvin cycle, high-energy molecules are used to make sugar:

High-energy molecules are used to make sugar

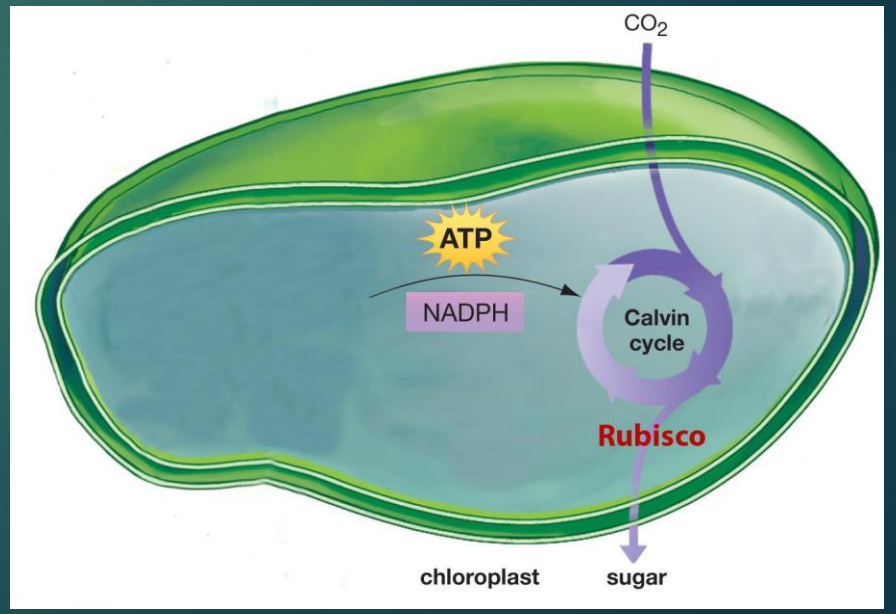
A. In the Calvin cycle, high-energy molecules (ATP and NADPH) are used to make *sugar*.
   1. Overall, the process of photosynthesis combines CO_2 and high energy electrons to make sugars.
      i. A bit of *ATP* is needed, along with *energy* from electrons in NADPH



In the Calvin cycle, high-energy molecules are used to make sugar:

High-energy molecules are used to make sugar

A. In the Calvin cycle, high-energy molecules (ATP and NADPH) are used to make *sugar*.
   1. Overall, the process of photosynthesis combines CO_2 and high energy electrons to make sugars.
      i. A bit of *ATP* is needed, along with *energy* from electrons in NADPH
   2. An enzyme called Rubisco makes all this possible
      i. It *combines* CO_2 and high energy electrons to make a sugar

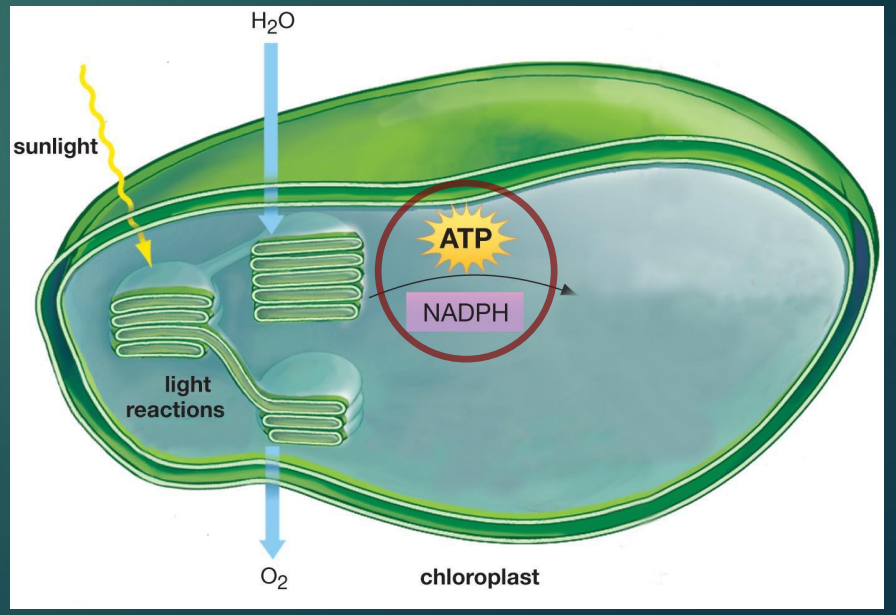


In the Calvin cycle, high-energy molecules are used to make sugar:

High-energy molecules are used to make sugar

A. In the Calvin cycle, high-energy molecules (ATP and NADPH) are used to make *sugar*.
   1. Overall, the process of photosynthesis combines CO_2 and H_2O to make sugars.
      i. A bit of *ATP* is needed, along with *energy* from electrons in NADPH

   2. Two stages of photosynthesis: *(summary)*
      a. **Light reactions** *capture energy* in sunlight and use it to produce high-energy molecules.
         i. High-energy molecules produced are ATP and NADPH.

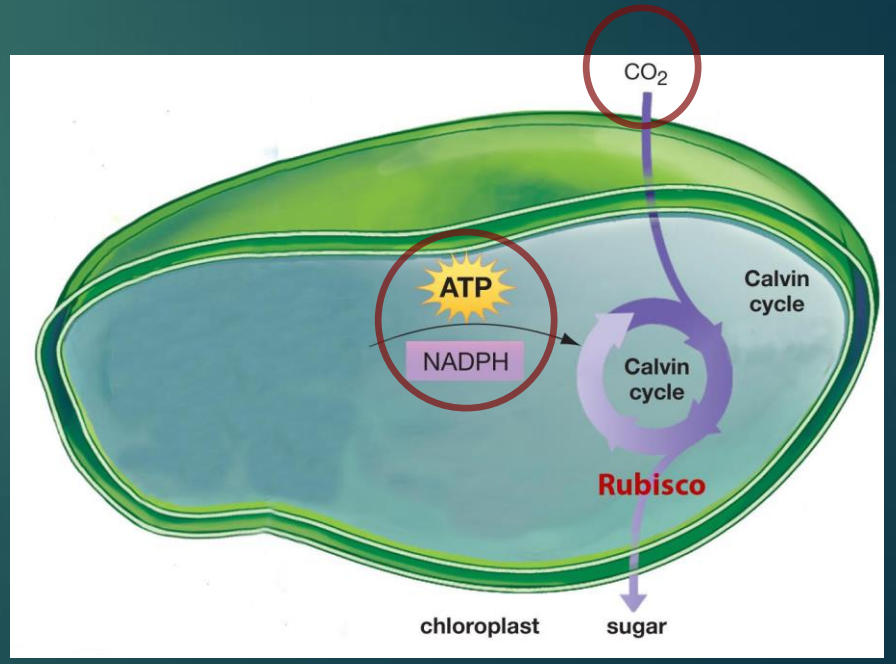


In the Calvin cycle, high-energy molecules are used to make sugar:

High-energy molecules are used to make sugar

A. In the Calvin cycle, high-energy molecules (ATP and NADPH) are used to make *sugar*.
   1. Overall, the process of photosynthesis combines CO_2 and H_2O to make sugars.
      i. A bit of *ATP* is needed, along with *energy* from electrons in NADPH

   2. Two stages of photosynthesis: *(summary)*
      a. **Light reactions** *capture energy* in sunlight and use it to produce high-energy molecules.
         i. High-energy molecules produced are ATP and NADPH.
      b. **Calvin cycle** uses *high-energy molecules* to produce sugars from CO_2.

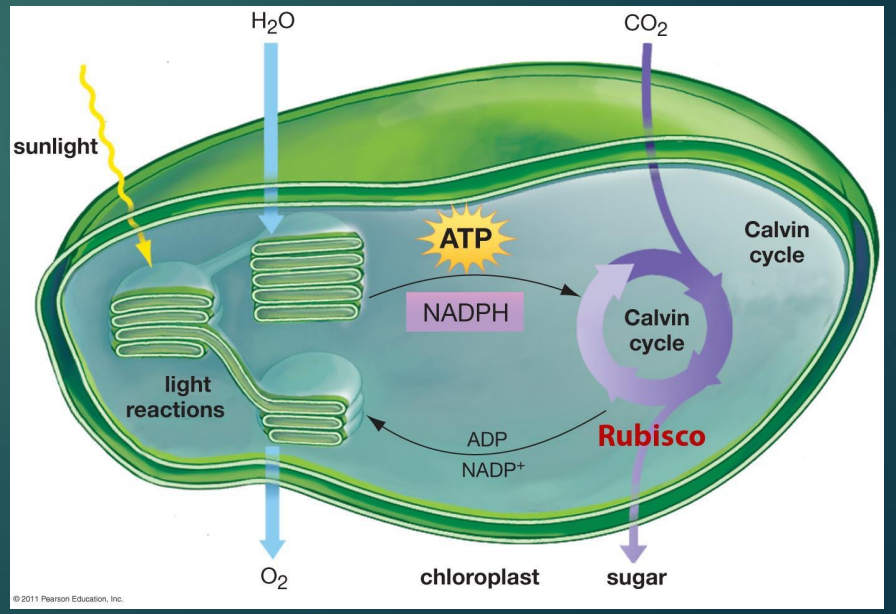


In the Calvin cycle, high-energy molecules are used to make sugar:

High-energy molecules are used to make sugar

A. In the Calvin cycle, high-energy molecules (ATP and NADPH) are used to make *sugar*.
   1. Overall, the process of photosynthesis combines CO_2 and H_2O to make sugars.
      i. A bit of *ATP* is needed, along with *energy* from electrons in NADPH

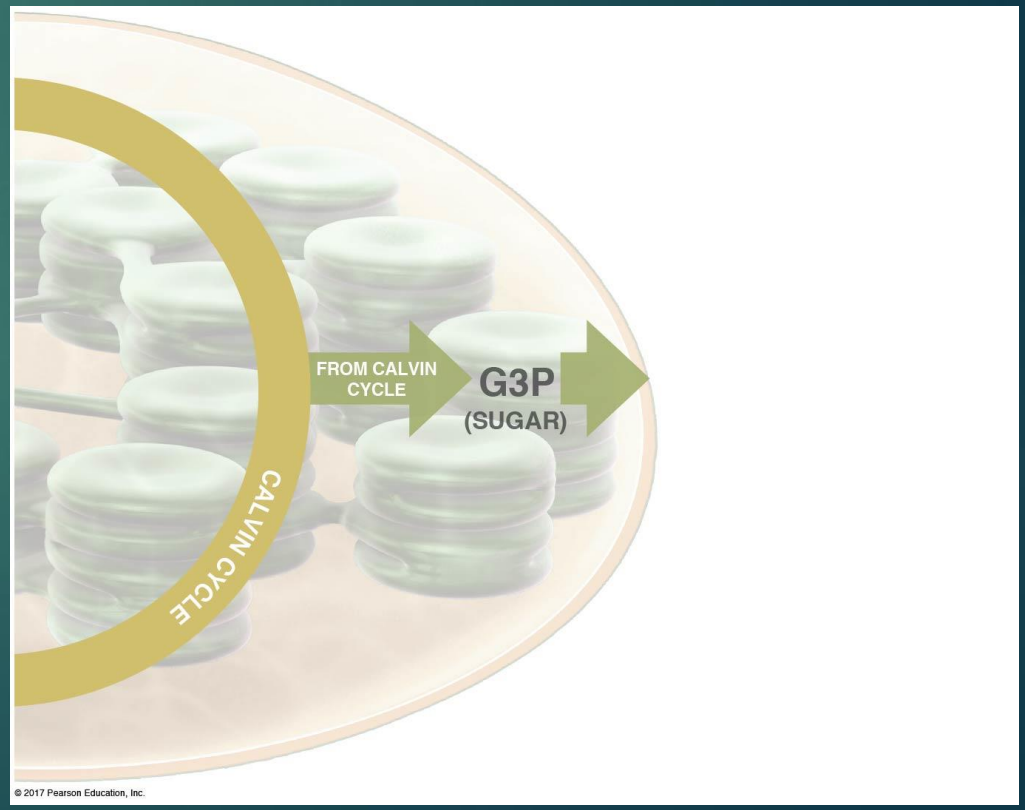
   2. Two stages of photosynthesis: *(summary)*
      a. **Light reactions** *capture energy* in sunlight and use it to produce high-energy molecules.
         i. High-energy molecules produced are ATP and NADPH.
      b. **Calvin cycle** uses *high-energy molecules* to produce sugars from CO_2.



In the Calvin cycle, high-energy molecules are used to make sugar:

Outputs from the Calvin cycle

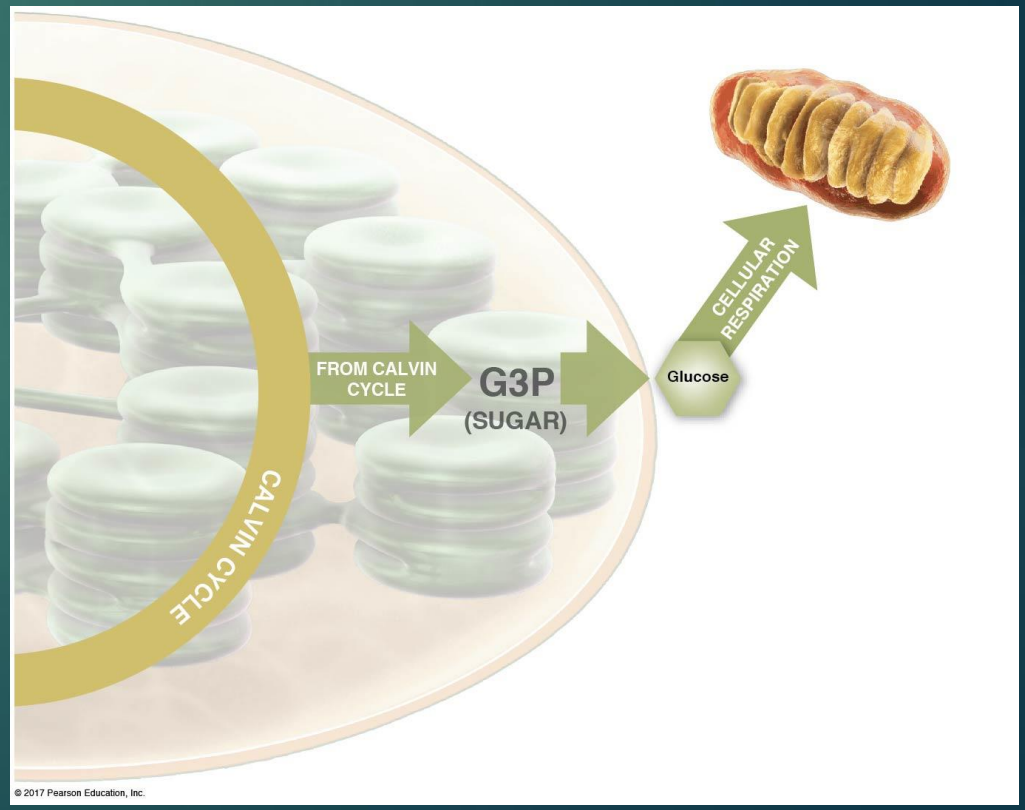
c. *Outputs* from the Calvin cycle
   1. It produces 3-carbon sugars called glyceraldehyde 3-phosphate (G3P).
   2. G3P can be used to make glucose.



In the Calvin cycle, high-energy molecules are used to make sugar:

Outputs from the Calvin cycle

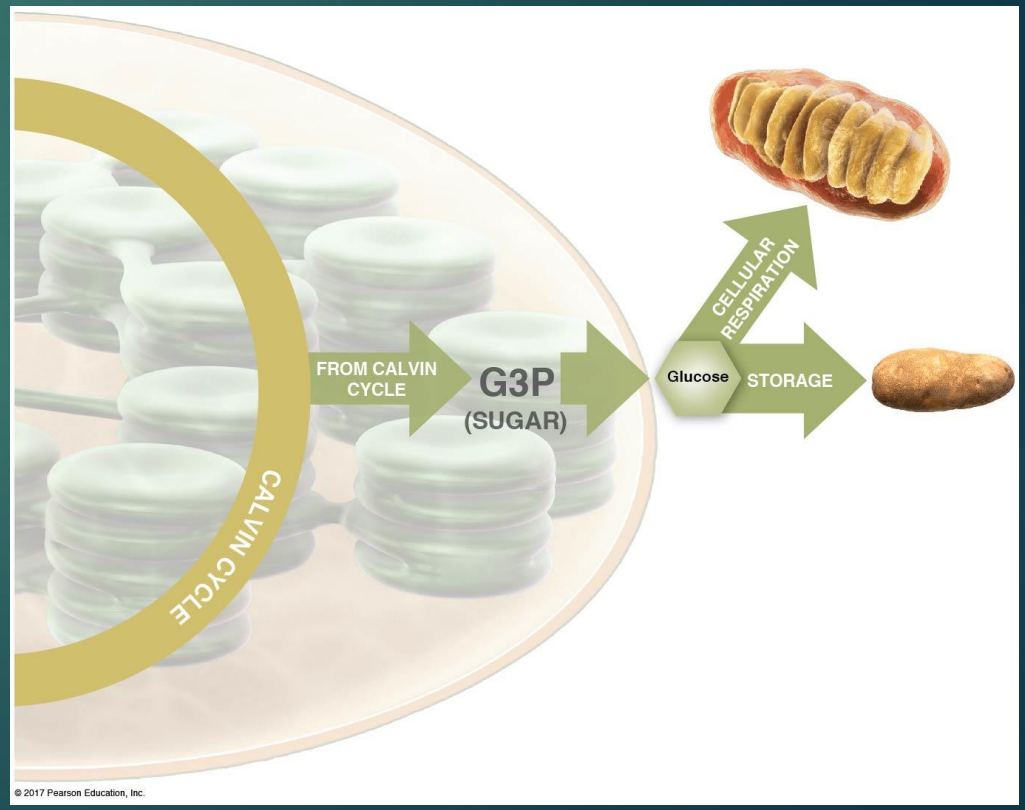
C. *Outputs* from the Calvin cycle
   1. It produces 3-carbon sugars called glyceraldehyde 3-phosphate (G3P).
   2. G3P can be used to make glucose.
   3. *Glucose* can be
      a. Used to make ATP in the mitochondrion using cellular *respiration*.



In the Calvin cycle, high-energy molecules are used to make sugar:

Outputs from the Calvin cycle

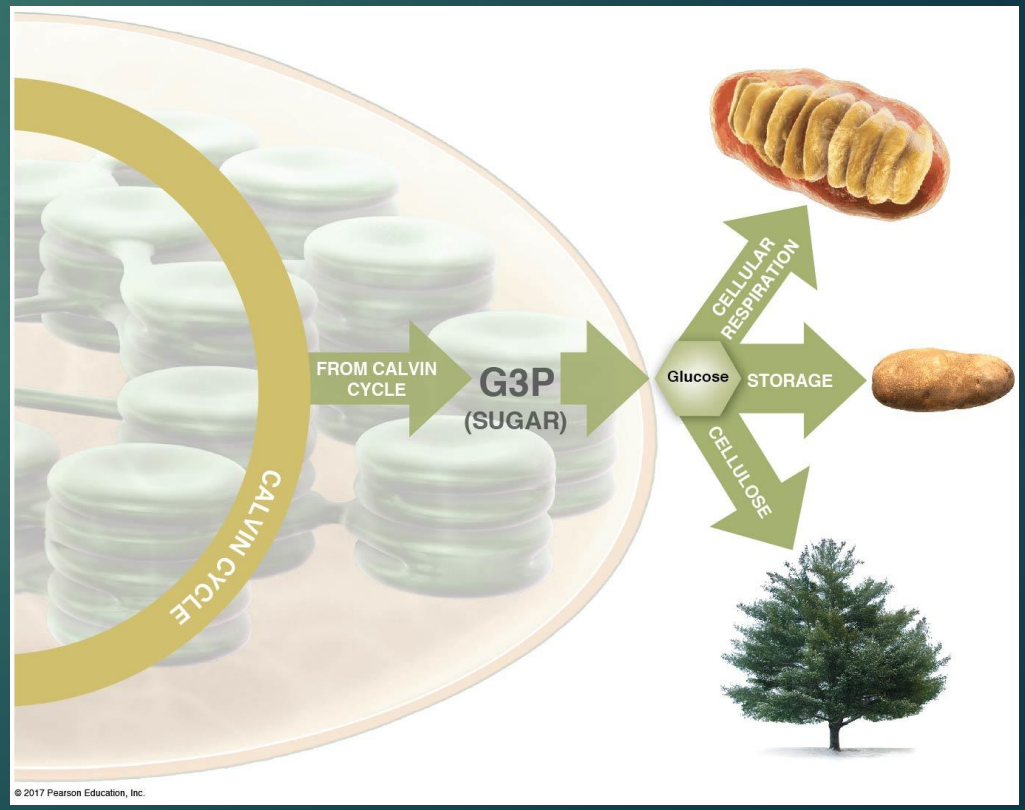
C. *Outputs* from the Calvin cycle
   1. It produces 3-carbon sugars called glyceraldehyde 3-phosphate (G3P).
   2. G3P can be used to make glucose.
   3. *Glucose* can be
      a. Used to make ATP in the mitochondrion using cellular respiration.
      b. Stored as carbohydrates.



In the Calvin cycle, high-energy molecules are used to make sugar:

Outputs from the Calvin cycle

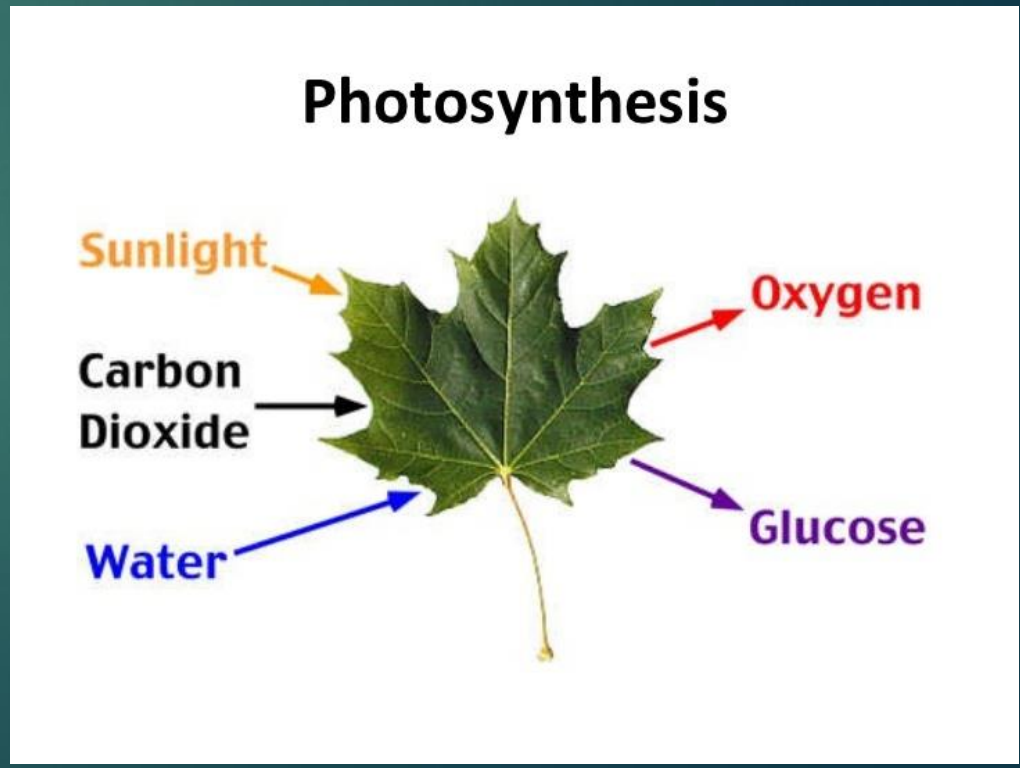
C. *Outputs* from the Calvin cycle
   1. It produces 3-carbon sugars called glyceraldehyde 3-phosphate (G3P).
   2. G3P can be used to make glucose.
   3. *Glucose* can be
      a. Used to make ATP in the mitochondrion using cellular respiration.
      b. Stored as carbohydrates.
      c. Linked to form cellulose



In the Calvin cycle, high-energy molecules are used to make sugar:

Outputs from the Calvin cycle

C. *Outputs* from the Calvin cycle
   1. It produces 3-carbon sugars called glyceraldehyde 3-phosphate (G3P).
   2. G3P can be used to make glucose.
   3. *Glucose* can be
      a. Used to make ATP in the mitochondrion using cellular respiration.
      b. Stored as carbohydrates.
      c. Linked to form cellulose



Photosynthesis:

Can you track the energy and electrons?