Go to the "Slide Show" shade above

Click on "Play from Beginning"

Photosynthesis:
Using ***Light*** *to* ***Make Food***

Chapter 7

Enzymes

WARM-UP

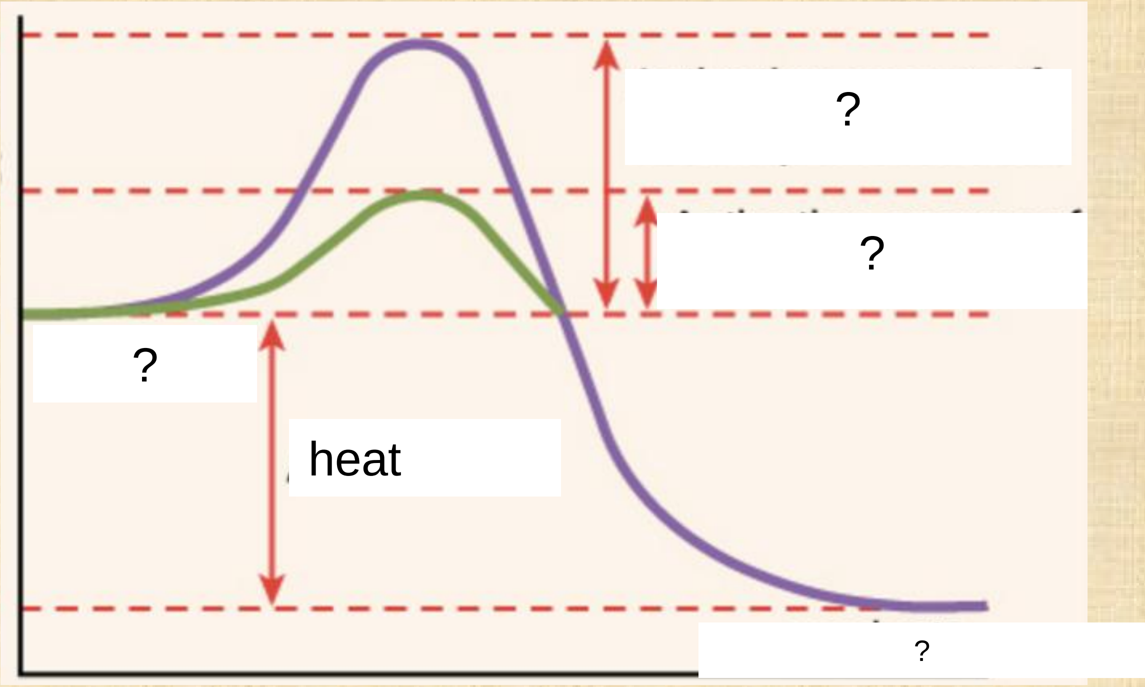
Put the steps of enzyme activity in order from first (1) to last (4).

[ ] The chemical reaction occurs.

[ ] A substrate enters the active site of enzyme.

[ ] New substances called “products” are formed.

[ ] The enzyme and the substrate bind to form the enzyme-substrate complex.



Label the diagram

Enzymes

WARM-UP

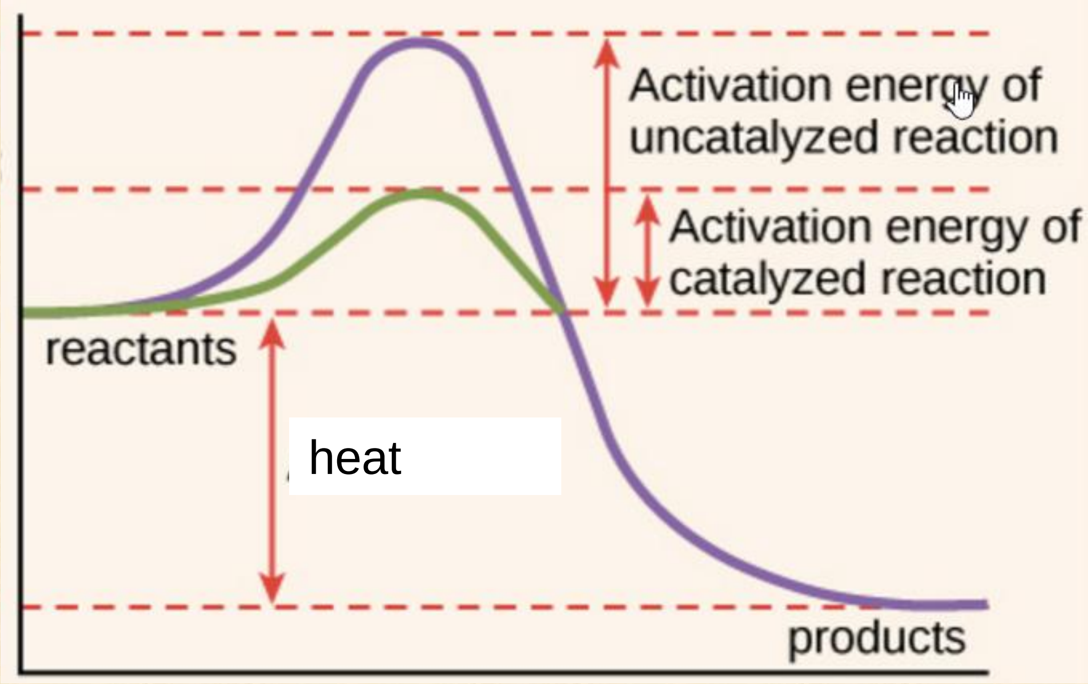
Put the steps of enzyme activity in order from first (1) to last (4).

[3] The chemical reaction occurs.

[1] A substrate enters the active site of enzyme.

[4] New substances called "products" are formed.

[2] The enzyme and the substrate bind to form the enzyme-substrate complex.



Label the diagram

Energy Is ?

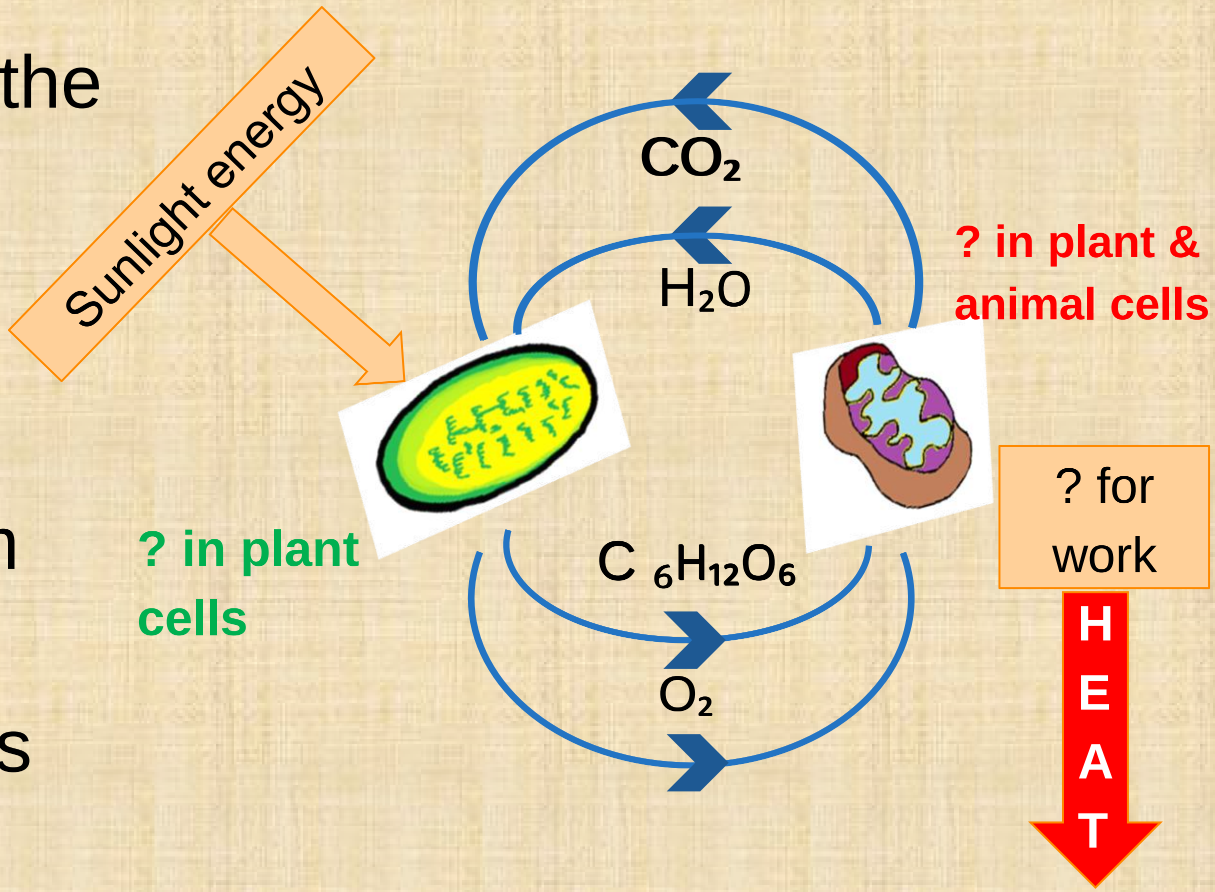
WARM-UP

?

- Uses sunlight as the energy source

?

- Uses energy from sugars and other organic molecules



Energy Is Cyclic

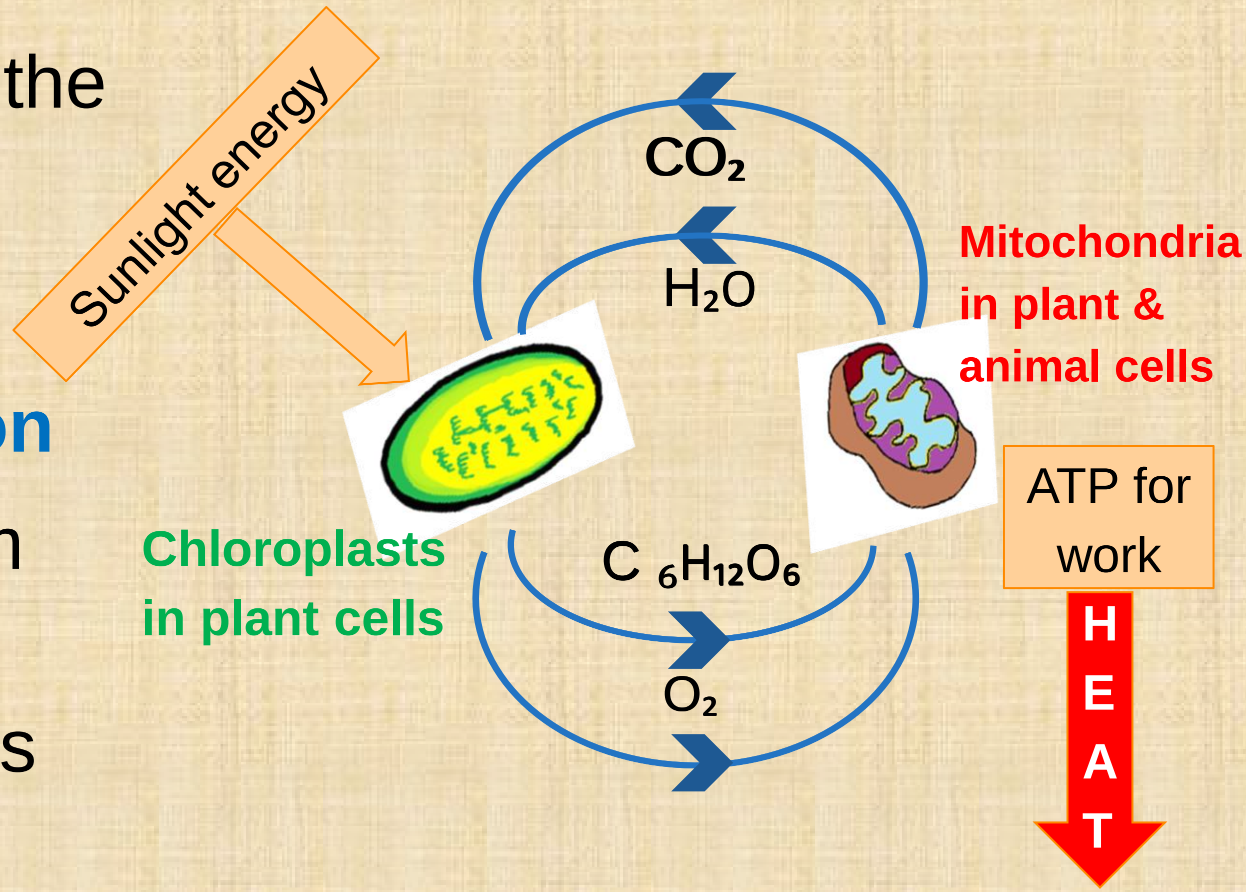
WARM-UP

Photosynthesis

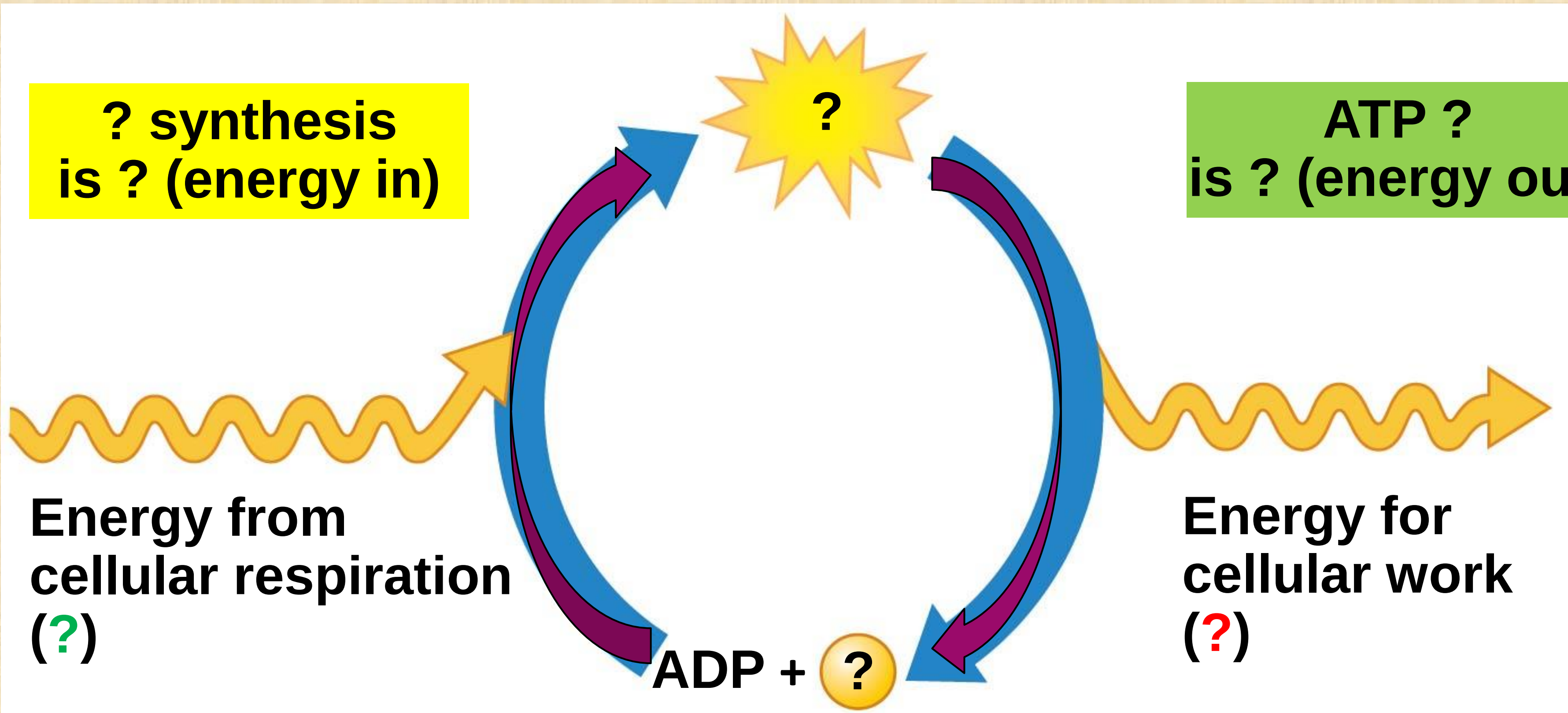
- Uses sunlight as the energy source

Cellular respiration

- Uses energy from sugars and other organic molecules

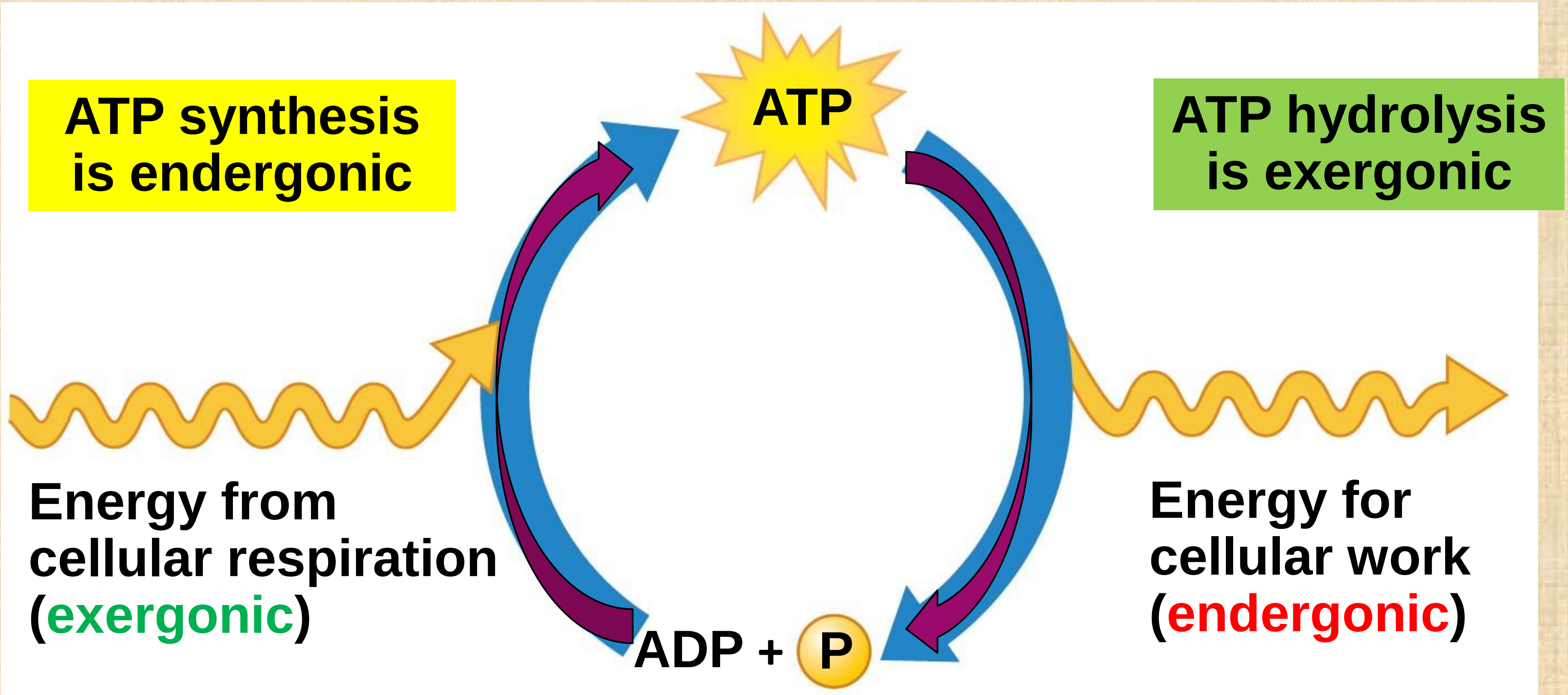


? drives Cellular Work by energy ?
Exergonic and Endergonic Reactions



WARM-UP

ATP drives Cellular Work by COUPLING Exergonic and Endergonic Reactions



Lesson Objectives

By the end of this lesson, you should be able to:

- Explain the importance of photosynthesis to living organisms.
- Write the chemical equation for photosynthesis.
- Summarize the process of photosynthesis (stages, components, chemicals, energy), including the two photo systems and the electron transport chain.
- Identify and explain the components and process within the Calvin cycle.

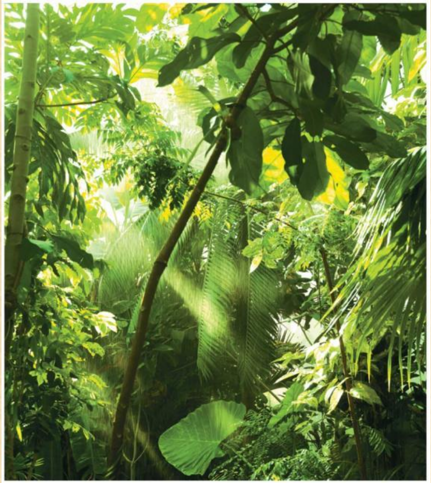
- **Science Practice: Study of the Cell (Elodea)**

Photosynthesis Fuels Life

- Plants are **Autotrophs**, which
  - sustain themselves.
  - do not usually consume organic molecules derived from other organisms.
  - make their own food through the process of **Photosynthesis**, in which they convert **CO_2 and H_2O** to **Sugars** and other organic molecules.

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

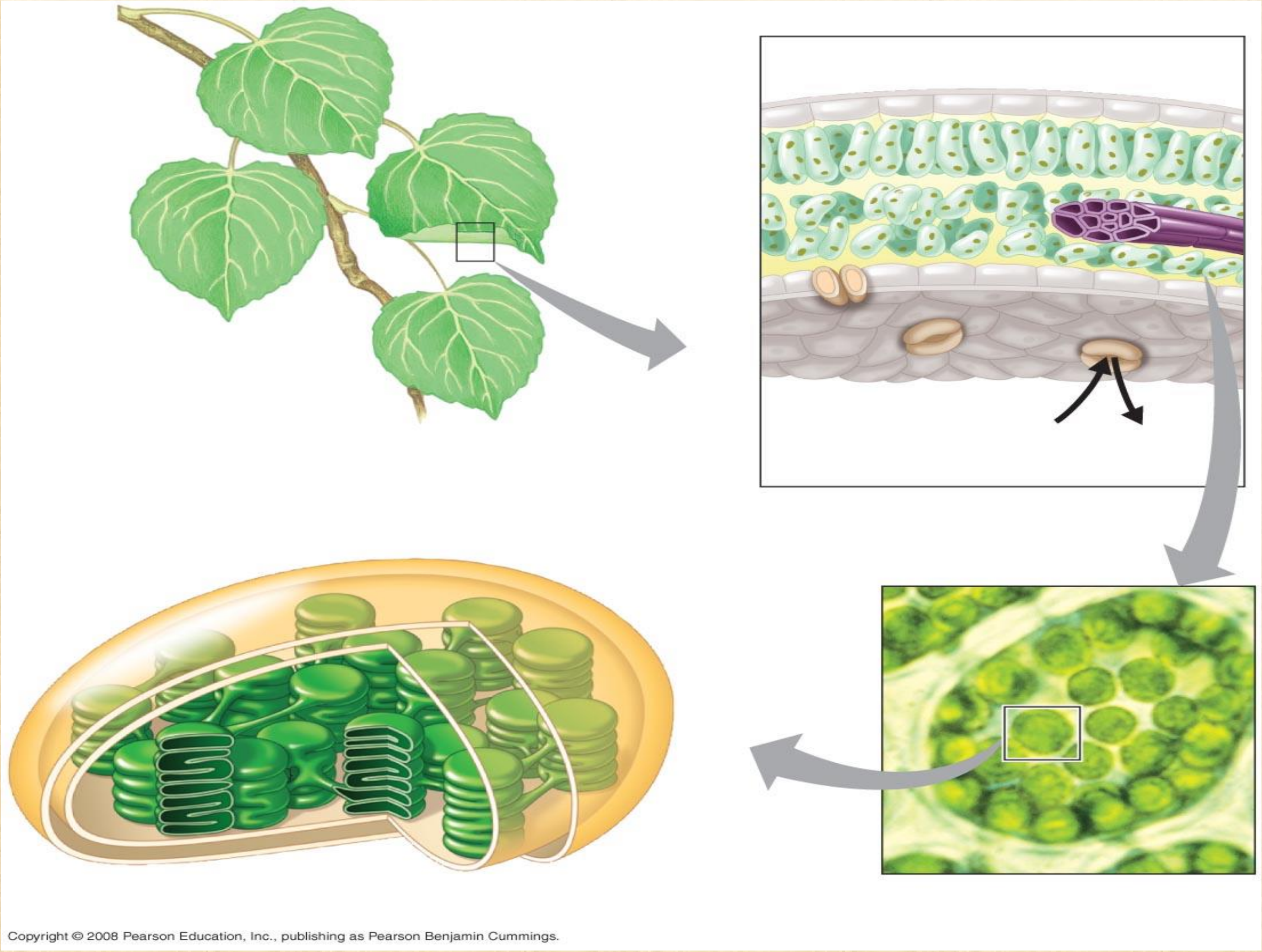
Water + Carbon Dioxide + Energy → Glucose + Oxygen



Where does photosynthesis occur?

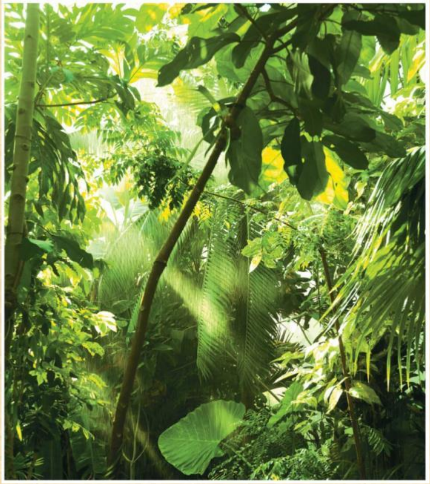
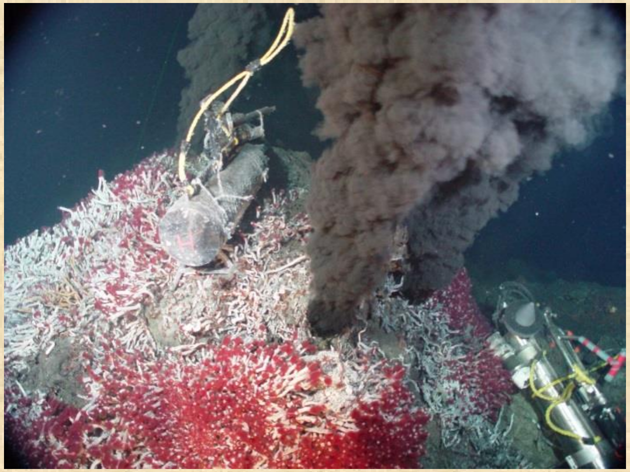
1. Green Parts of Plants

   - Leaves and stems: contain chloroplasts (organelles).



Photosynthesis Fuels Life

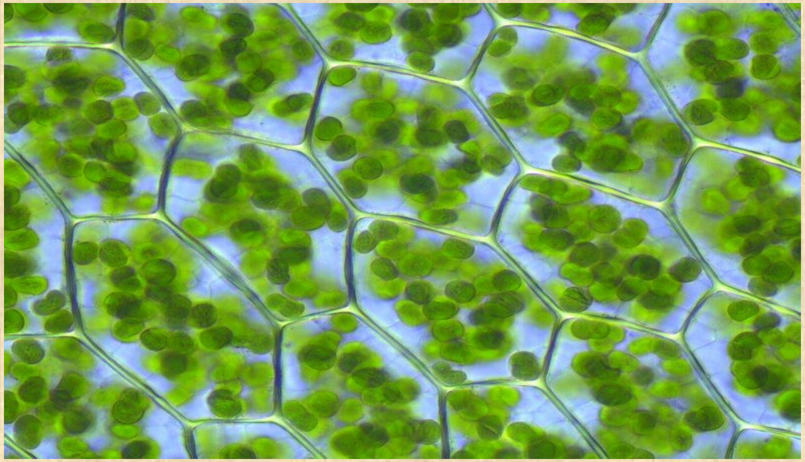
- **Photoautotrophs** use the energy of light to produce organic molecules.
- **Chemoautotrophs** are prokaryotes that use inorganic chemicals as their energy source.
- **Heterotrophs** are consumers that feed on plants or animals or decompose organic material.


Photosynthesis Occurs in Chloroplasts in Plant Cells

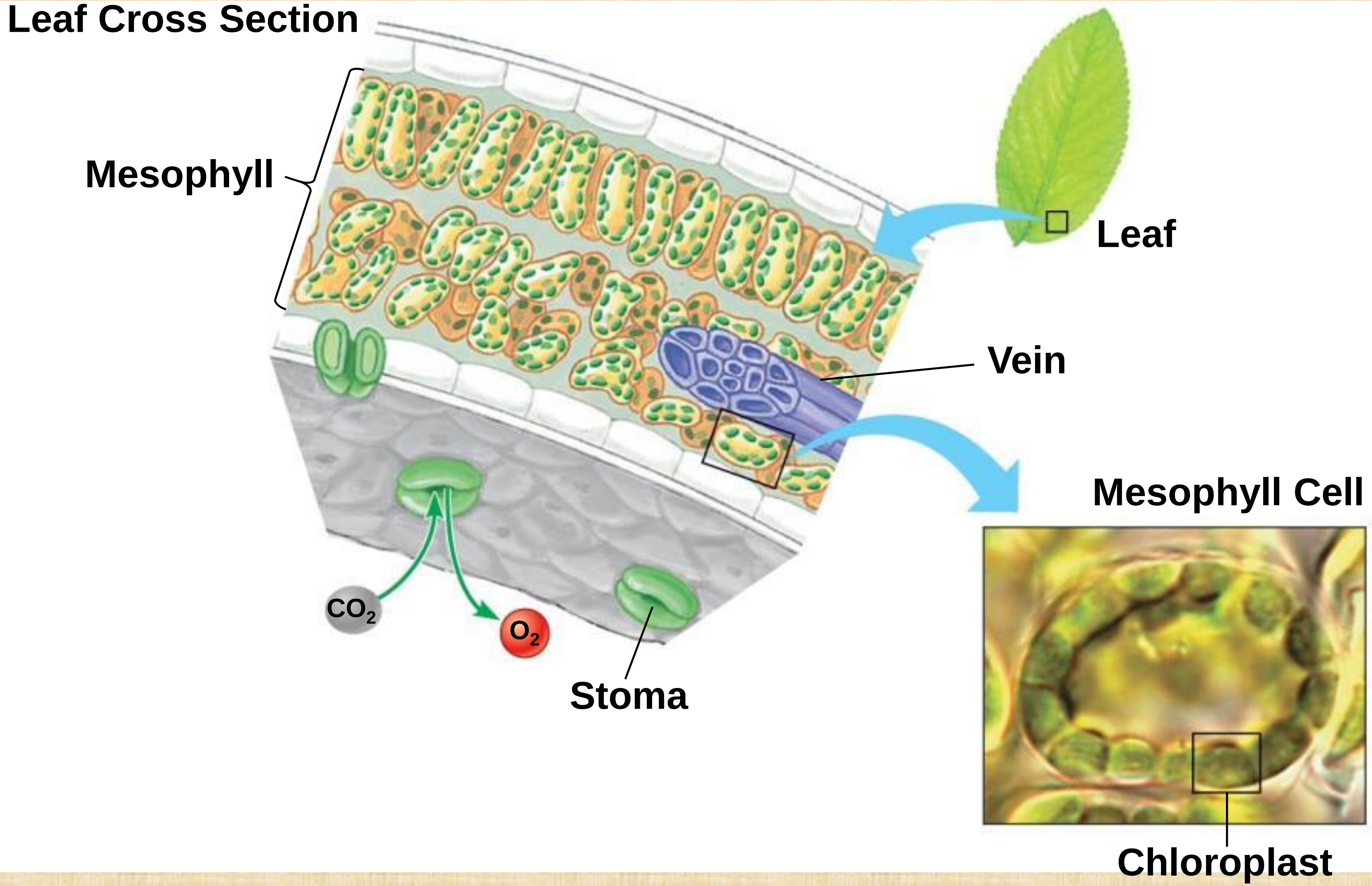
Photosynthesis in plants takes place in **CHLOROPLASTS.**

- **CHLOROPHYLL**
  - is an important light-absorbing pigment in chloroplasts.
  - is responsible for the **green** color of plants.
  - plays a central role in **converting solar energy to chemical energy.**



Photosynthesis Occurs in Chloroplasts in Plant Cells

- **Chloroplasts** are concentrated in the cells of the **Mesophyll**, the green tissue in the interior of the **LEAF.**
- **Stomata** are tiny pores in the **LEAF** that allow
  - **Carbon Dioxide** to **enter**
  - **Oxygen** to **exit.**
- **Veins** in the **LEAF** deliver **Water** absorbed by **roots.**


Leaf Cross Section
Mesophyll
Leaf
Vein
Mesophyll Cell
CO_2
O_2
Stoma
Chloroplast

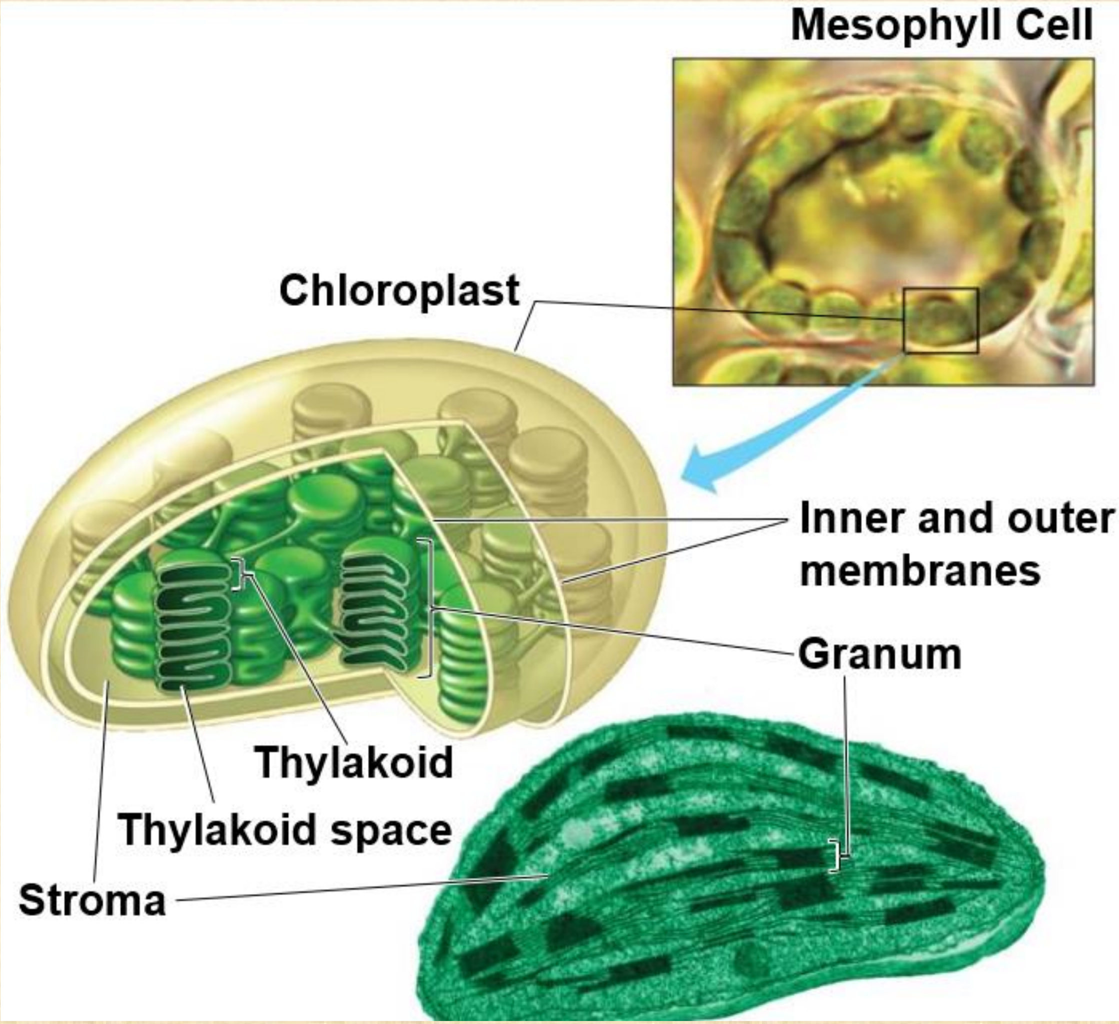
CHLOROPLASTS

consist of an envelope of two membranes,

which encloses an inner compartment filled with a thick fluid called **Stroma**

that contains a system of interconnected membranous sacs called **Thylakoids.**

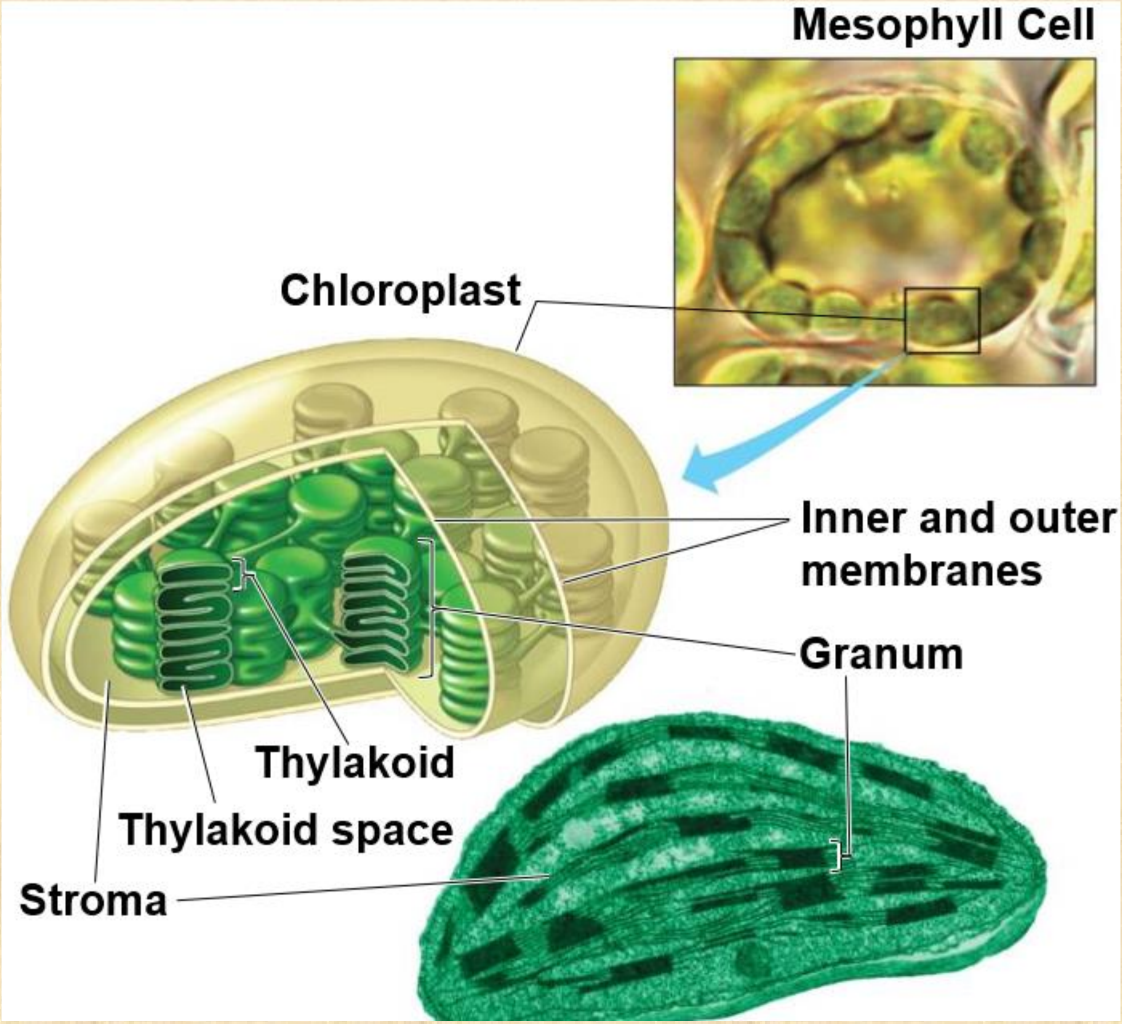
Photosynthesis Occurs in Chloroplasts in Plant Cells

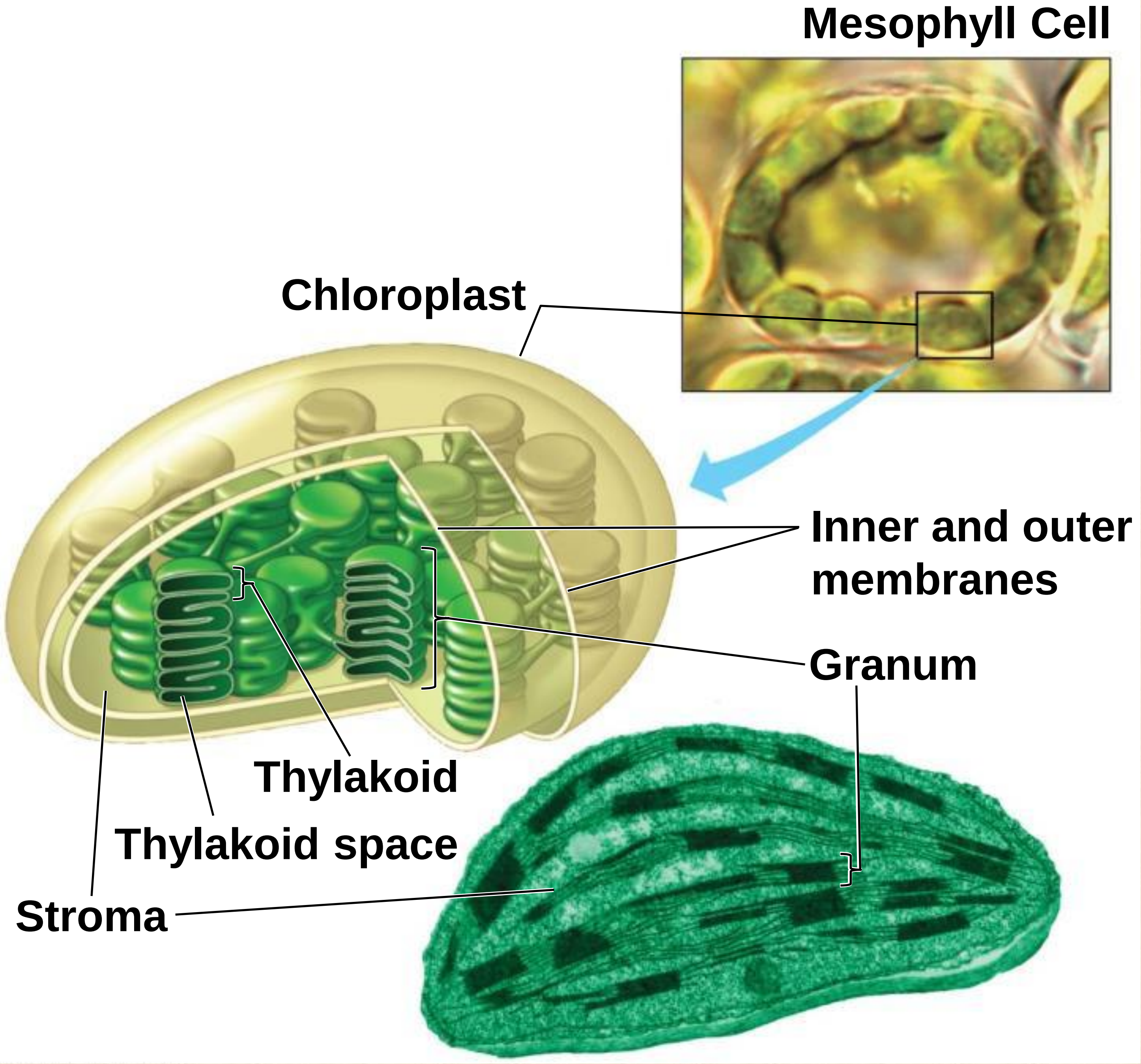


Photosynthesis Occurs in Chloroplasts in Plant Cells

THYLAKOIDS

- are often concentrated in stacks called **Grana**
- have an internal compartment called the **Thylakoid Space**,
- which has functions analogous to the outer compartment of a mitochondria in the generation of ATP.



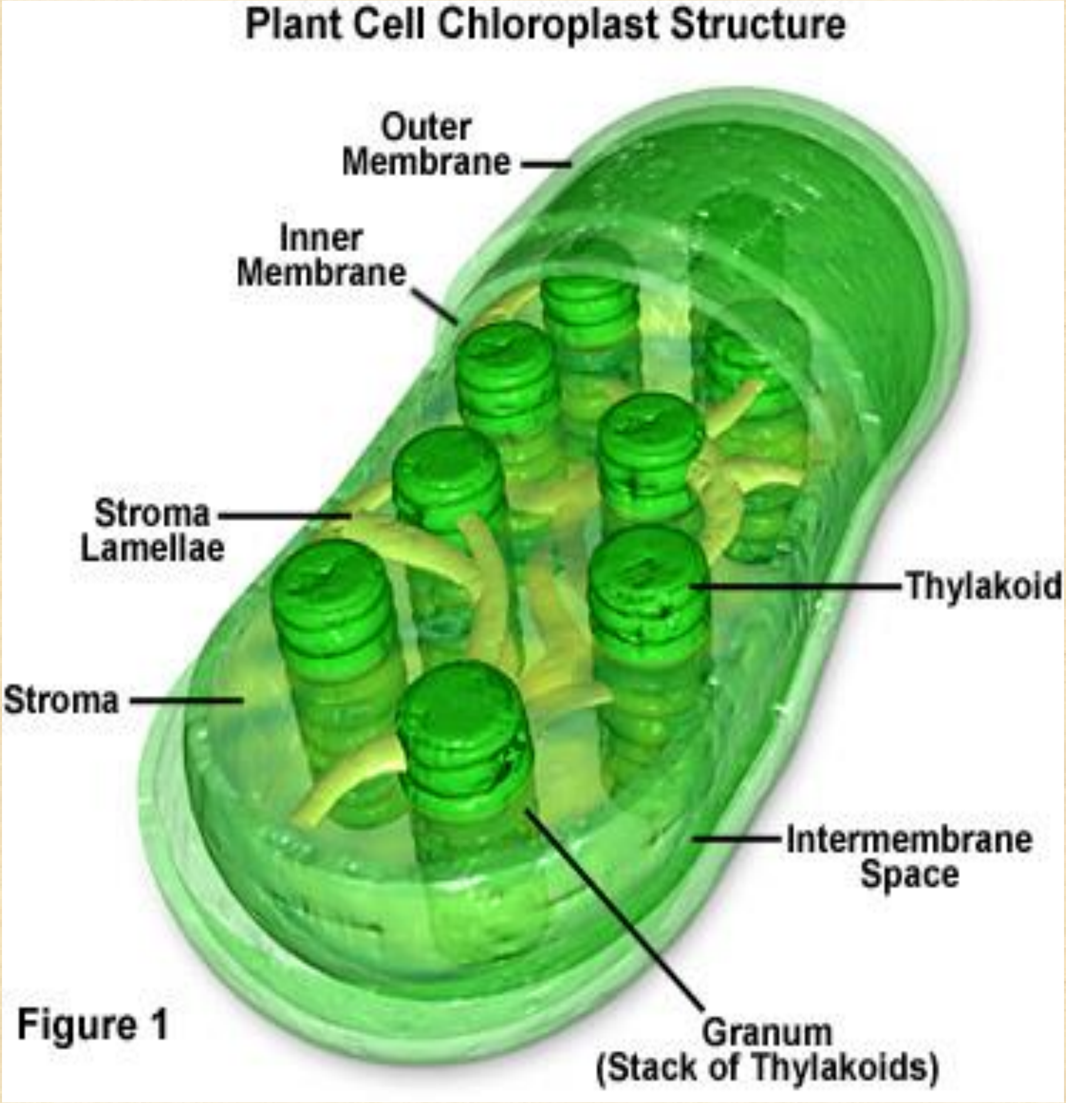

Mesophyll Cell
Chloroplast
Inner and outer
membranes
Granum
Thylakoid
Thylakoid space
Stroma

Grana (s: granum)

- stacks of thylakoids

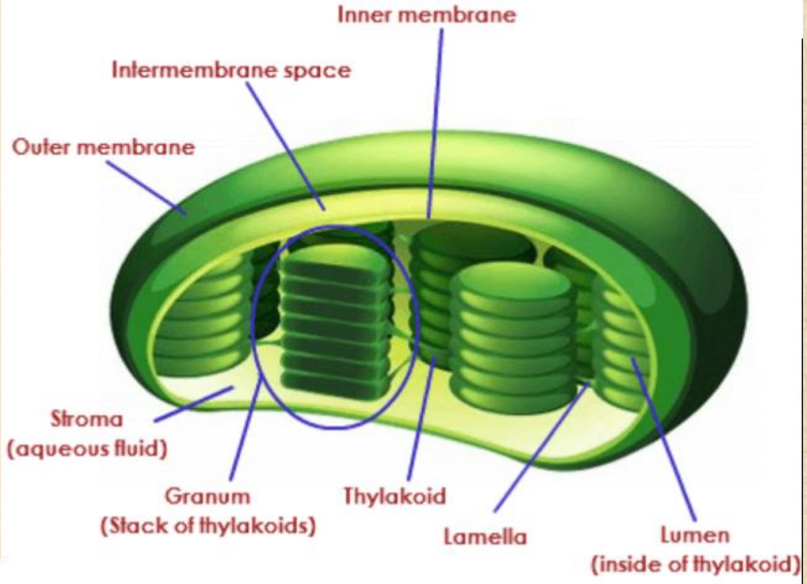
Stroma

- semi-fluid material that contains enzymes and takes up space inside the chloroplast.



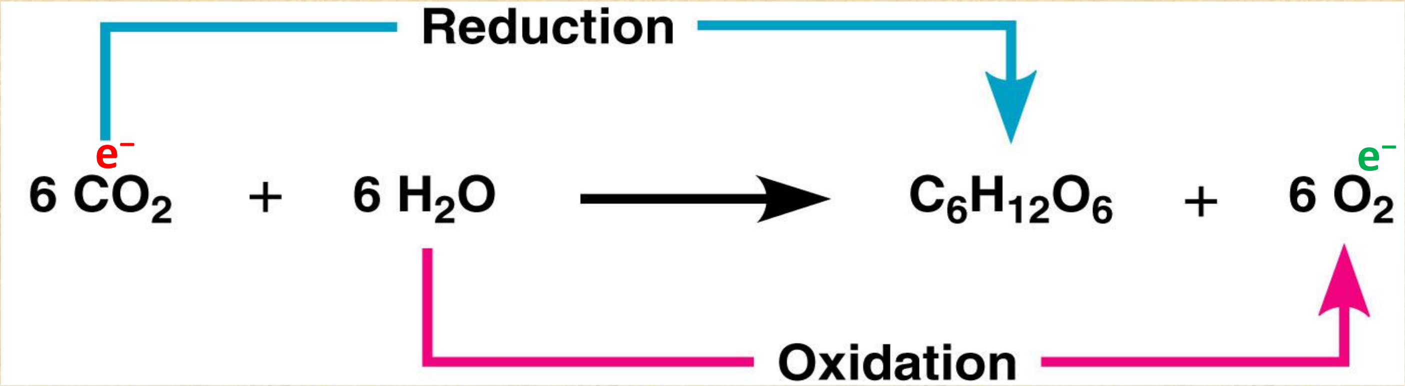
Photosynthesis Occurs in Chloroplasts in Plant Cells

- **THYLAKOID MEMBRANES** also house much of the machinery that converts light energy to chemical energy.
- **CHLOROPHYLL MOLECULES**
  - Are embedded into the thylakoid membrane.
  - Capture light energy.



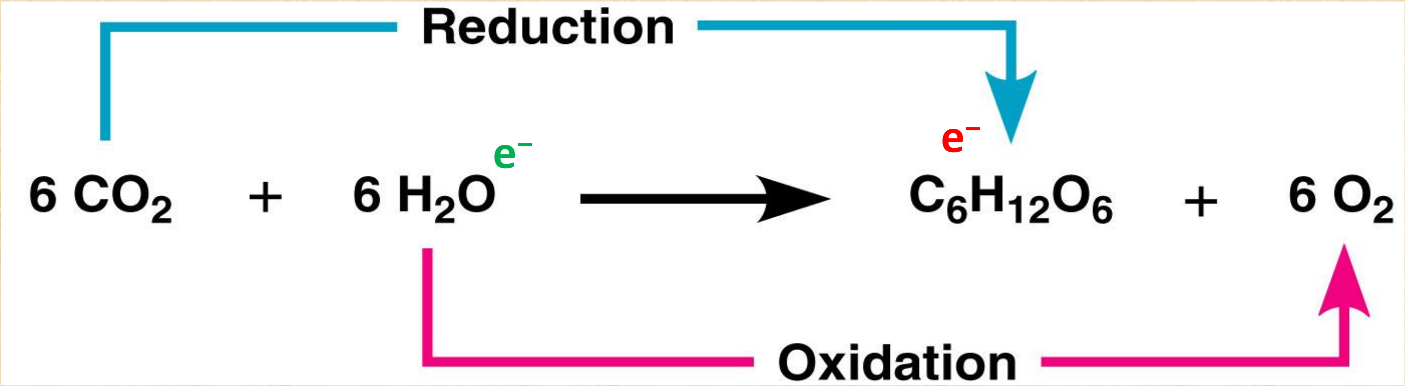
Photosynthesis is a Redox Process, as is Cellular Respiration

- **Photosynthesis**, like **Cell Respiration**, is a **Redox (Oxidation-Reduction)** process.
- **CO_2** becomes **reduced** to **Sugar** as electrons, along with hydrogen ions (H^+) **from Water,** are added to it.
- **Water** molecules are **oxidized** when they lose electrons along with hydrogen ions.



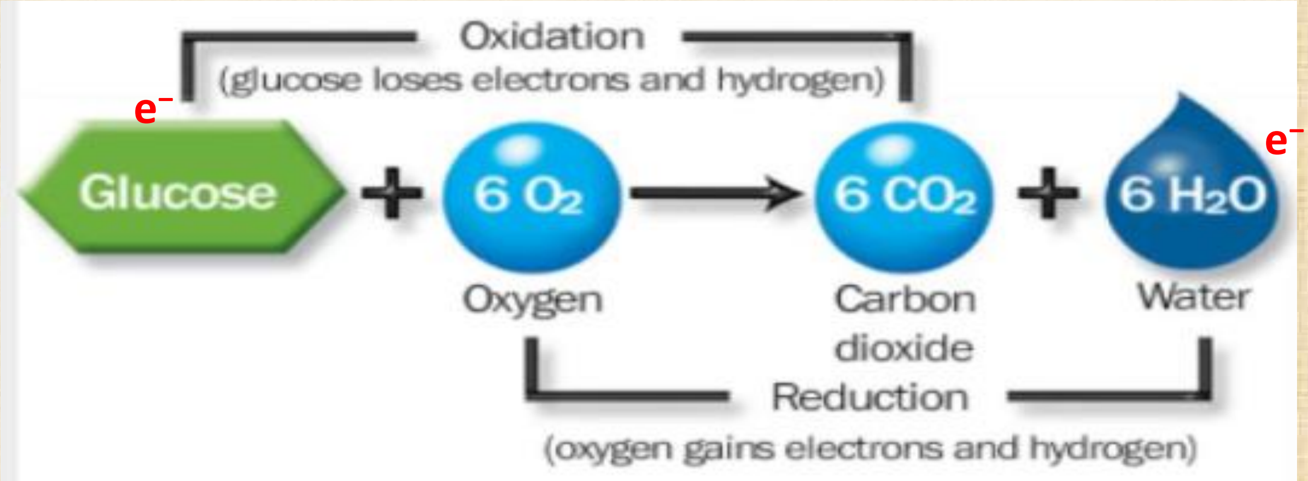
Photosynthesis is a Redox Process, as is Cellular Respiration

- **Photosynthesis**, like **Cell Respiration**, is a **Redox (Oxidation-Reduction)** process.
- **The electrons are transferred.**



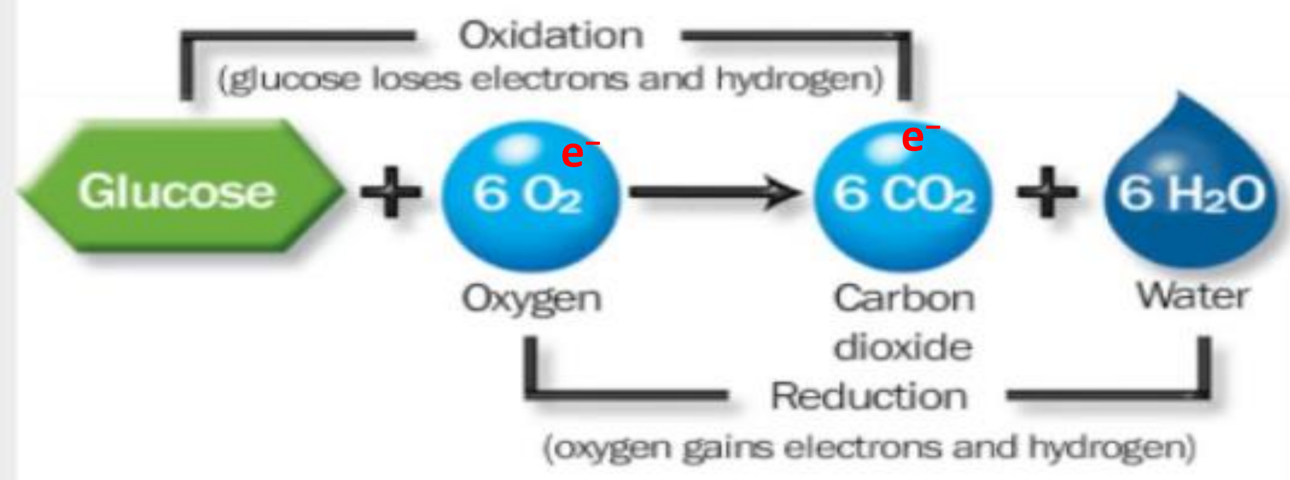
Photosynthesis is a Redox Process, as is Cellular Respiration

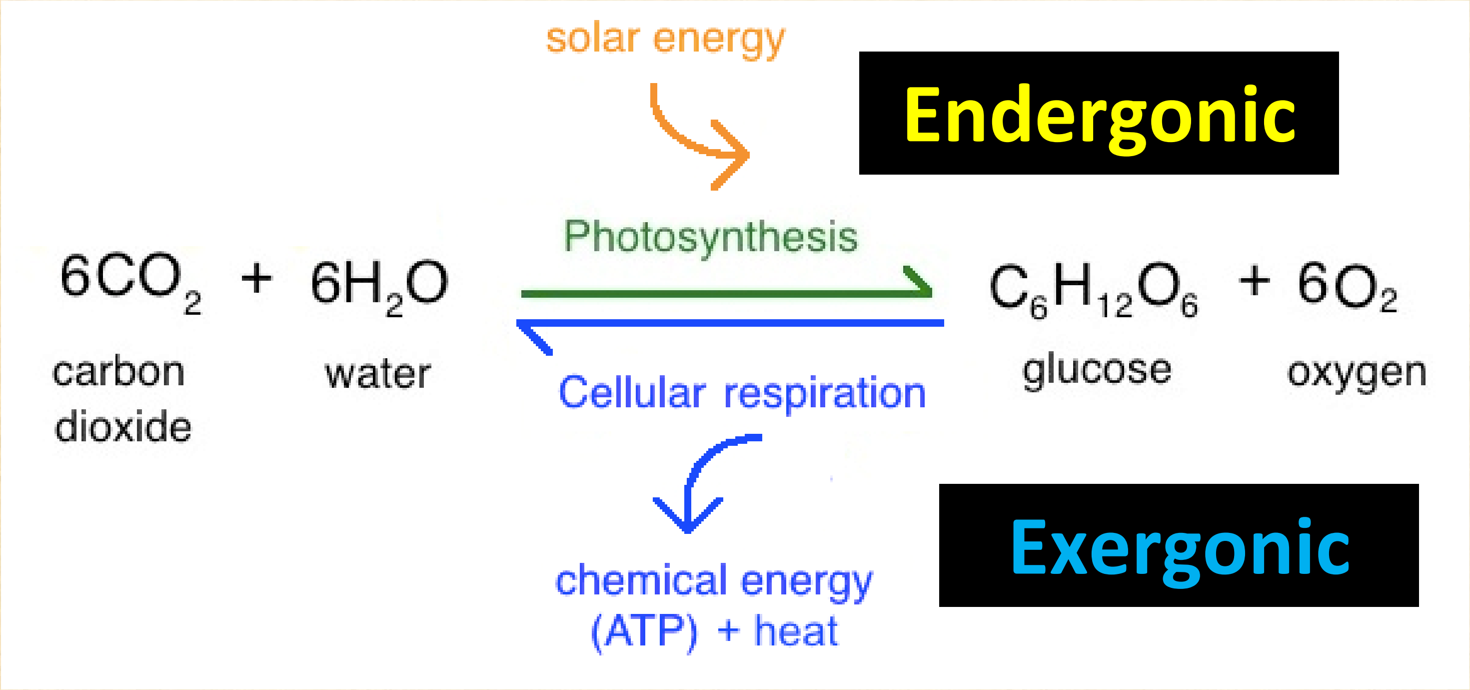
- **Cellular Respiration** uses **redox** reactions to harvest the chemical energy stored in a glucose molecule.
  - This is accomplished by oxidizing the sugar and reducing O_2 to H_2O.
  - The electrons **lose potential energy** as they travel down the electron transport chain to O_2.



Photosynthesis is a Redox Process, as is Cellular Respiration

- **Cellular Respiration** uses **redox** reactions to harvest the chemical energy stored in a glucose molecule.
- **The electrons are transferred** *(opposite direction to photosynthesis).*
- In contrast, the **Photosynthesis** (food-producing) **redox** reactions require an **input of energy**.





photosynthesis

$$6CO_2 + 6H_2O + \underline{energy} \longrightarrow \boxed{C_6H_{12}O_6} + 6O_2$$

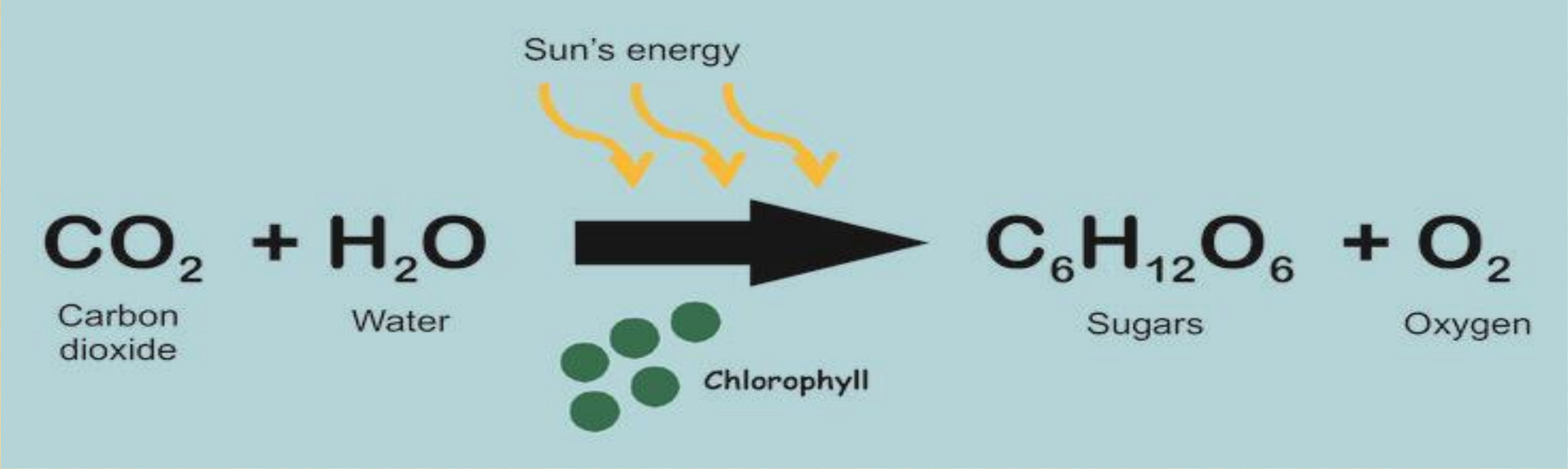
energy in

aerobic respiration

$$\boxed{C_6H_{12}O_6} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \underline{energy}$$

energy out

- In **PHOTOSYNTHESIS**,
  - **light energy** is captured by **chlorophyll** molecules to boost the energy of electrons.
  - **light energy** is converted to **chemical energy.**
  - **chemical energy** is stored in the **chemical bonds of sugars.**

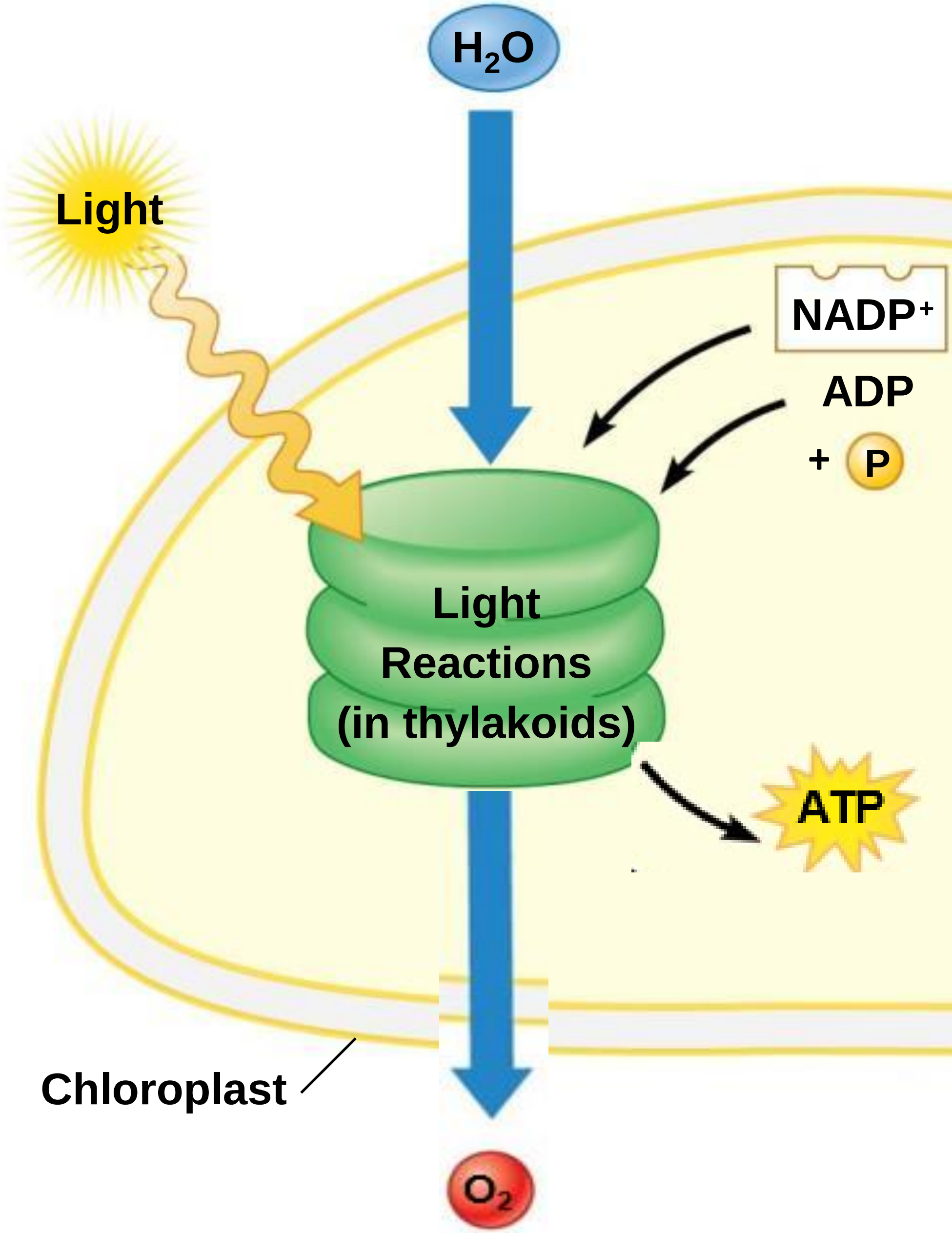


The Two Stages of Photosynthesis Are Linked by ATP and NADPH

- **PHOTOSYNTHESIS** occurs in **two stages**:

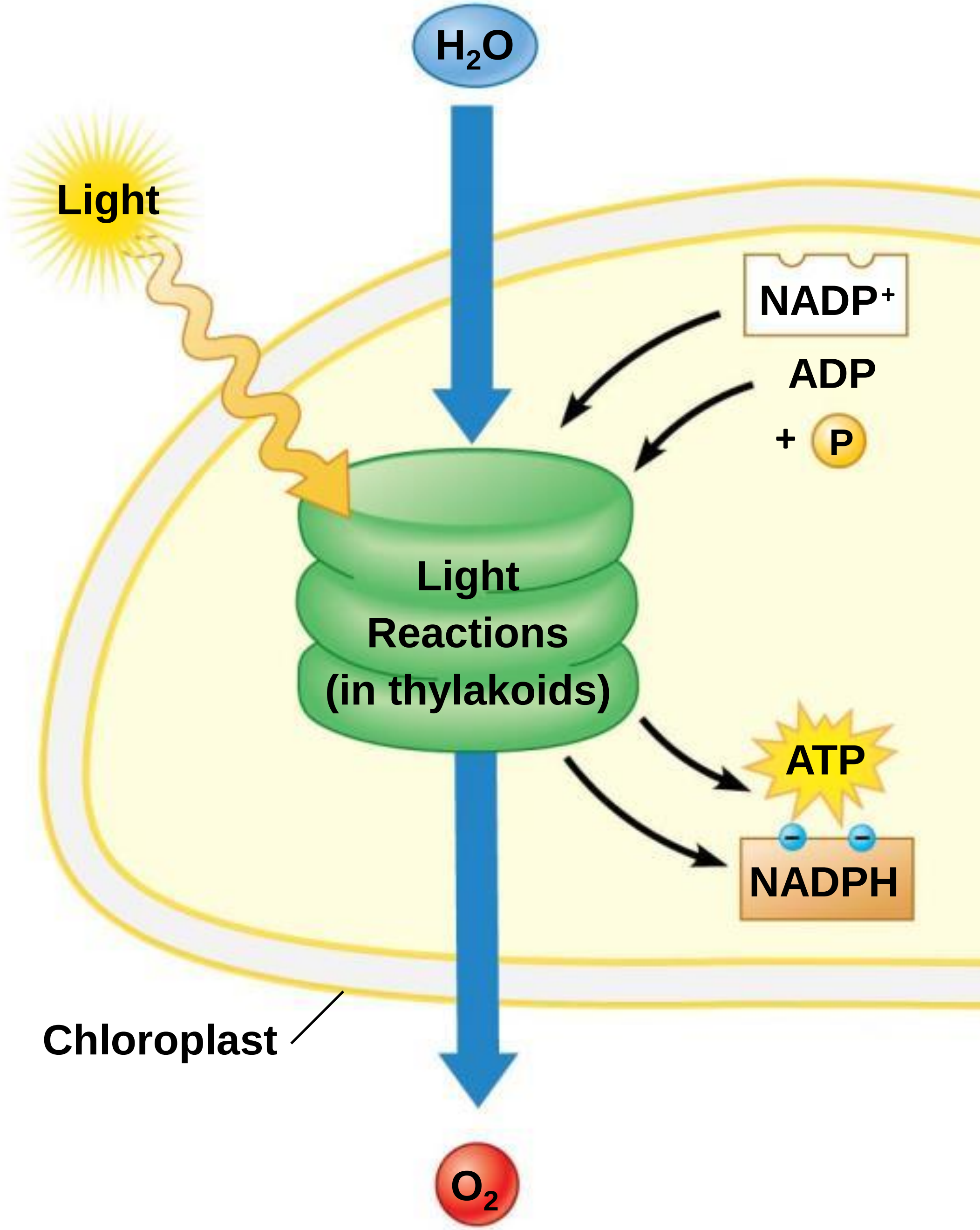
1) LIGHT REACTIONS

  - Occur in the **Thylakoid Membranes.**
  - **Water** is split by an enzyme, providing a **source of electrons** and giving off **Oxygen** as a by-product.
  - **ATP** is generated from **ADP and a Phosphate group.**
  - **Light energy** is absorbed by the **Chlorophyll** molecules to drive the **transfer of electrons and H^+** from water to the electron acceptor **$NADP^+$,** reducing it to **NADPH.**
  - **NADPH**, produced by the light reactions, provides the "reducing power" for the **Calvin Cycle.**



Water is split (*by an enzyme*), providing a **source of electrons** and giving off **Oxygen** as a by-product.

ATP is generated from **ADP and a Phosphate group.**

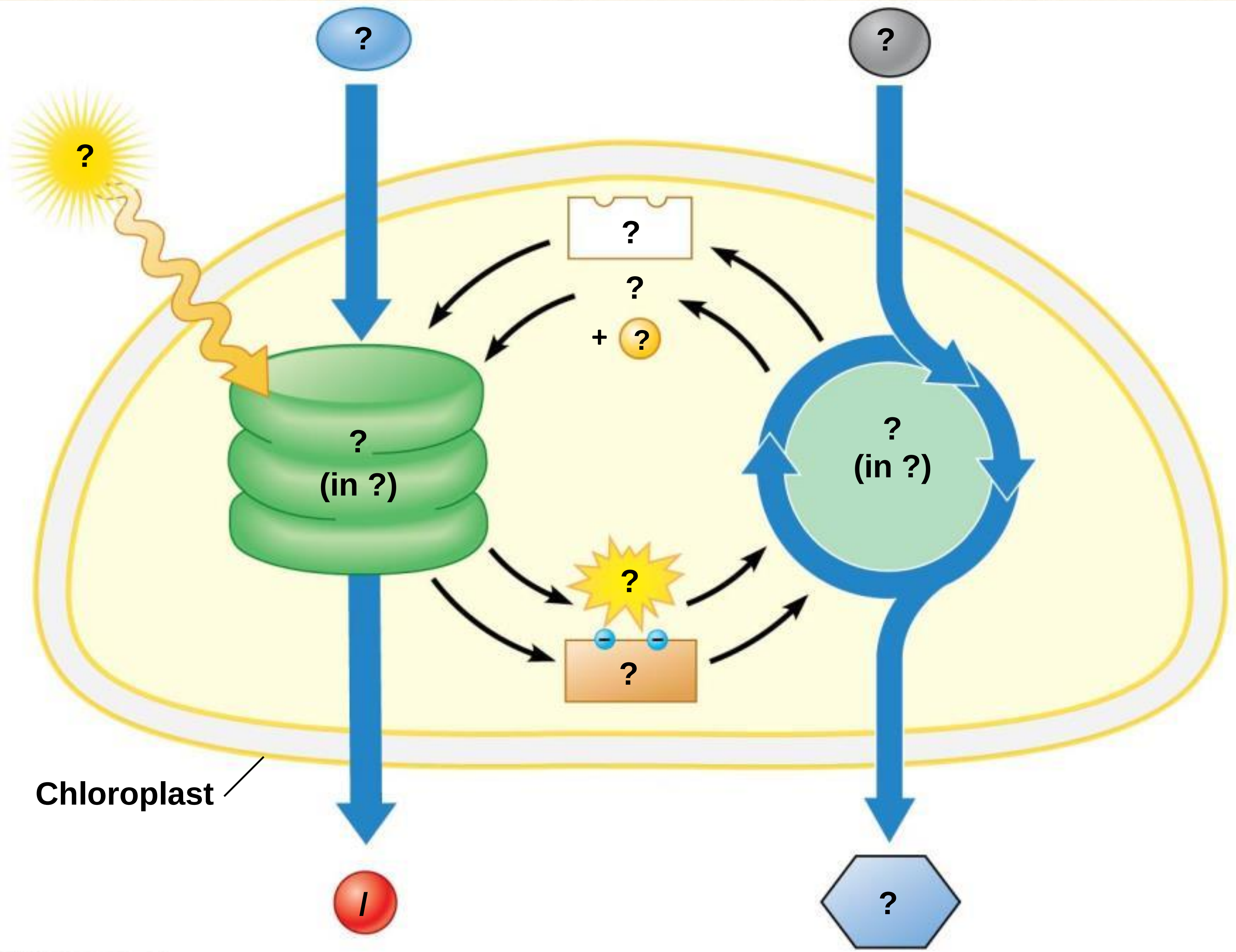


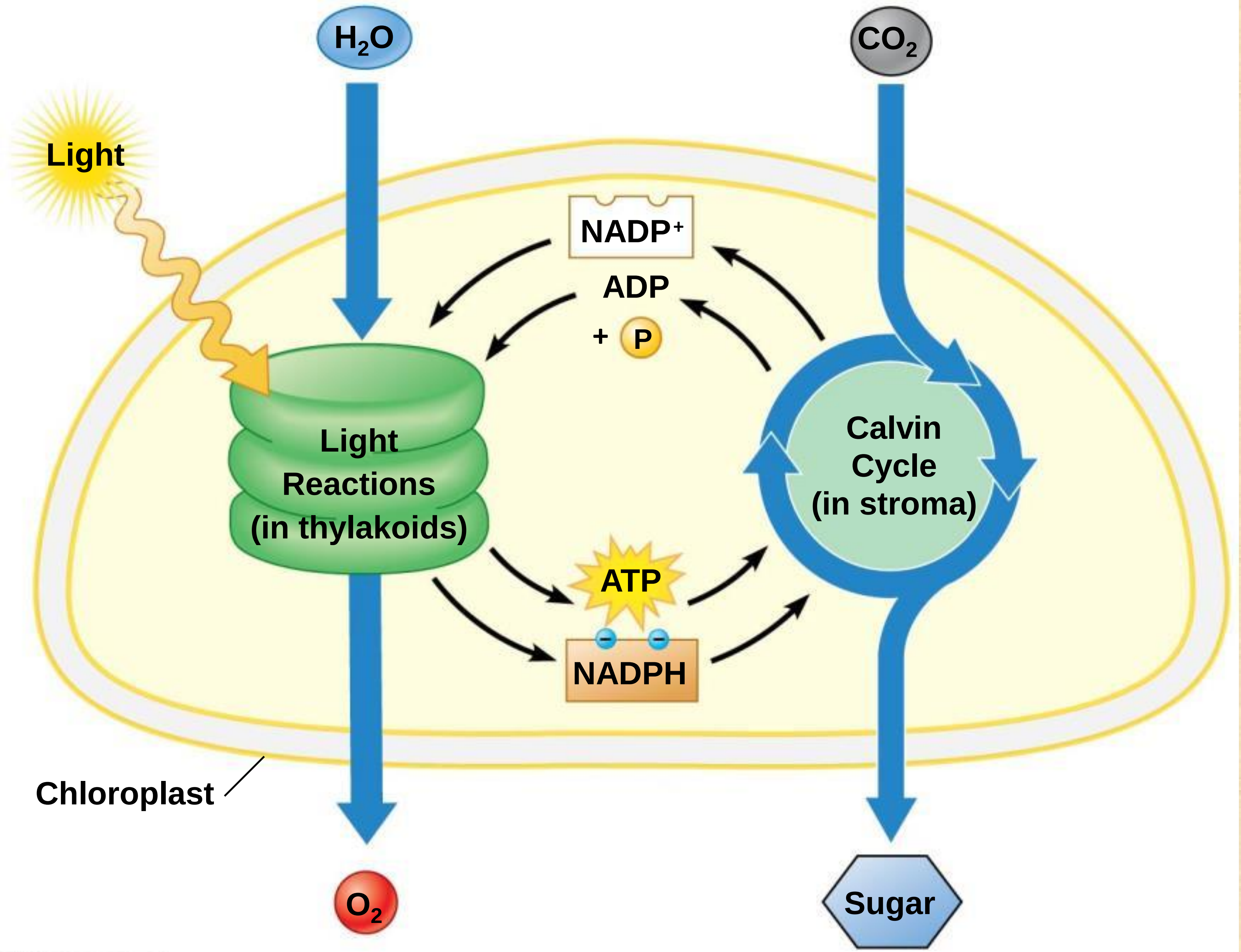
Light energy is absorbed by the **Chlorophyll** molecules to drive the **transfer of electrons and H^+** from water to the electron acceptor **$NADP^+$,** reducing it to **NADPH.**

The Two Stages of Photosynthesis Are Linked by ATP and NADPH

2) CALVIN CYCLE

- Occurs in the **Stroma of the Chloroplast.**
- The **Calvin Cycle** is a cyclic series of reactions that **assembles Sugar** molecules using **CO_2 and the energy-rich products of the light reactions.**
- During the **Calvin Cycle**, **CO_2** is incorporated into organic compounds in a process called **Carbon Fixation.**
- After **Carbon Fixation**, the carbon compounds are **reduced** to **Sugars.**
- The **Calvin Cycle** is often called the **Dark Reactions**, or **Light-Independent Reactions**, because none of the steps requires light directly.


?
?
?
?
?
+ ?
?
(in ?)
?
(in ?)
?
?
Chloroplast
/
?

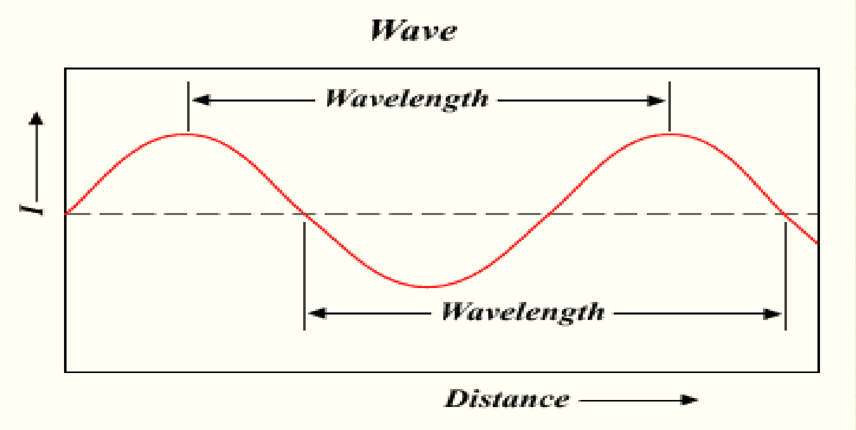

H_2O
CO_2
Light
$NADP^+$
ADP
+ P
Light
Reactions
(in thylakoids)
Calvin
Cycle
(in stroma)
ATP
NADPH
Chloroplast
O_2
Sugar

The Light Reactions:

Converting Solar Energy to Chemical Energy

Visible Radiation absorbed by Pigments drives the Light Reactions

- **Sunlight** contains energy called **Electromagnetic energy or Radiation.**
  - **Visible Light** is only a small part of the **Electromagnetic Spectrum**, the full range of electromagnetic wavelengths.
  - **Electromagnetic energy** travels in **Waves**
  - The **Wavelength** is the distance between the crests of two adjacent waves.

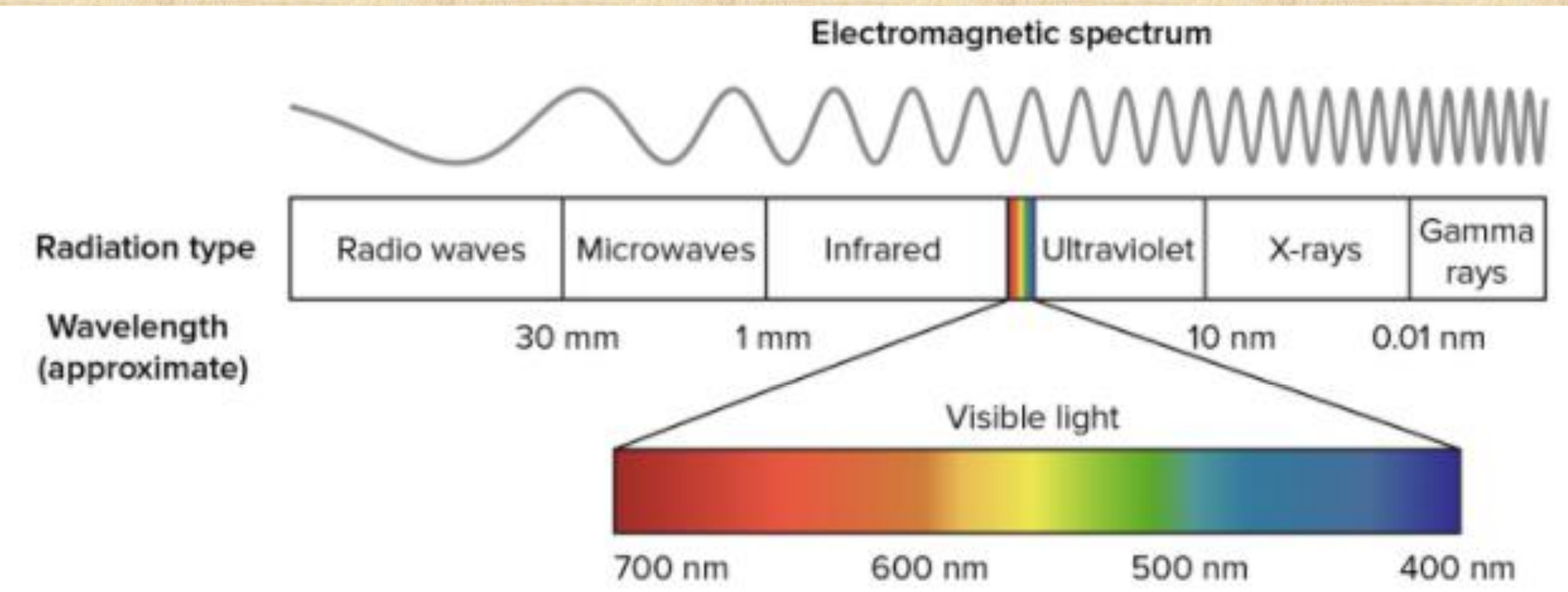


Visible Radiation absorbed by Pigments drives the Light Reactions

- **Light** behaves as discrete packets of energy called **Photons.**
  - A **Photon** is a fixed quantity of light energy.
  - **The shorter the wavelength, the greater the energy.**

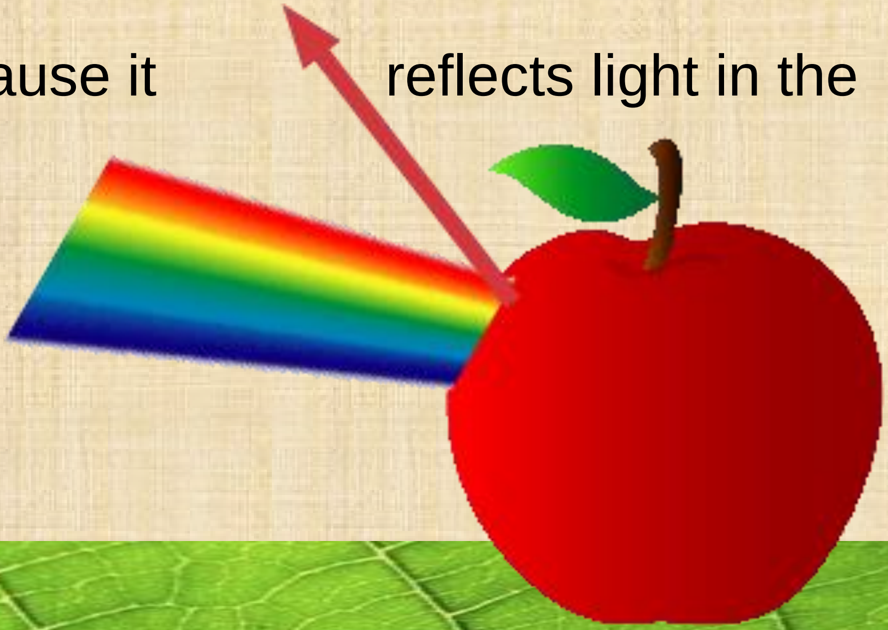
Longer wavelength → **Shorter wavelength**

Lower energy ← **Higher energy**



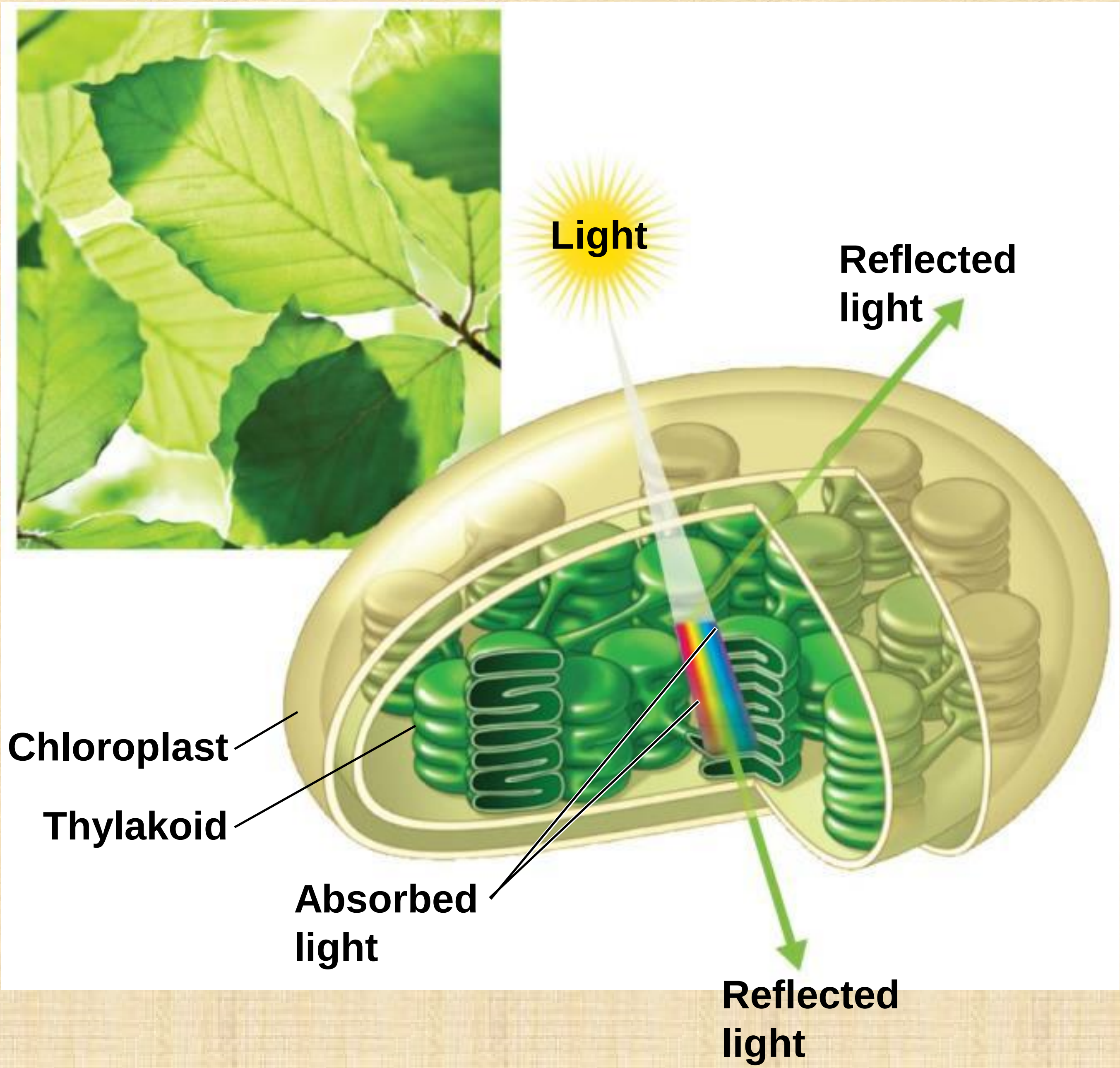
Why does a red apple appear red?

- When white light strikes an object, some wavelengths are **absorbed** and some are **reflected**.
- Wavelengths absorbed cannot be seen.
  - A **red** apple absorbs all wavelengths of white light, except **red**.
  - The red wavelength of light is reflected to our eye, and perceived as **red**.
- A **red** apple appears **red** because it reflects light in the **red** wavelength.



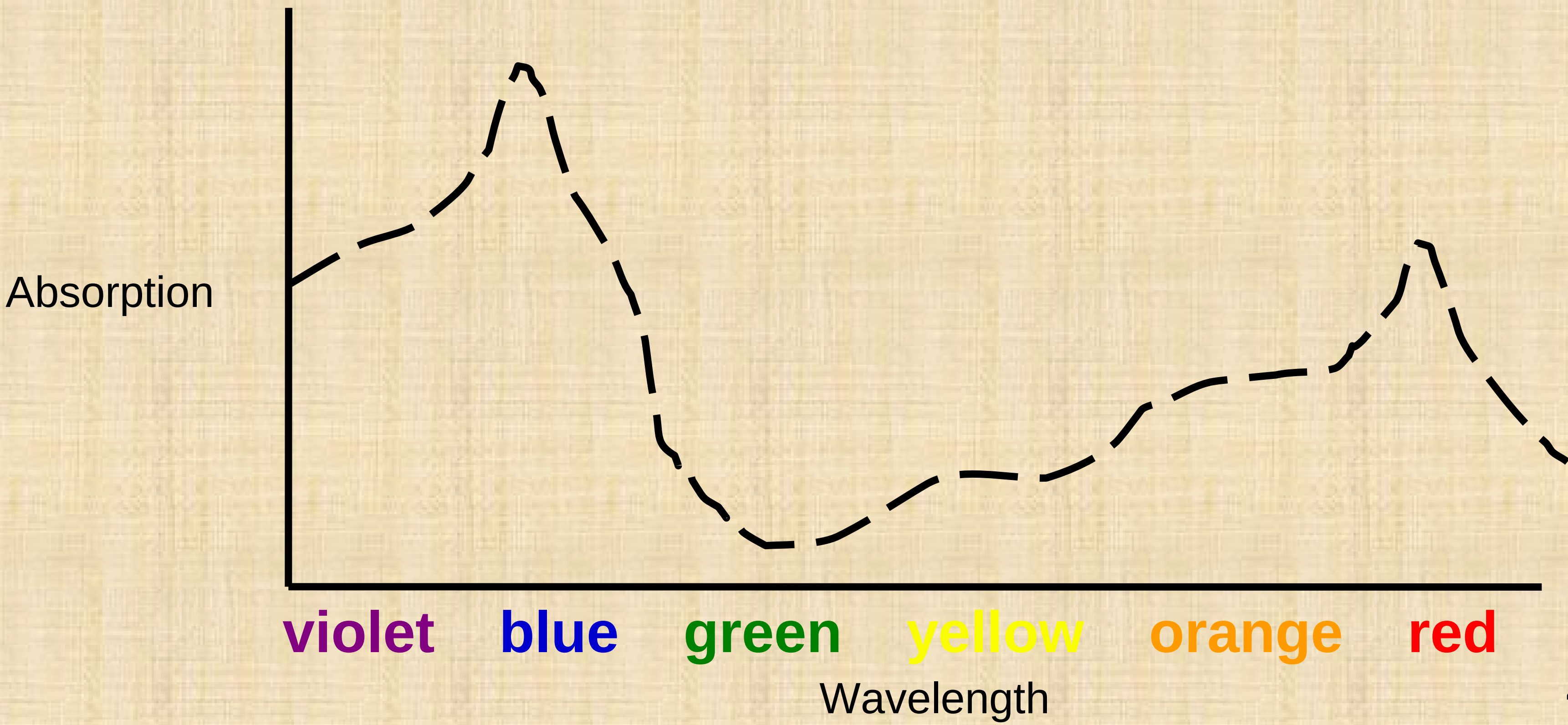
Visible Radiation absorbed by Pigments drives the Light Reactions

- **PLANT PIGMENTS**
  - are built into the **Thylakoid Membrane.**
  - **absorb** some wavelengths of light.
  - **reflect** other wavelengths.
- We see the color of the wavelengths that are **reflected** by pigments.
- For example, **Chlorophyll** reflects **green** wavelengths.
  - The **energy** provided by the sun to fuel **photosynthesis** comes from the wavelengths of light **chlorophyll** absorbs.


Light
Reflected light
Chloroplast
Thylakoid
Absorbed light
Reflected light

Absorption of Light by Chlorophyll

Chlorophyll absorbs blue-violet and red light best

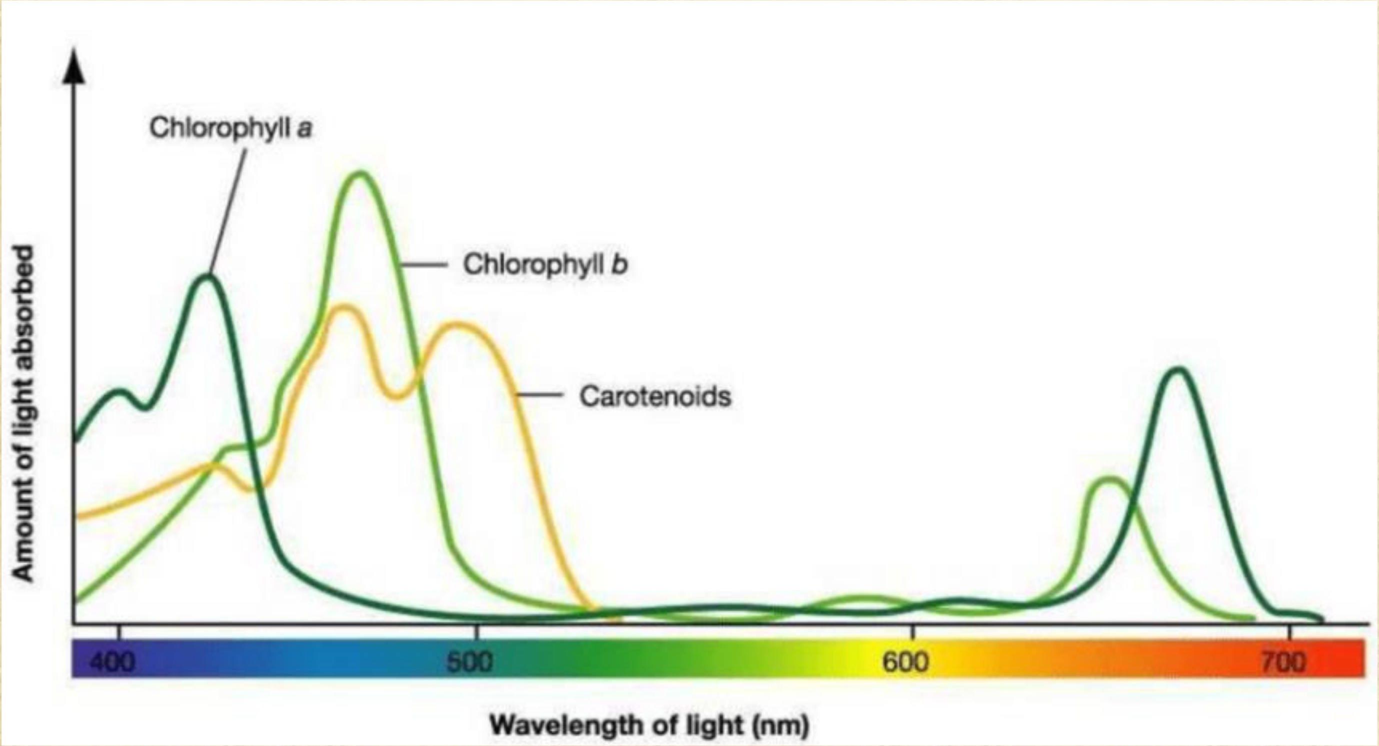


Carotenoids:

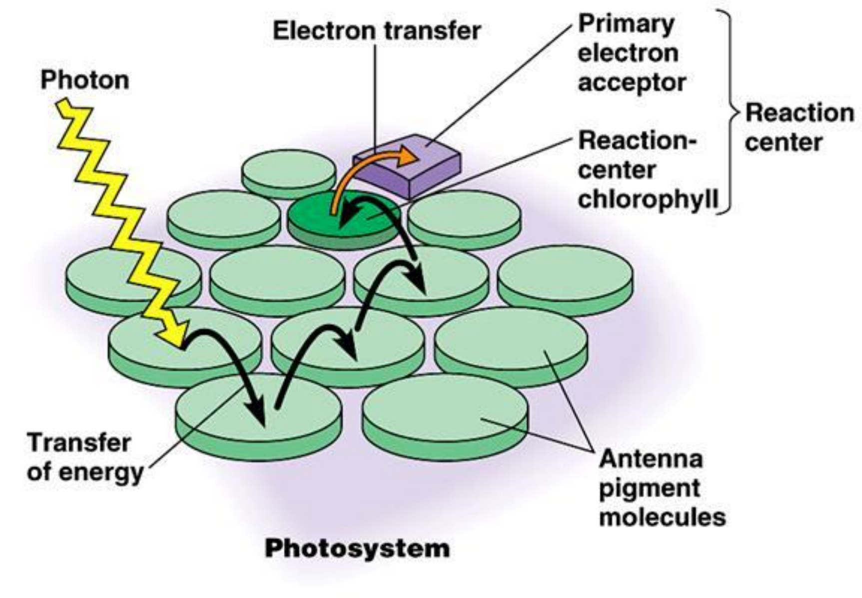
- Other types of photosynthetic pigments.
- They **enhance the absorption spectrum of chlorophyll** so that more of the sun's energy can be used in photosynthesis.
- They "pass along" the energy they absorb to the chlorophyll.
- **Fall colors** are due to the presence of carotenoids in leaves.

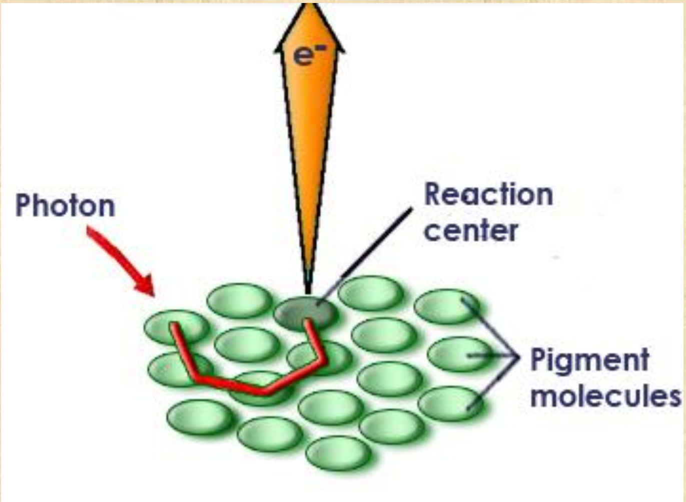
Why do leaves change colors in the Fall?

- Plants stop producing **chlorophyll** during the fall, so they lose their green color.
- **Carotenoids** are still present in the leaves.
- Since they **absorb green** light and reflect other wavelengths (**red**, **orange**, **yellow**, **brown**), the leaves take on the color of the carotenoid that is present.



When chlorophyll absorbs light, **energy** is transferred directly to **electrons** in the chlorophyll molecule.





This raises the energy level of these electrons. These high-**energy** electrons make photosynthesis work.

Two Photosystems connected by an Electron Transport Chain generate ATP and NADPH

- In the **Light Reactions**, light energy is transformed into the chemical energy of **ATP** and **NADPH.**
- To accomplish this, **electrons** are
  - removed from **Water.**
  - passed from **Photosystem II** to **Photosystem I.**
  - accepted by **$NADP^+$**, reducing it to **NADPH.**
- Between the two photosystems, the electrons
  - move down an **Electron Transport Chain** and
  - provide energy for the synthesis of **ATP.**

Light Reaction Summary

1. What is used (reactants)?

   Water (H_2O)

2. What is produced?

   Oxygen (O_2)

3. What is the energy source?

   Sunlight

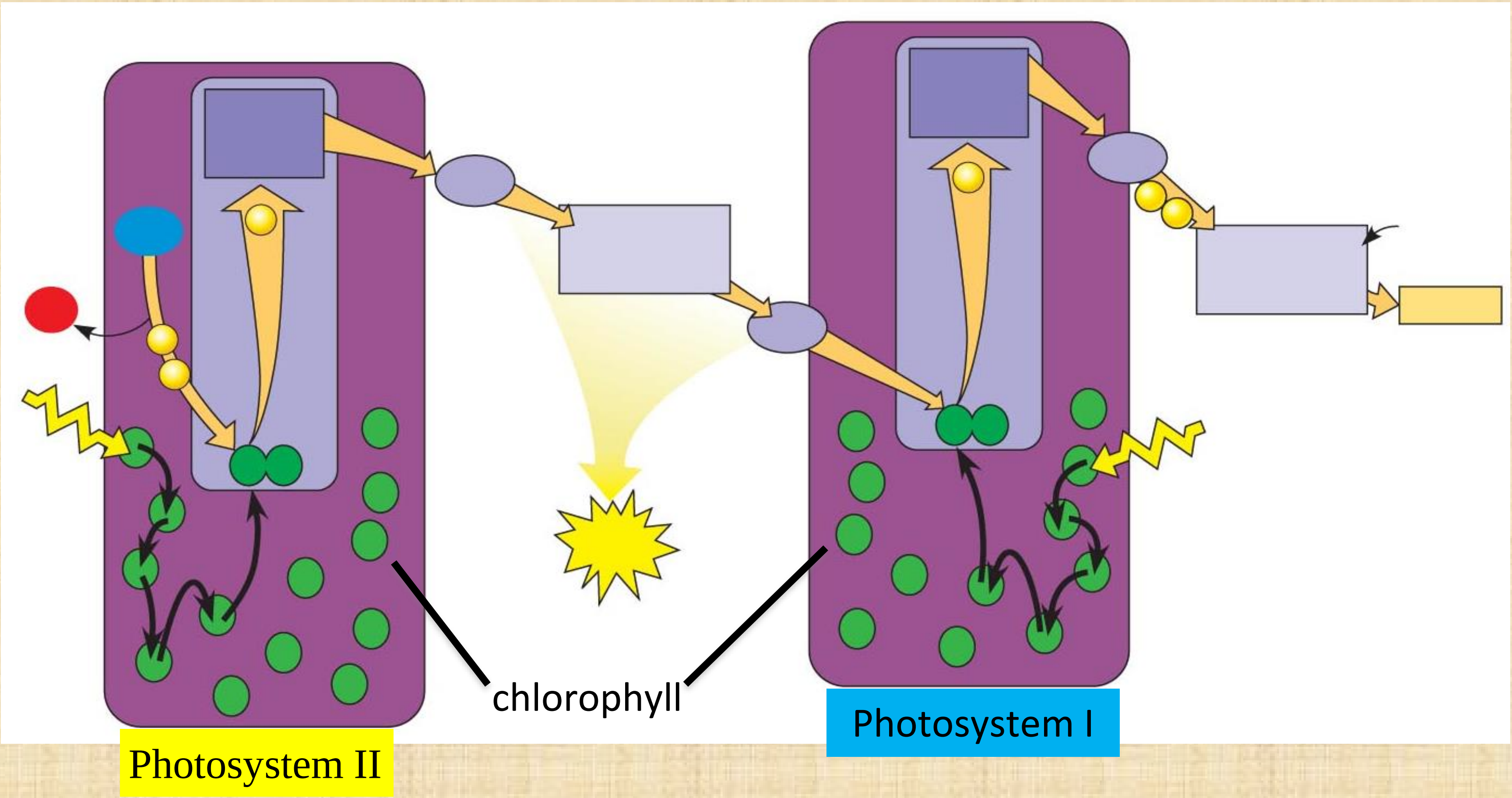
4. What are the by-products?

   ATP and NADPH

5. Where does this occur?

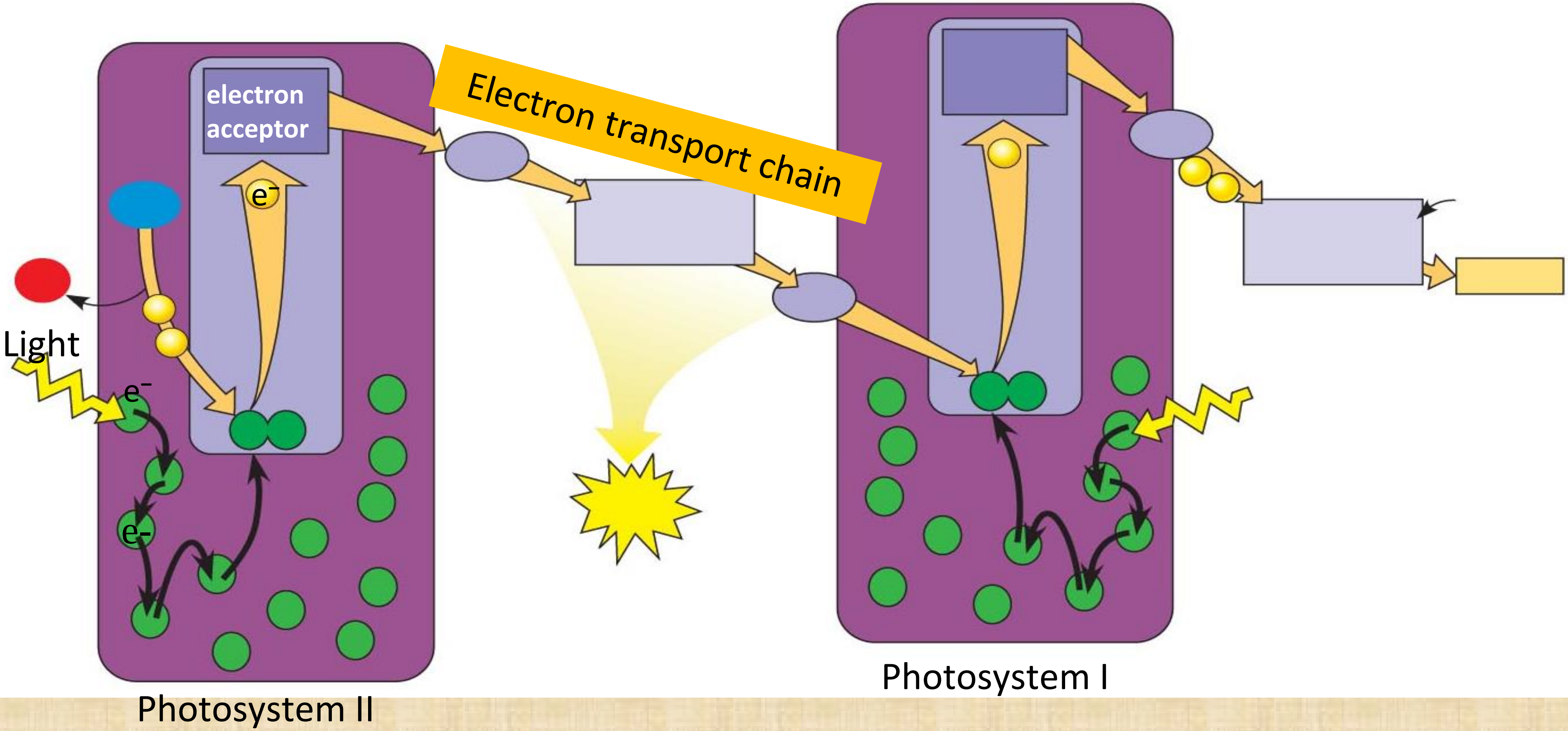
   Grana of the chloroplasts

The Light Dependent Reactions - Photosystems



There are two photosystems: **Photosystem I** and **Photosystem II**.

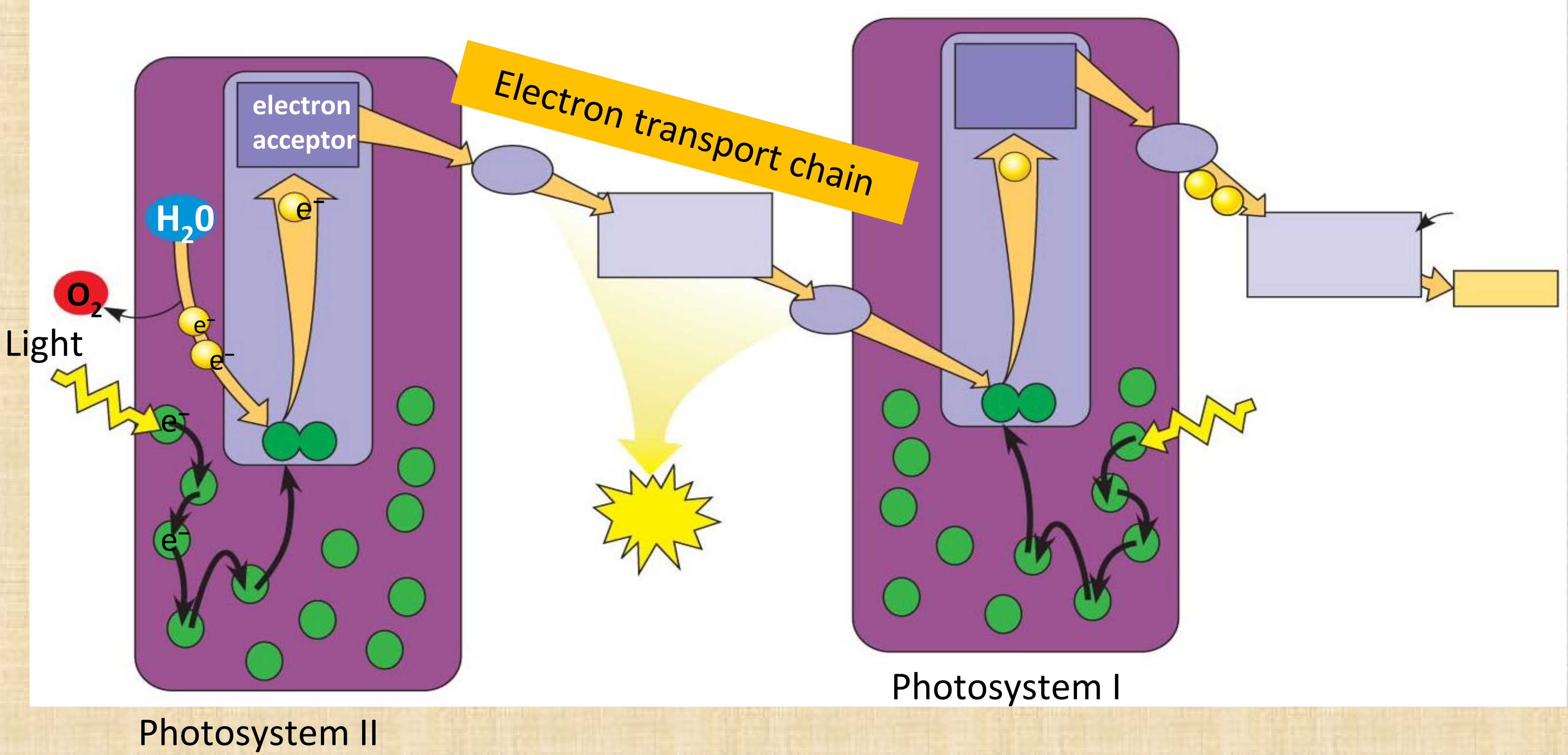
Photosystem: A collection of pigment molecules (chlorophyll) that serve as the **light collecting unit**.



Chlorophyll molecules in photosystem II absorb light.

This light energy is absorbed by chlorophyll's **electrons**, increasing their energy level.

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

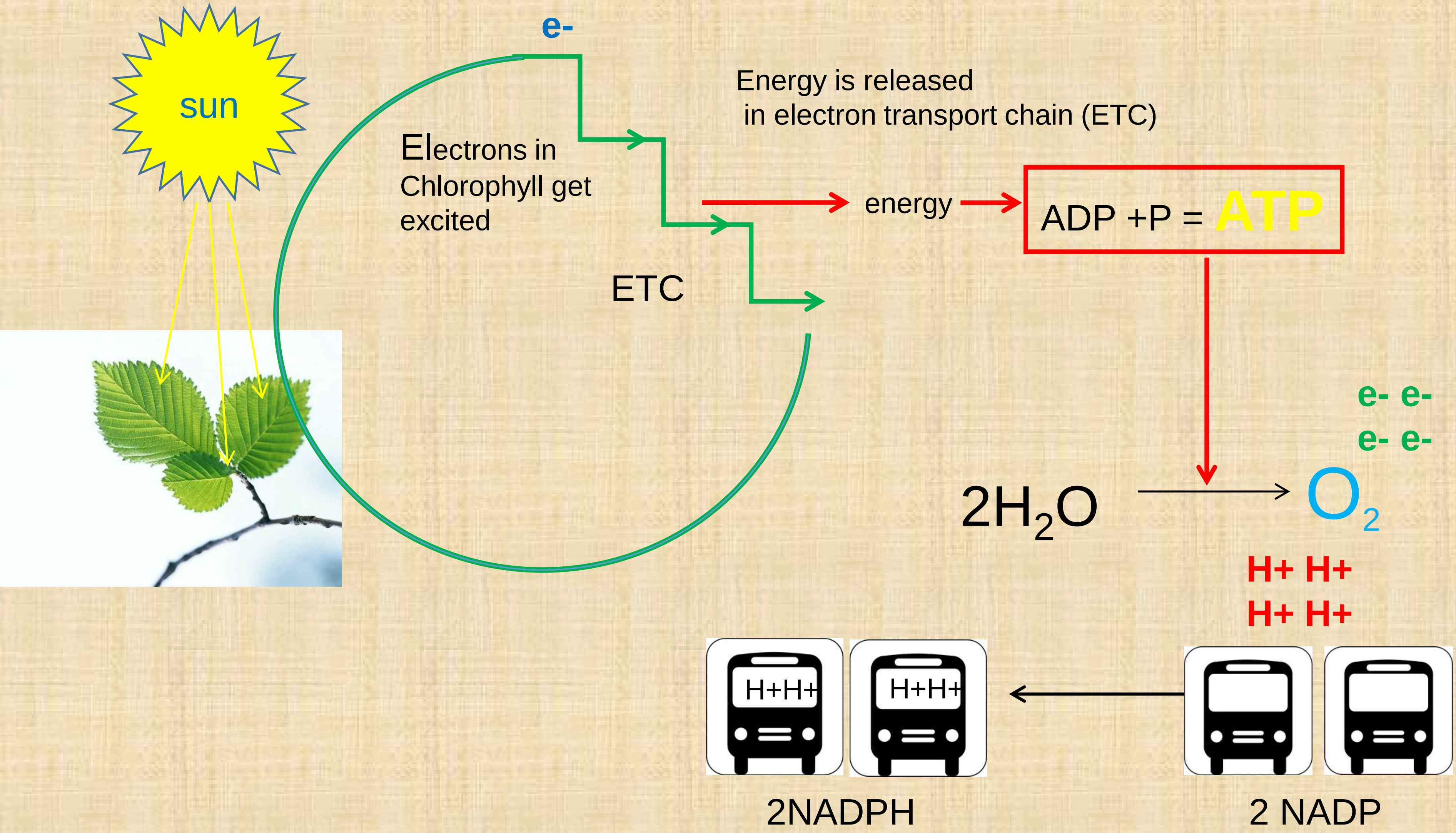


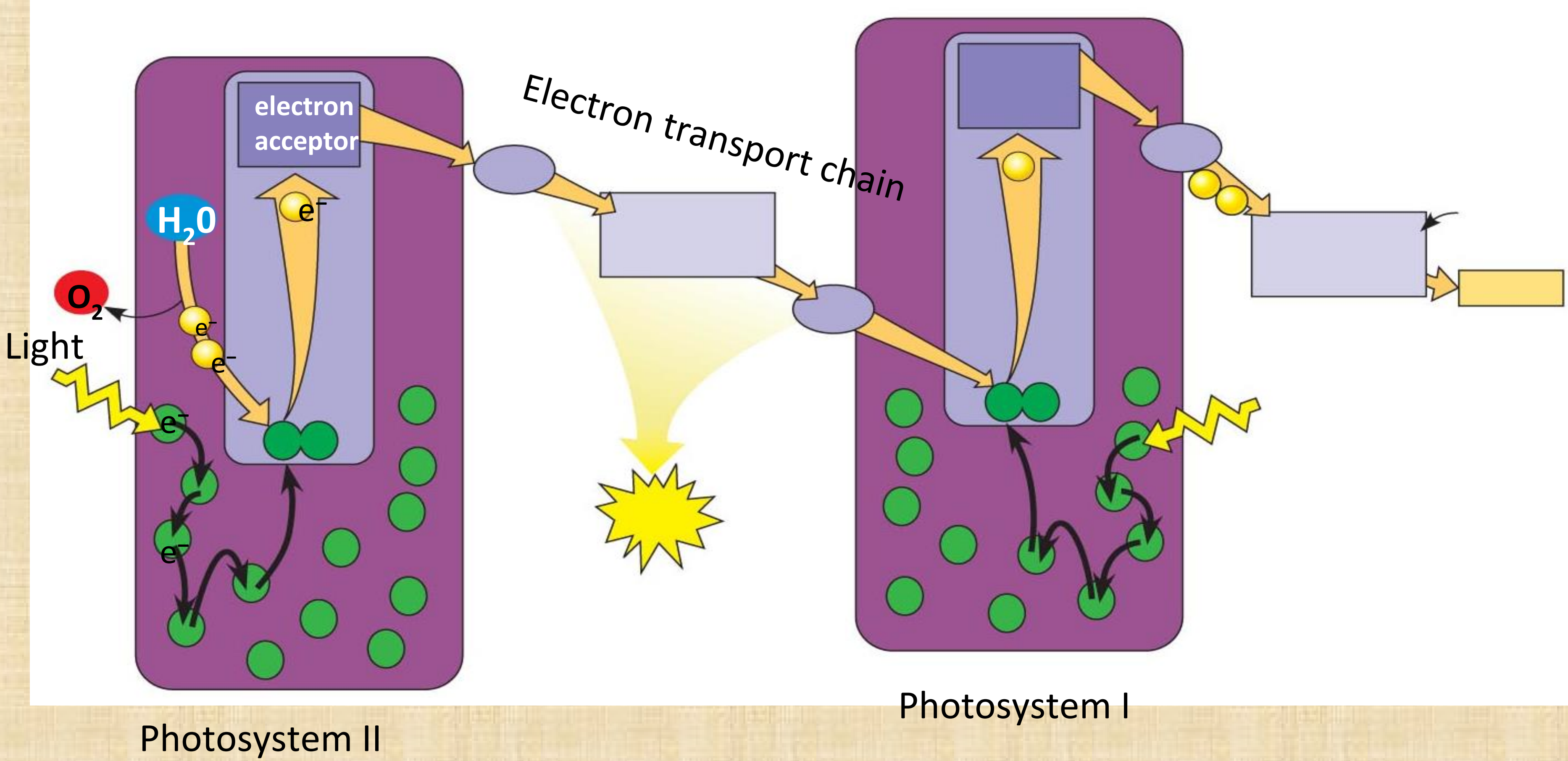
The electrons that were lost must now be replaced.

Enzymes in the thylakoid membrane break apart water molecules into 2 electrons, 2 H+ ions, and 1 oxygen molecule.

These electrons replace the high-energy electrons that chlorophyll has lost to the electron transport chain.

LIGHT REACTION OF PHOTOSYNTHESIS

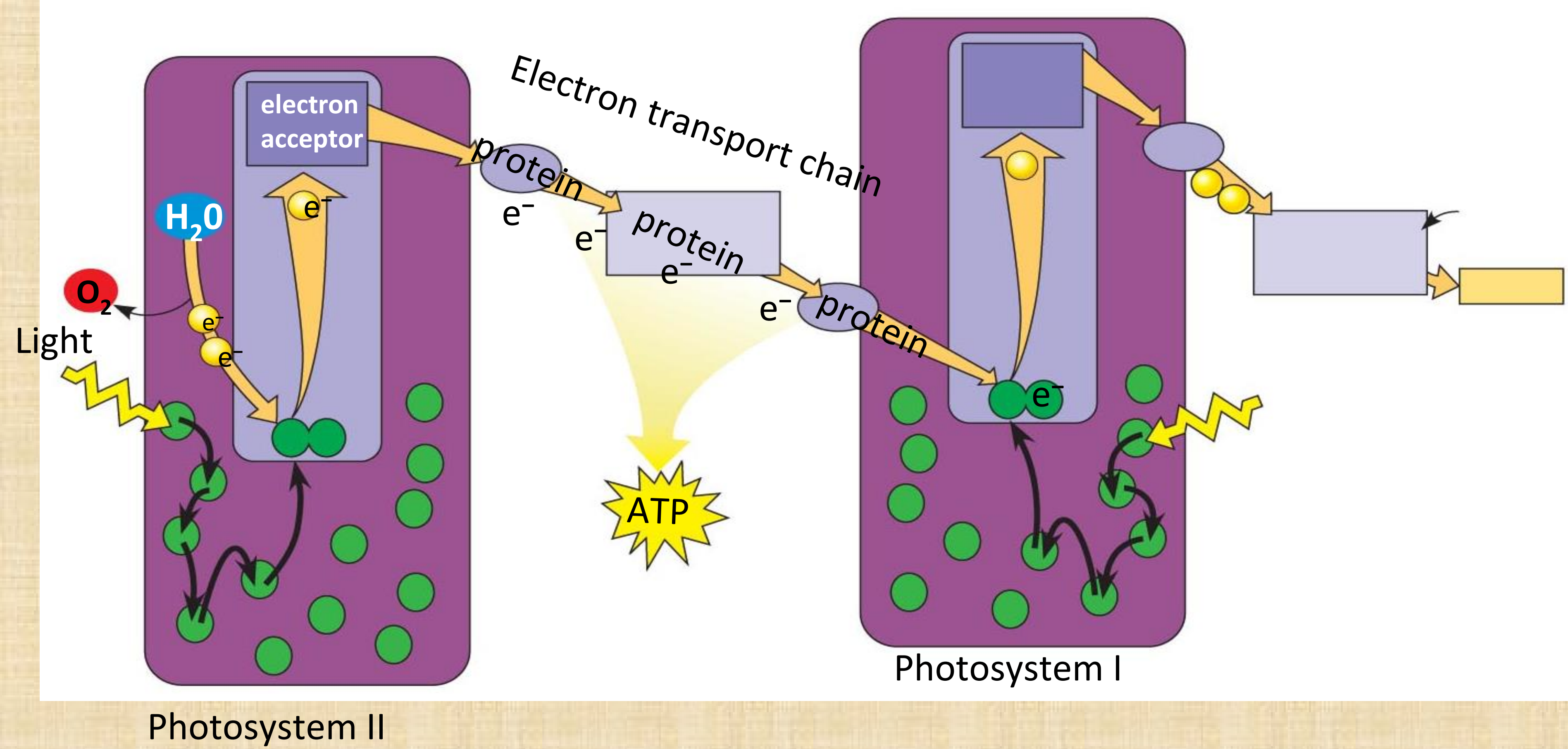




The **oxygen** is considered a waste product and is released into the air.

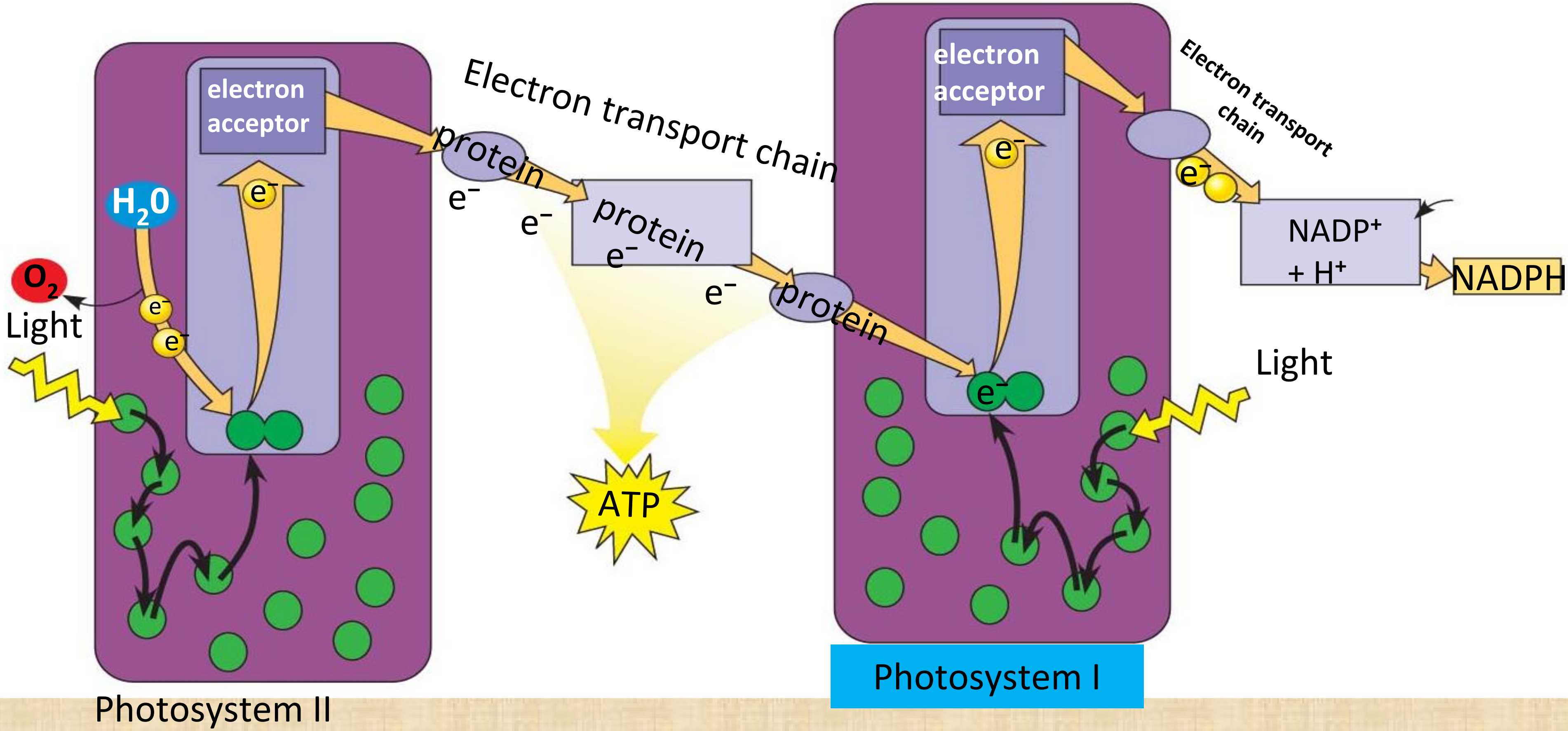
This splitting apart of water molecules is responsible for nearly all of the oxygen in our **atmosphere**.

The hydrogen ions from the water are released inside the thylakoid.



The high-energy electrons move through the electron transport chain from **photosystem II** to **photosystem I**.

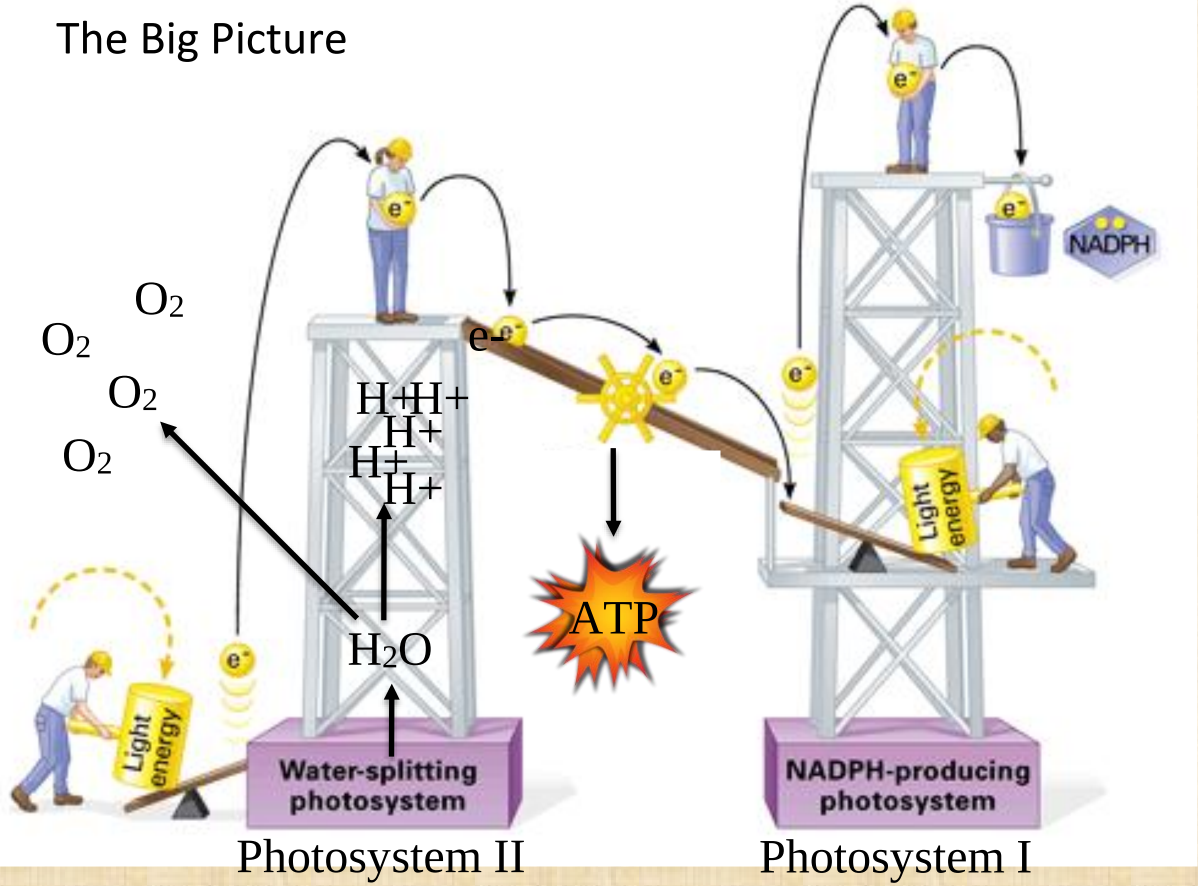
As the electrons are passed down the electron transport chain, protein molecules use the energy from these electrons to create **ATP**.



The **chlorophyll** molecules in **photosystem I** absorb energy from the sun and use it to re-energize the electrons.

The electron carrier NADP+ picks up these high-energy electrons along with a H+ to form NADPH.

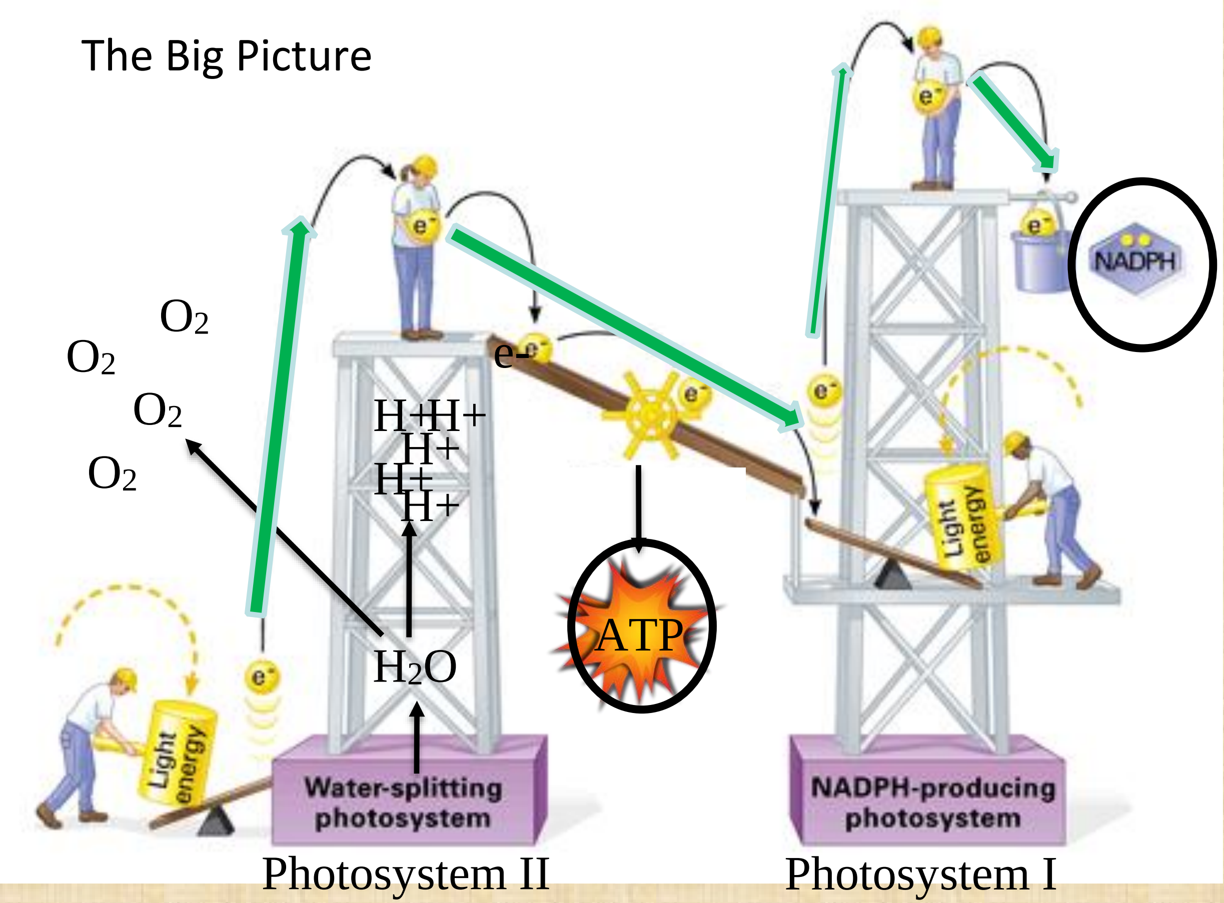
The Big Picture



The **purpose** of the **Light-Dependent Reactions** is to produce **ATP** and **NADPH** that are needed for the **Light-Independent Reactions**.

- The reaction that takes place along the **thylakoid** membrane:
- Water molecules are continuously **split** by an enzyme.
  - The **hydrogen** will accumulate inside the thylakoid.
  - The **oxygen** is released to the atmosphere (by-product).

The Big Picture

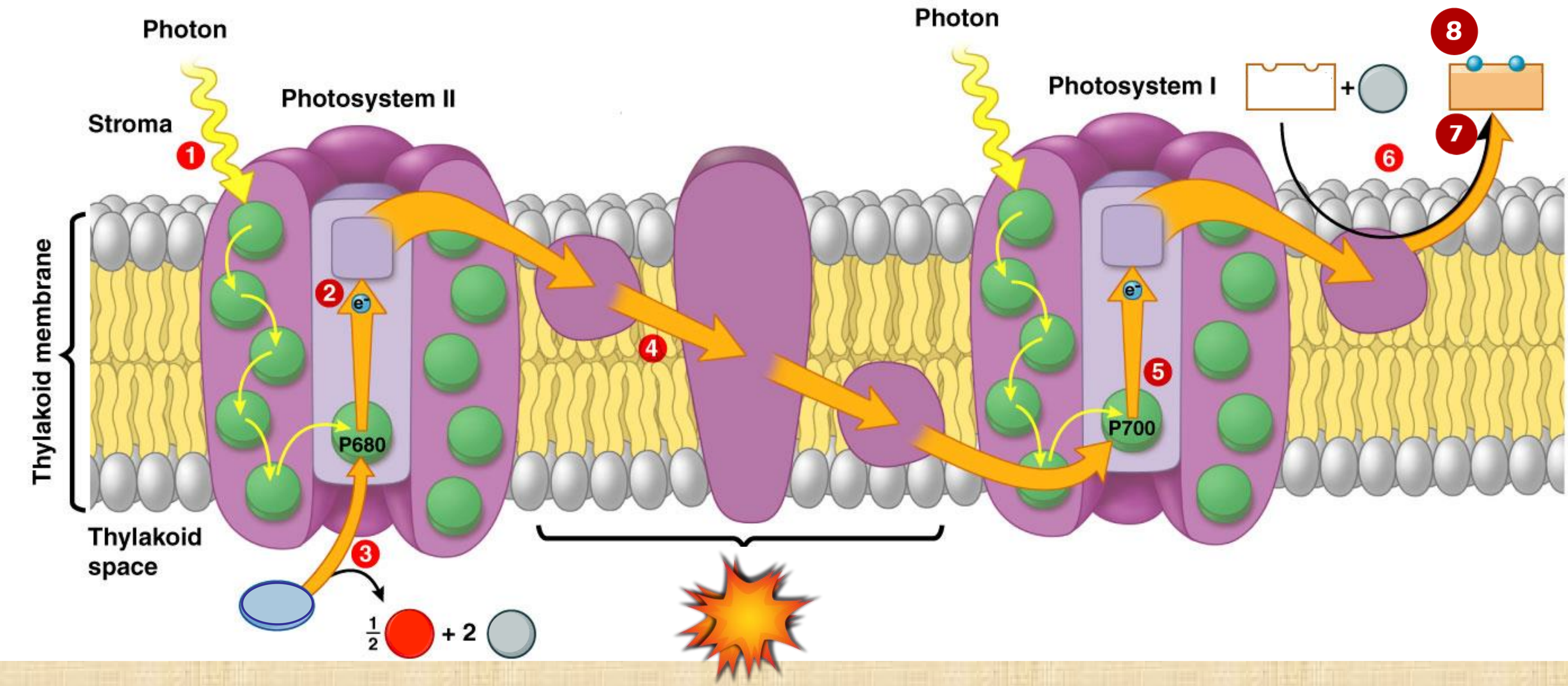


The **purpose** of the **Light-Dependent Reactions** is to produce **ATP** and **NADPH** that are needed for the **Light-Independent Reactions**.

- **The light-dependent reactions pass electrons continuously from Water to NADPH.**
- The two photosystems work together using the light energy from the sun to produce **ATP** and **NADPH**.

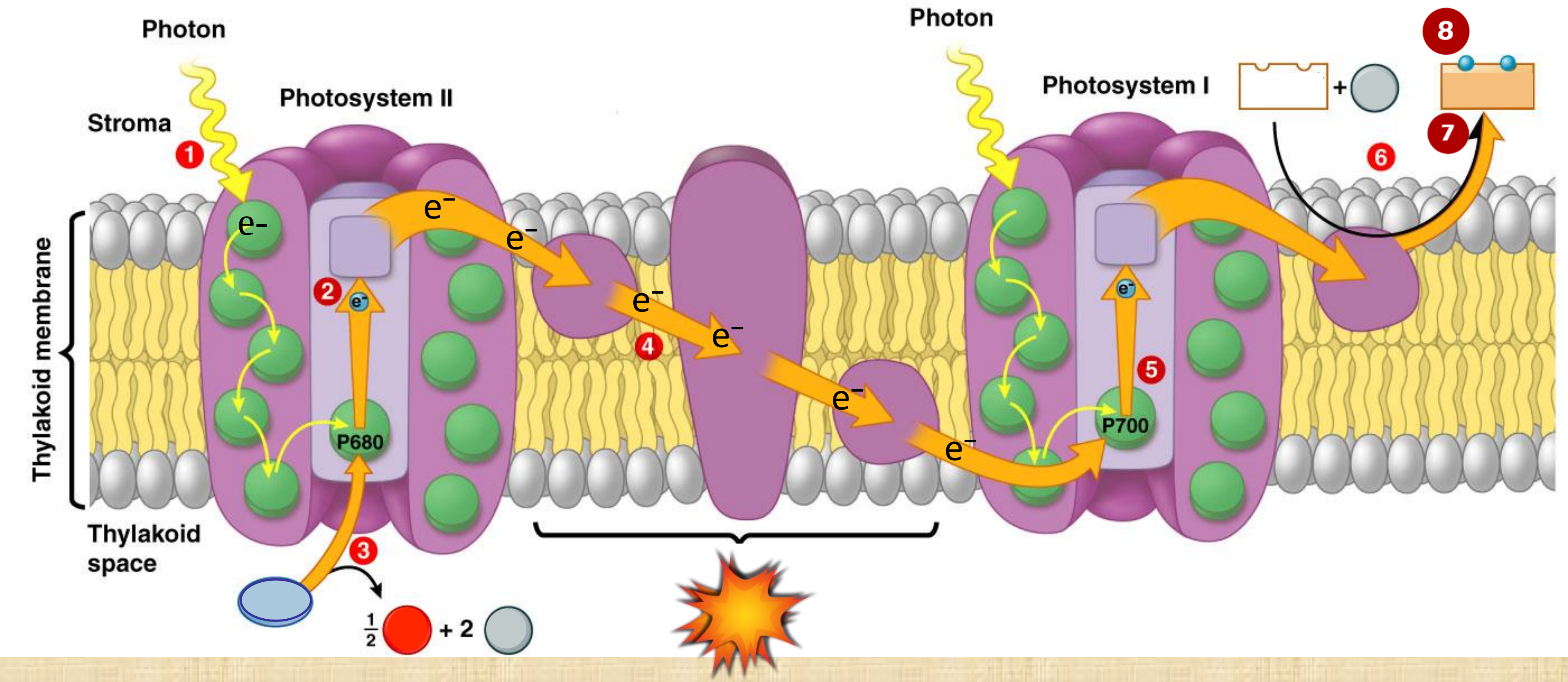
The Light Reactions take place within the Thylakoid Membranes

- A **Thylakoid Membrane** includes numerous copies of
  - the two photosystems and
  - the electron transport chain.
- Light energy absorbed by the two photosystems drives the flow of electrons from **Water to NADPH**.
- The electron transport chain helps to produce the concentration gradient of H^+ across the thylakoid membrane, which drives H^+ through ATP synthase, producing **ATP.**



This diagram is a slice of a section of the thylakoid membrane. Embedded in the membrane are photosystems.

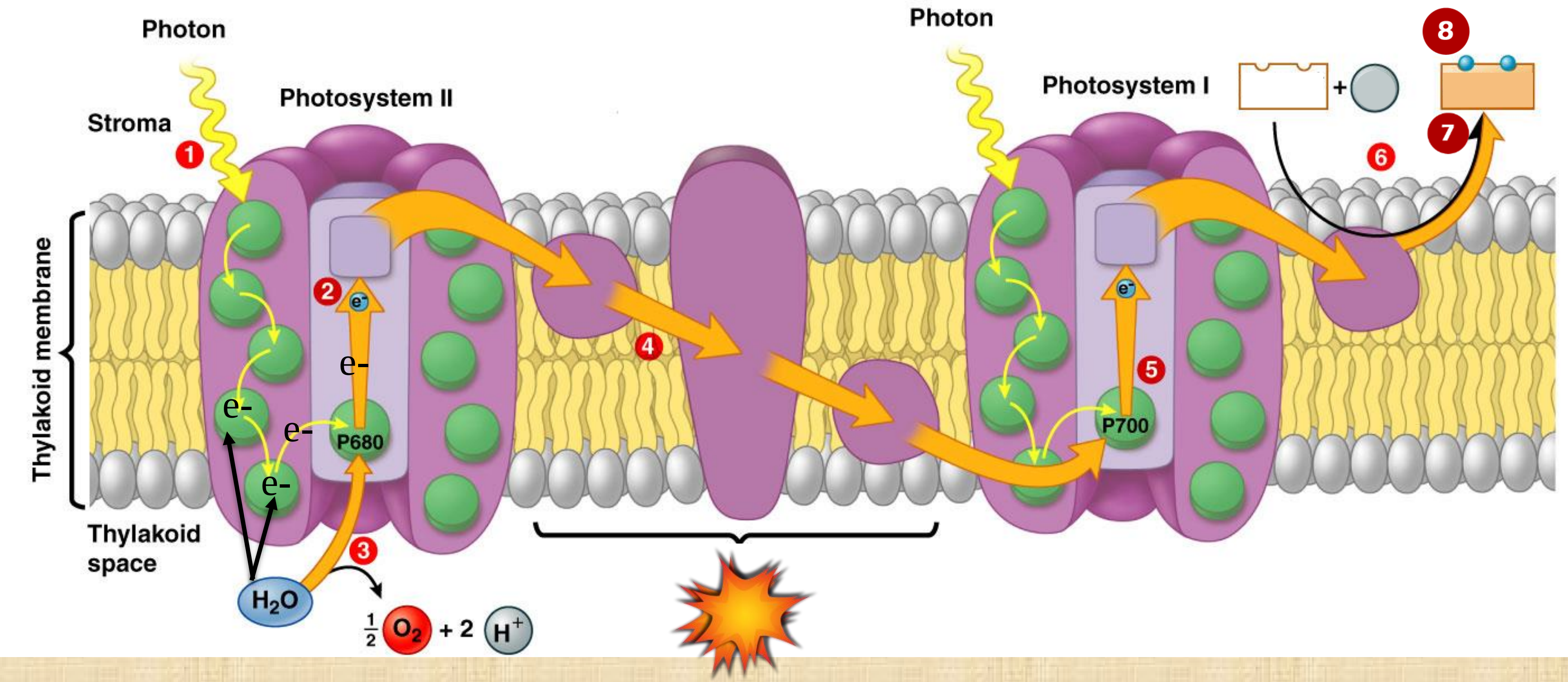
Photosystem II is a collection of **chlorophyll** molecules that absorb the **light energy** from the sun.



1 When **sunlight** strikes the surface of the leaf, the **chlorophyll** molecules absorb the energy from the sun.

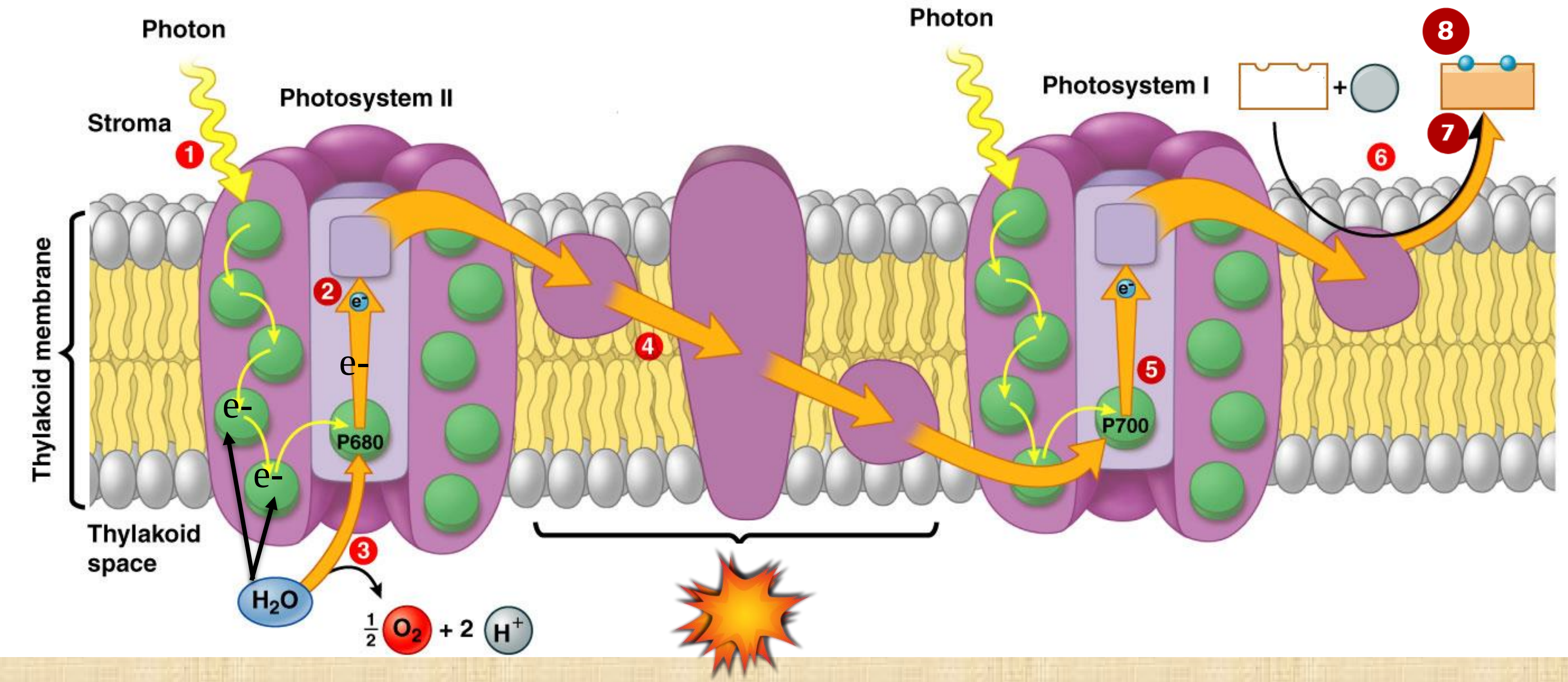
2 This light energy increases the energy level of the electrons in chlorophyll molecules.

These high-energy electrons are passed to the ETC (Electron Transport Chain) .



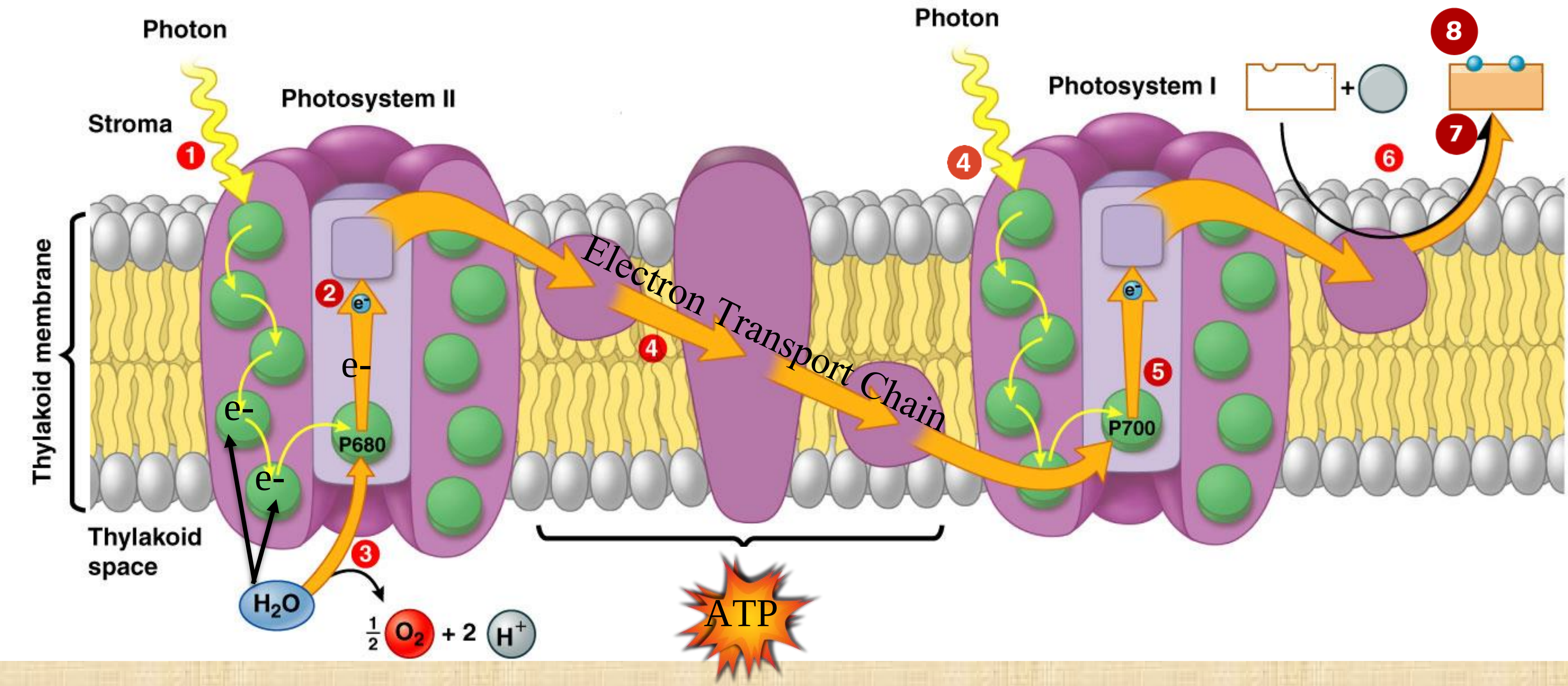
3 The electrons that were lost must now be replaced. Enzymes in the thylakoid membrane break apart water molecules into 2 electrons, 2 H^+ ions, and 1 oxygen molecule.

These electrons replace the high-energy electrons that chlorophyll has lost to the electron transport chain (ETC).



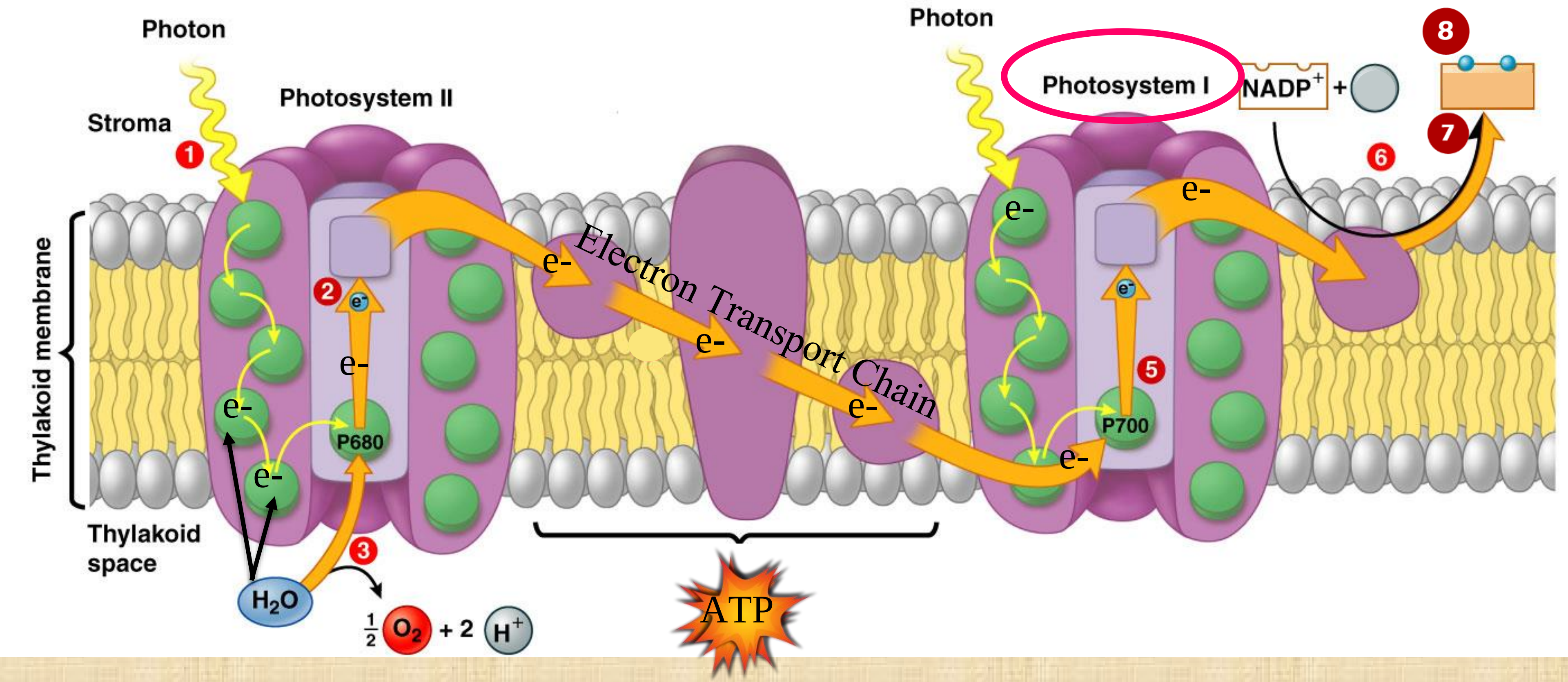
The **oxygen** is considered a waste product and is released into the air.

The **hydrogen** ions from the water are released inside the thylakoid space.



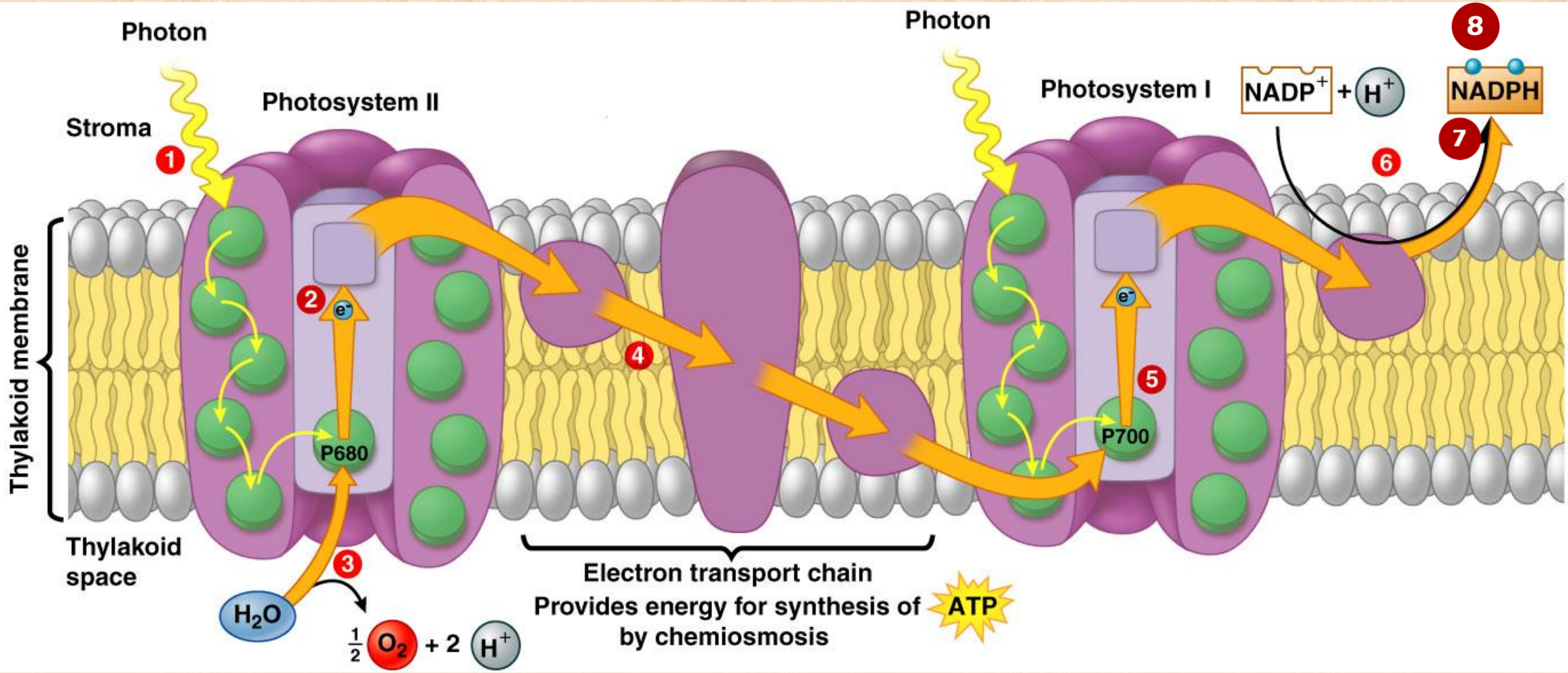
4 The high-energy electrons move through the electron transport chain from photosystem II to photosystem I.

As the electrons are passed down the electron transport chain, protein molecules use the energy from these electrons to create ATP.



5 The chlorophyll molecules in Photosystem I absorb energy from the sun and use it to re-energize the electrons.

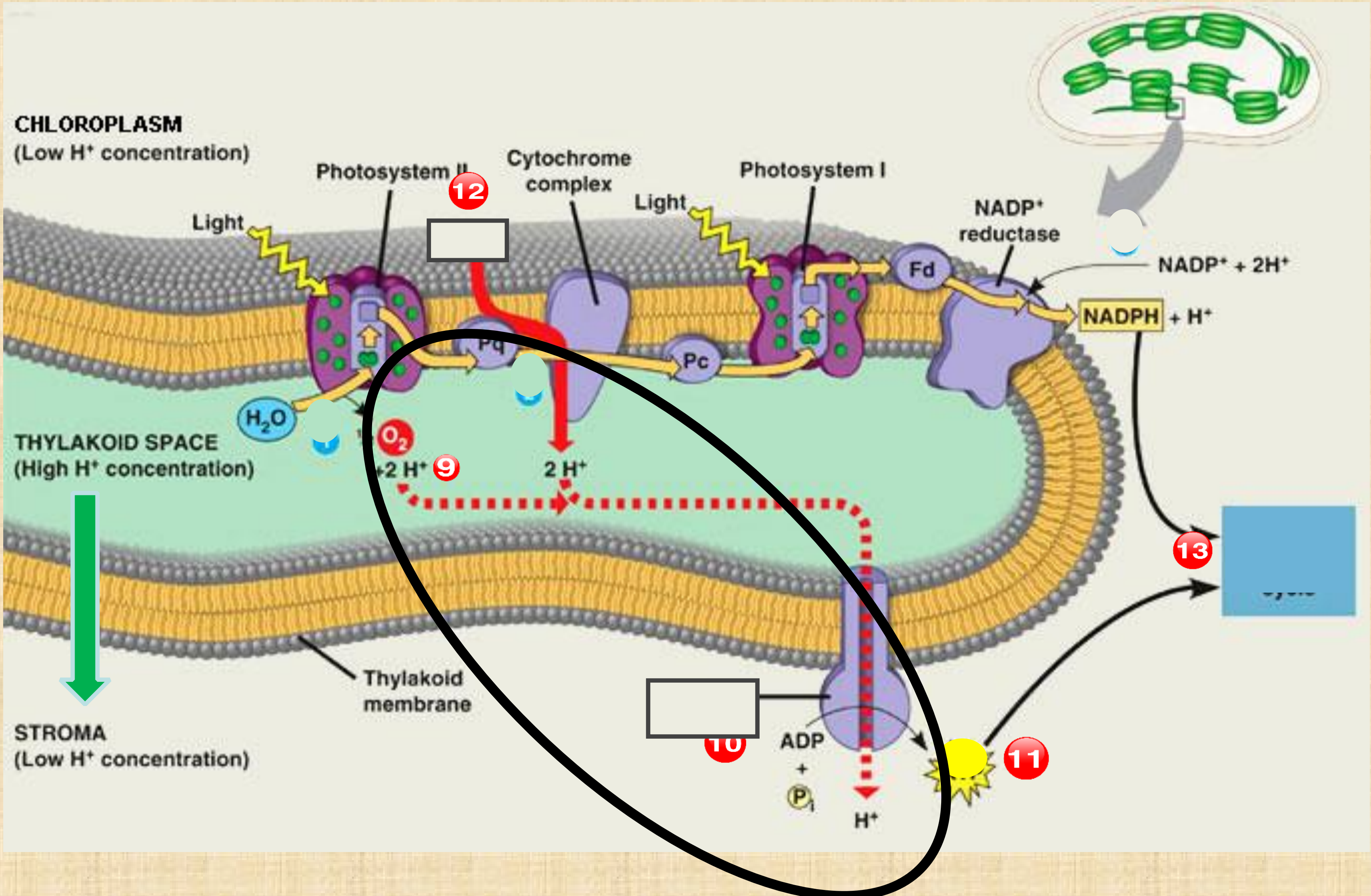
6 These electrons are passed down a second electron transport chain to the electron acceptor called NADP+.



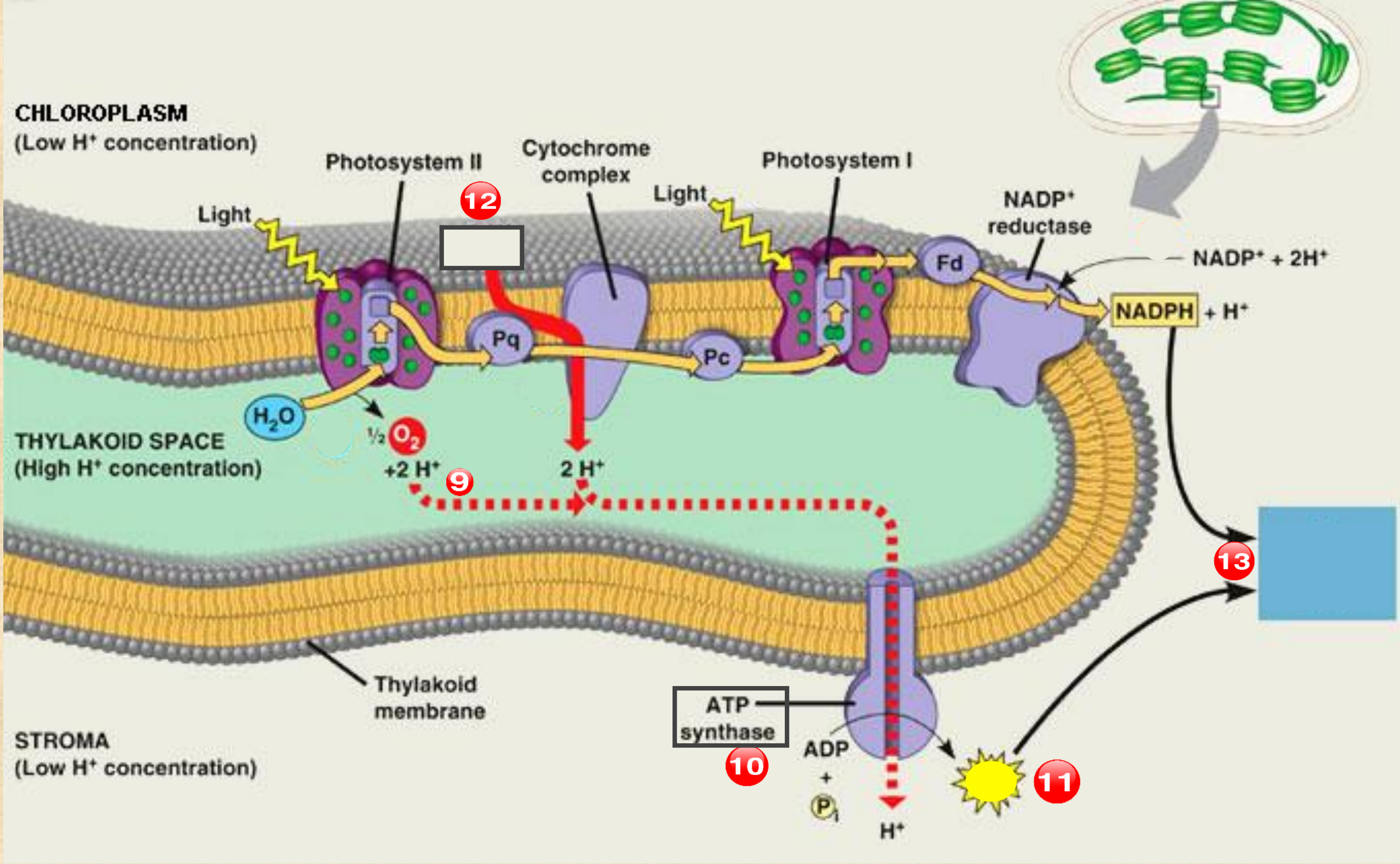
6 NADP+ joins with one hydrogen atom and two electrons to form …

7 **NADPH** in a space outside of the thylakoid.

8 This area of the chloroplast is called the stroma. It is a dense, enzyme-rich liquid area of the chloroplast outside of the thylakoid.

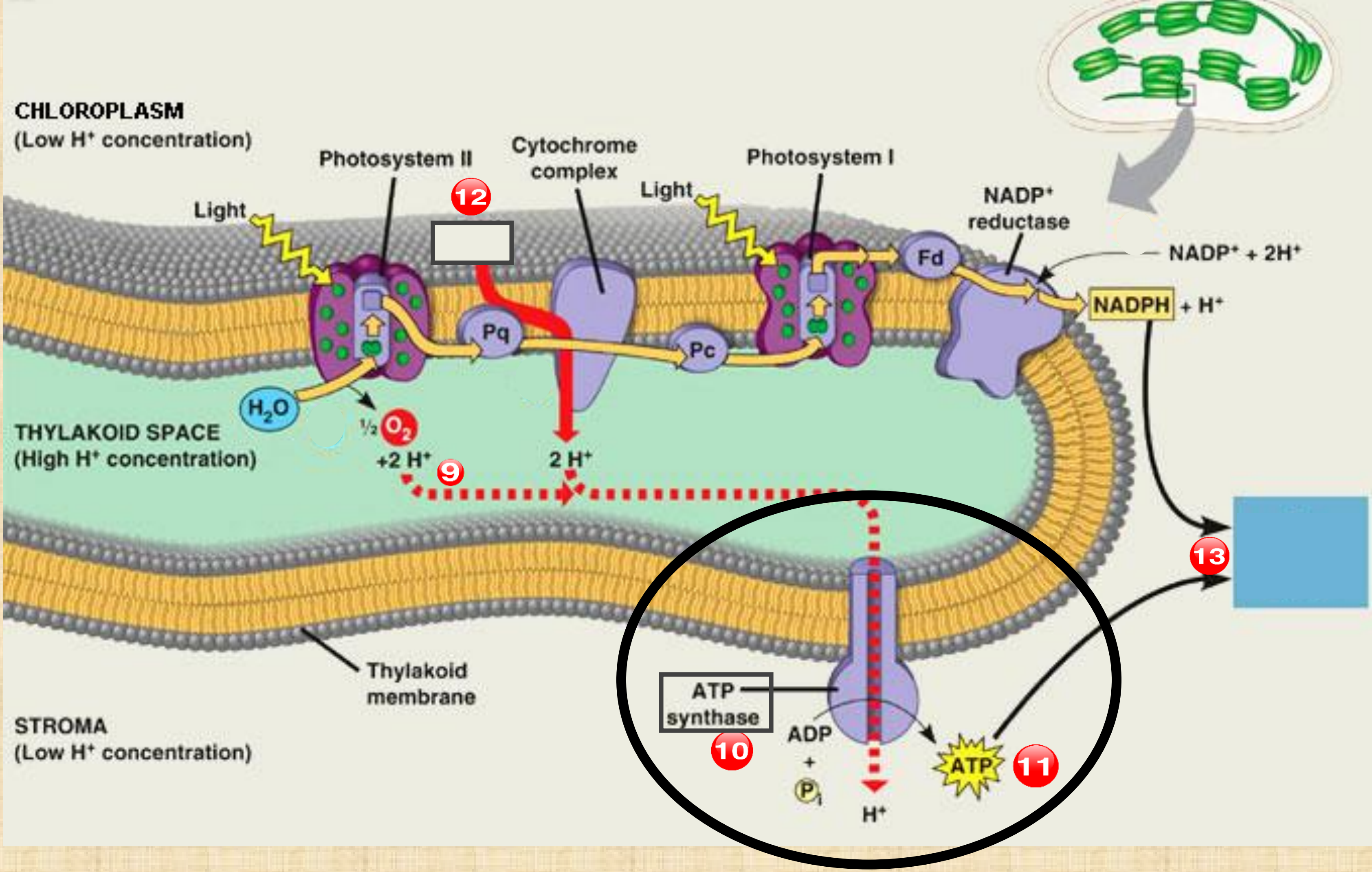


9 Hydrogen ions flow from an area of high concentration inside the thylakoid space to an area of low concentration in the stroma.

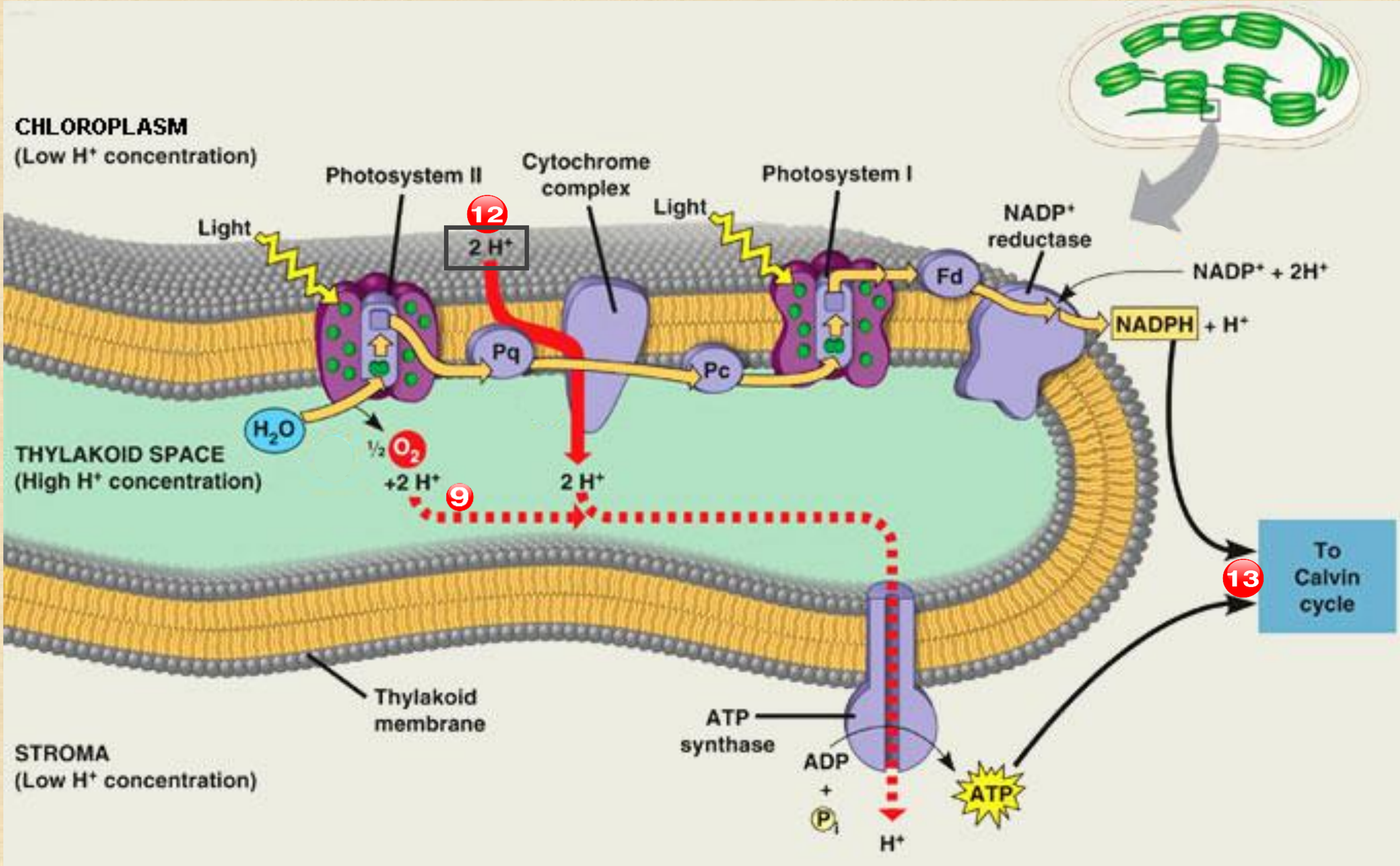


10 The hydrogen is flowing through a protein enzyme called ATP synthase.

As the hydrogen flows through ATP synthase, the protein rotates just like a turbine being turned by water.

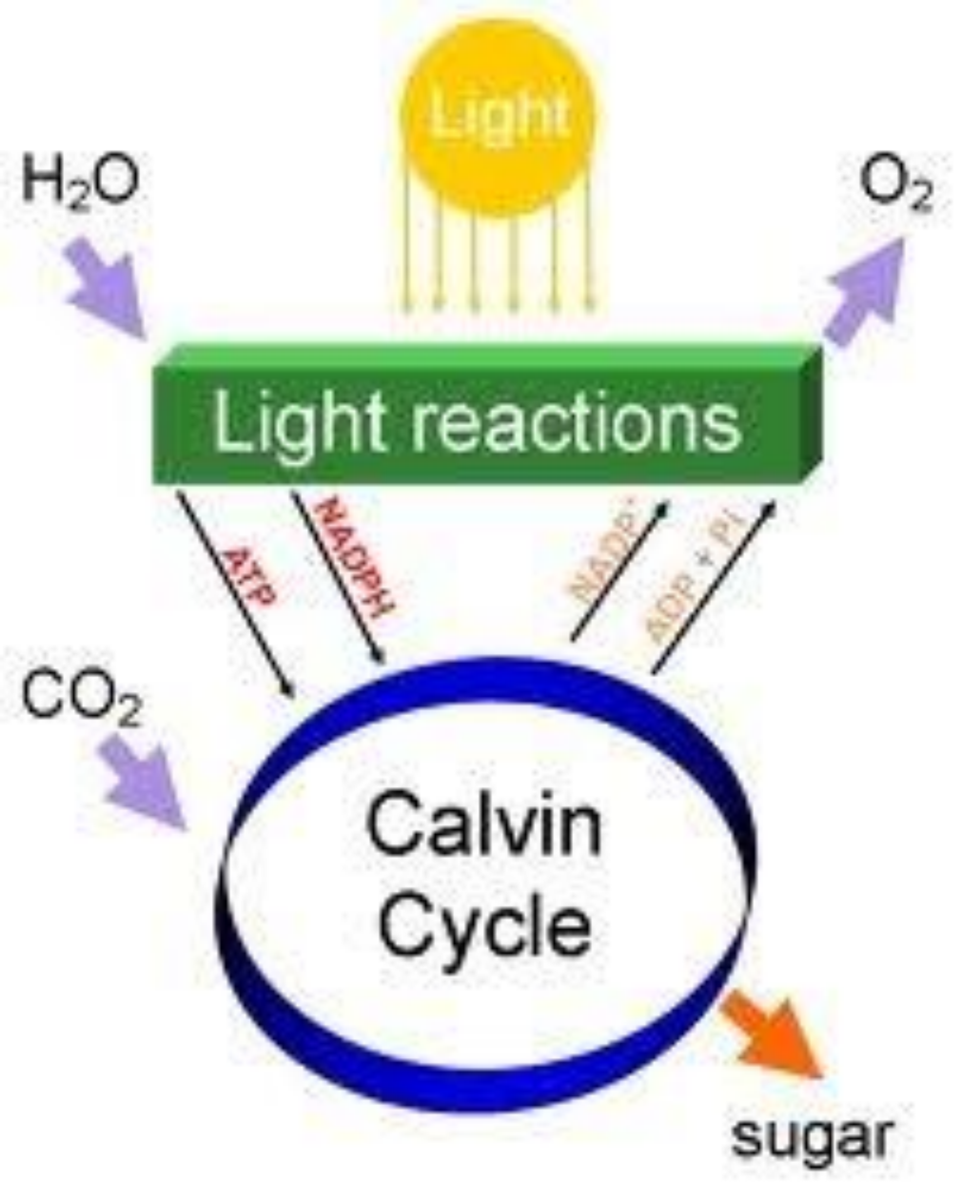


11 As this protein rotates, ATP synthase binds a phosphate to ADP to form ATP.



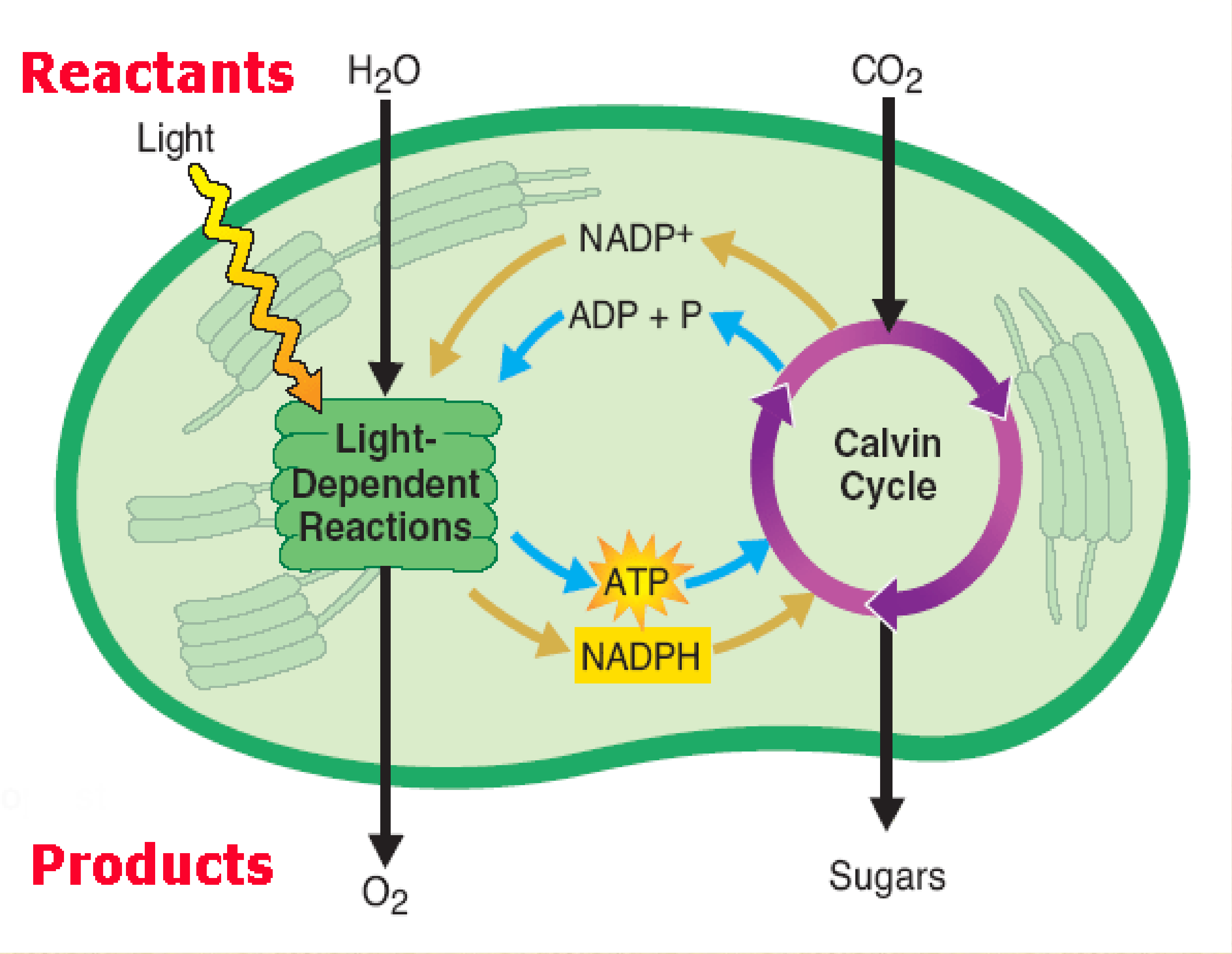
12 Hydrogen ions are pumped back inside the thylakoid space to keep the concentration of hydrogen very high inside of it.

13 NADPH and ATP are sent to the Calvin Cycle.



The purpose of the **light reactions** is to produce the high-energy compounds of **ATP** and **NADPH** which will be used in the **light-independent reactions** or “Dark Reactions”.

Photosynthesis Overview



Photosynthesis Overview

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Light Reactions of Photosynthesis

THE CALVIN CYCLE:

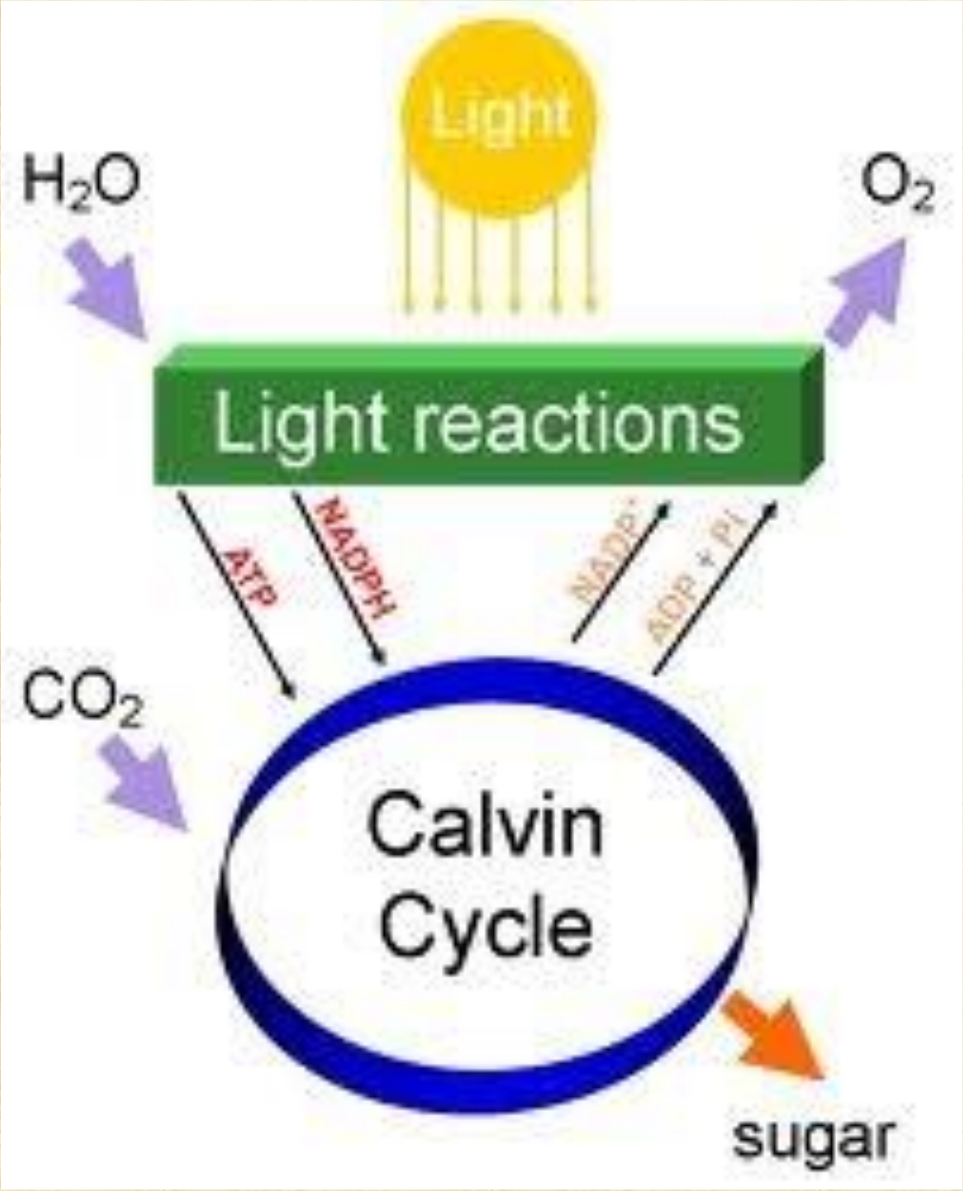
REDUCING CO_2 TO SUGAR

The Calvin Cycle

The Calvin Cycle, the Dark Reaction, or the Light-Independent Reactions …

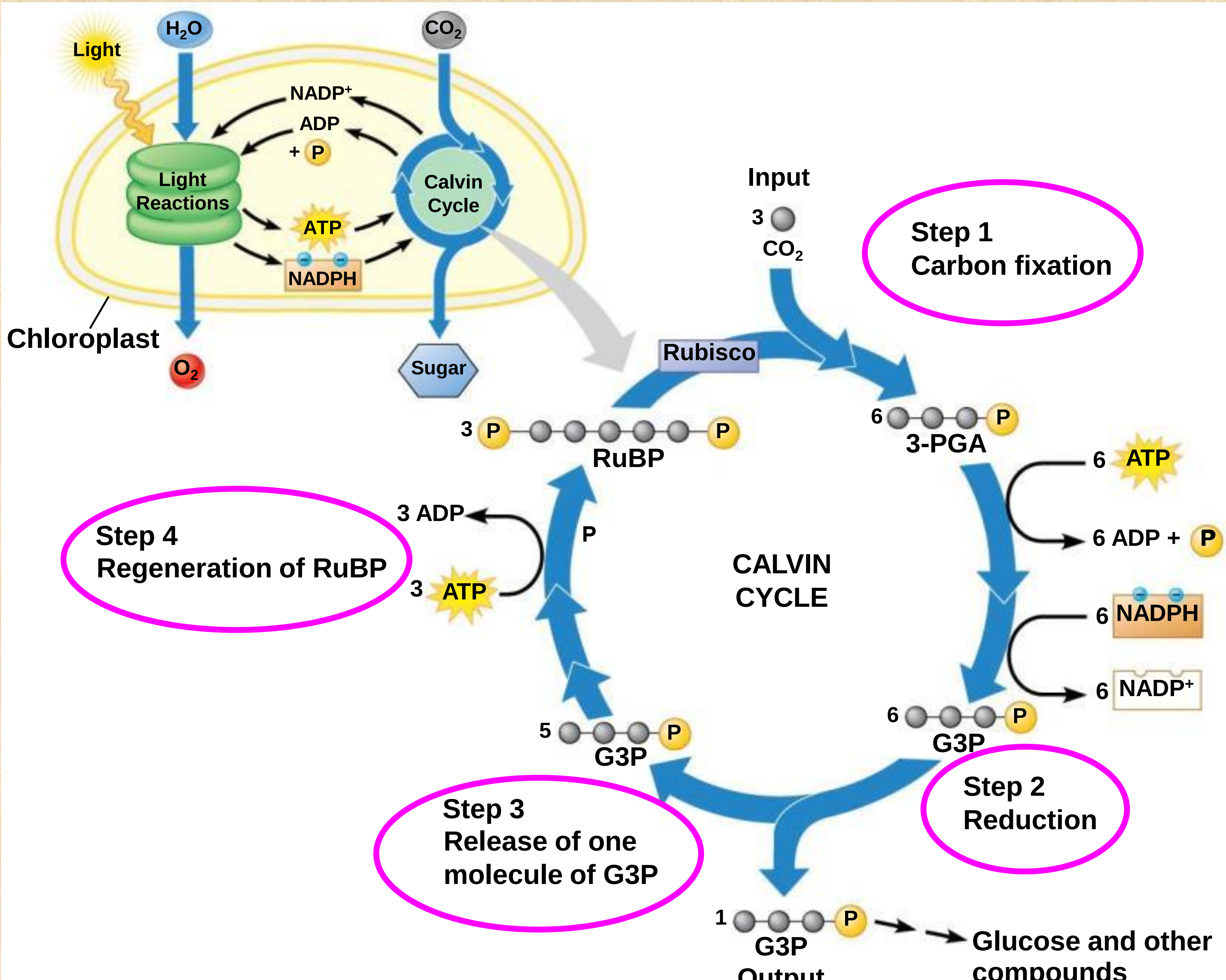
occurs in the stroma of the chloroplast.

The purpose of this stage is to take carbon dioxide and the high-energy products from the light reaction (NADPH and ATP) and make glucose molecules.



CALVIN CYCLE

- The steps of the **Calvin Cycle** include
  - Carbon Fixation
  - Reduction
  - release of one molecule of G3P
  - regeneration of the starting molecule, Ribulose Biphosphate (RuBP).

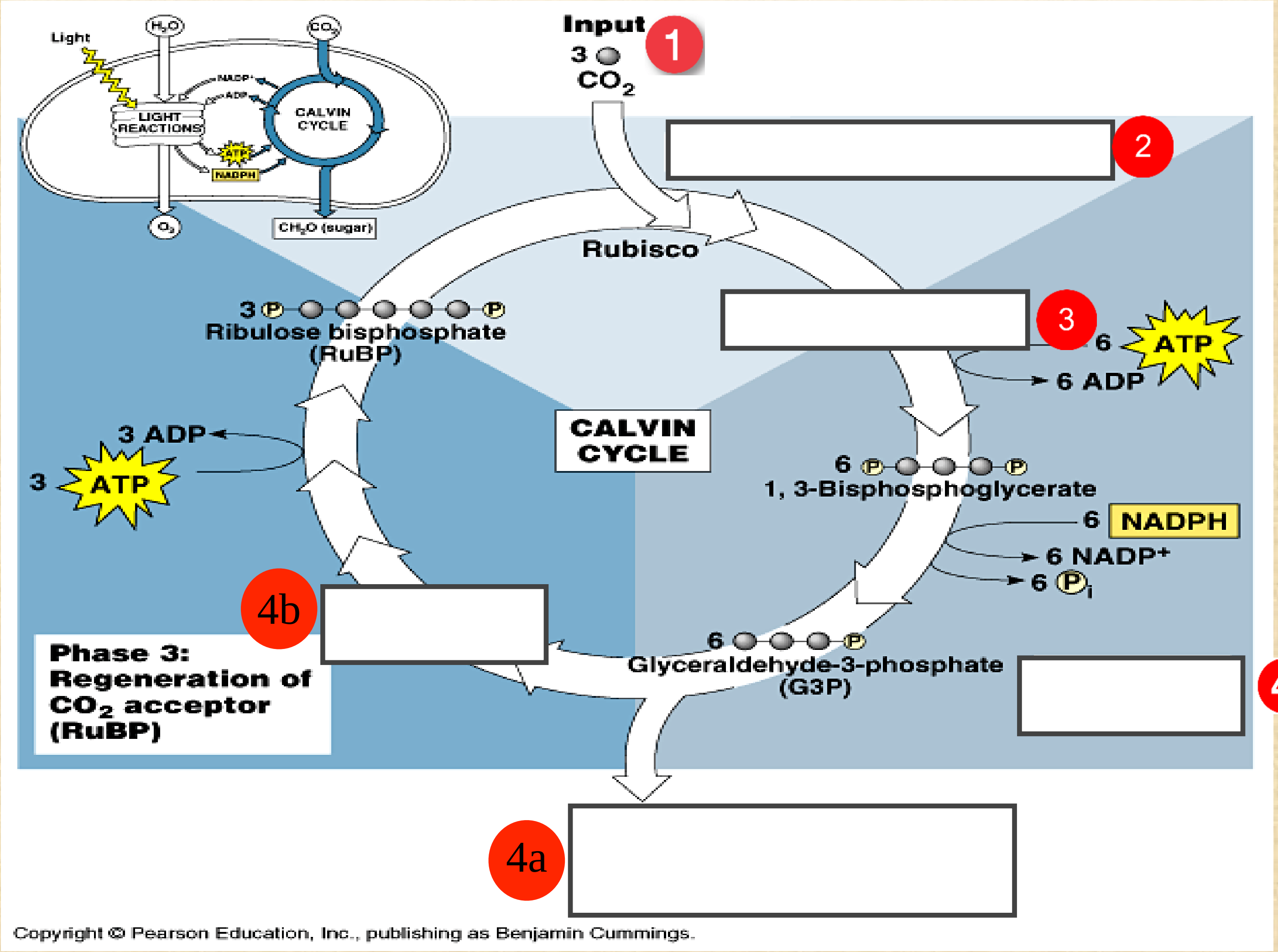


Light
H_2O
CO_2
$NADP^+$
ADP
+ P
Light Reactions
Calvin Cycle
ATP
NADPH
Chloroplast
O_2
Sugar
Input
3 CO_2
Step 1
Carbon fixation
Rubisco
6 P
3-PGA
6 ATP
6 ADP + P
6 NADPH
6 $NADP^+$
3 P P
RuBP
3 ADP
3 ATP
P
Step 4
Regeneration of RuBP
CALVIN CYCLE
5 P
G3P
6 P
G3P
Step 2
Reduction
Step 3
Release of one molecule of G3P
1 P
G3P
Output
Glucose and other compounds

CALVIN CYCLE

- Can occur with or without light.
- Calvin Cycle uses CO_2 + ATP + NADPH to make a 3-Carbon Sugar = G-3-P (glyceraldehyde-3-phosphate)
- A plant cell uses TWO G3Ps to make ONE 6-carbon molecule Glucose.
- Two turns of the Calvin Cycle are required to make one molecule of GLUCOSE (6 Carbons).
- Glucose is used by plants in cellular respiration to make many ATP molecules.

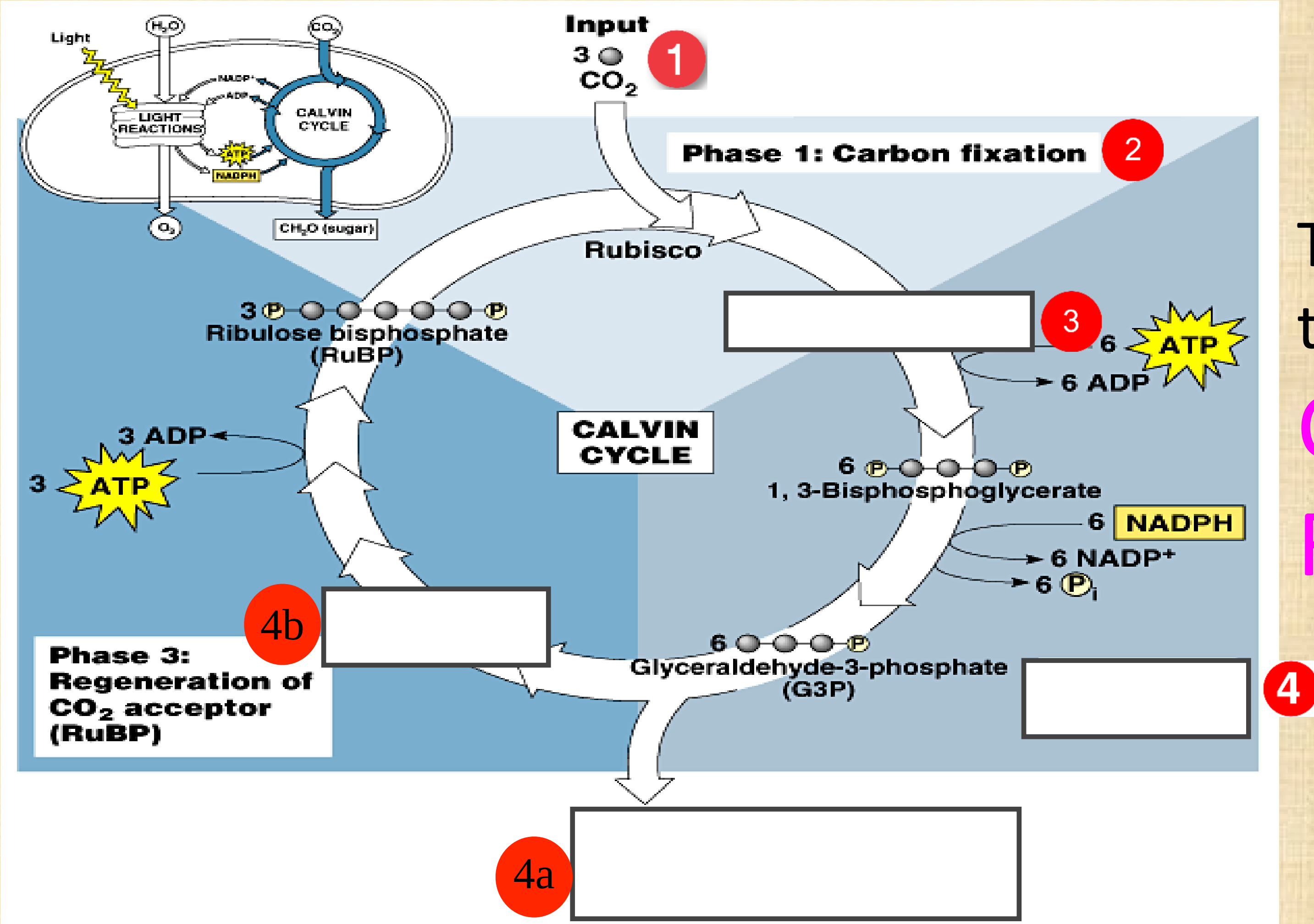
Steps of the Calvin Cycle



Stomata

1 **Carbon dioxide** is obtained from the atmosphere. It enters the leaf through the pores in the leaf called **stomata**.

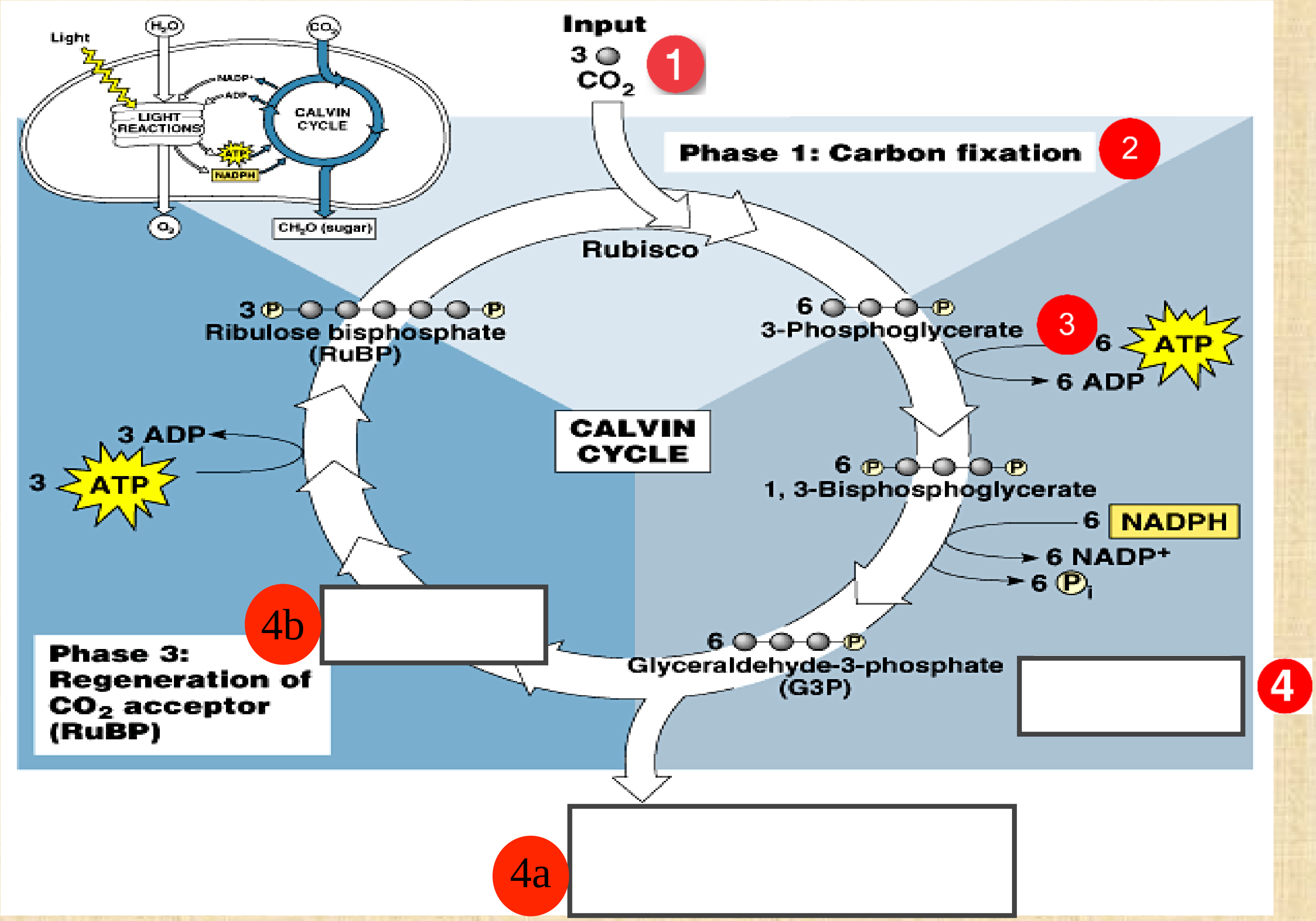
Steps of the Calvin Cycle



This is referred to as **Carbon Fixation**.

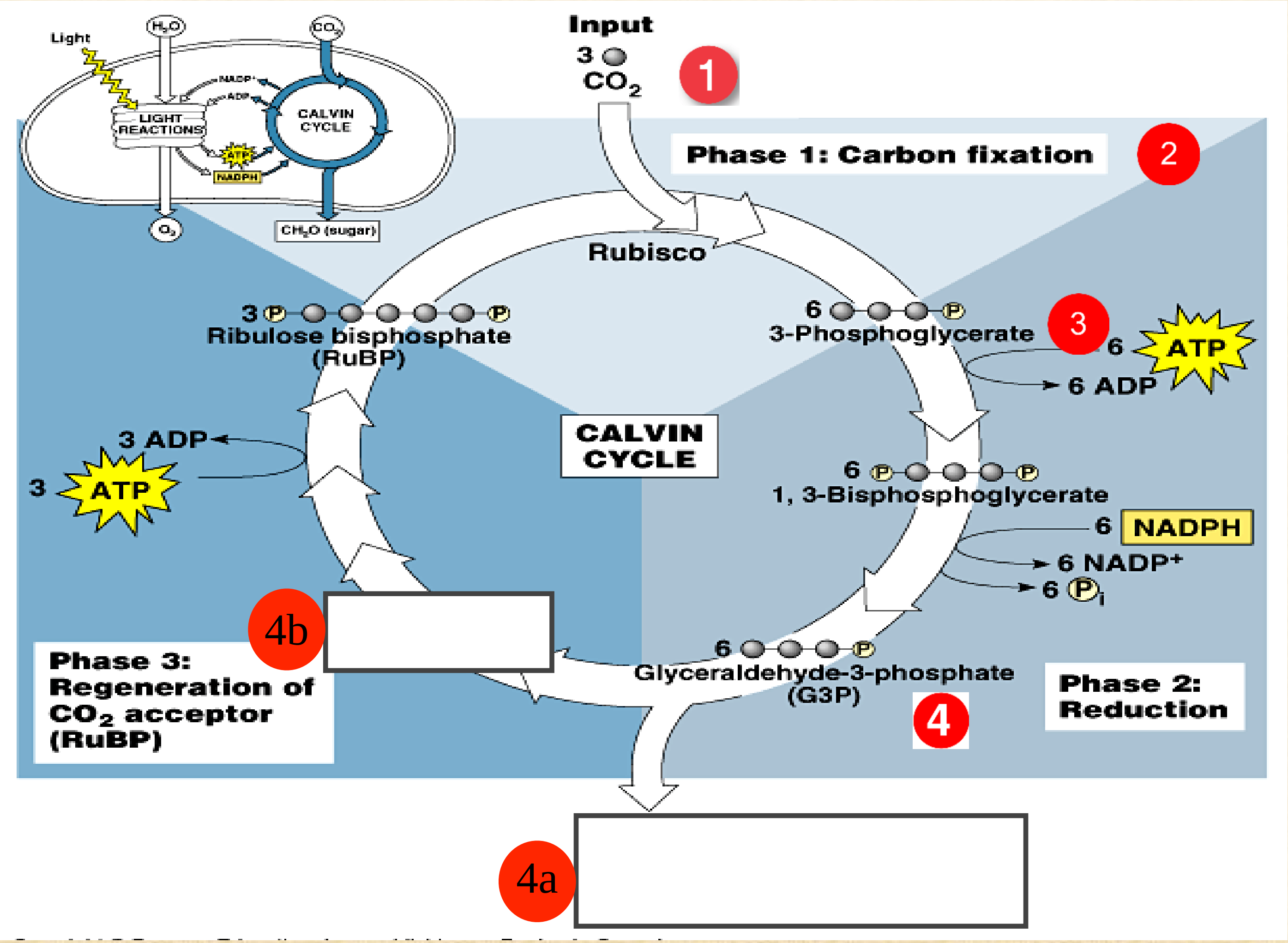
2 The overall Calvin cycle combines the carbon from carbon dioxide with a 5-carbon sugar called RuBP – **Ribulose Biphosphate**.

Steps of the Calvin Cycle



3 This forms a very unstable 6-carbon compound that immediately breaks apart into 2 three carbon molecules.

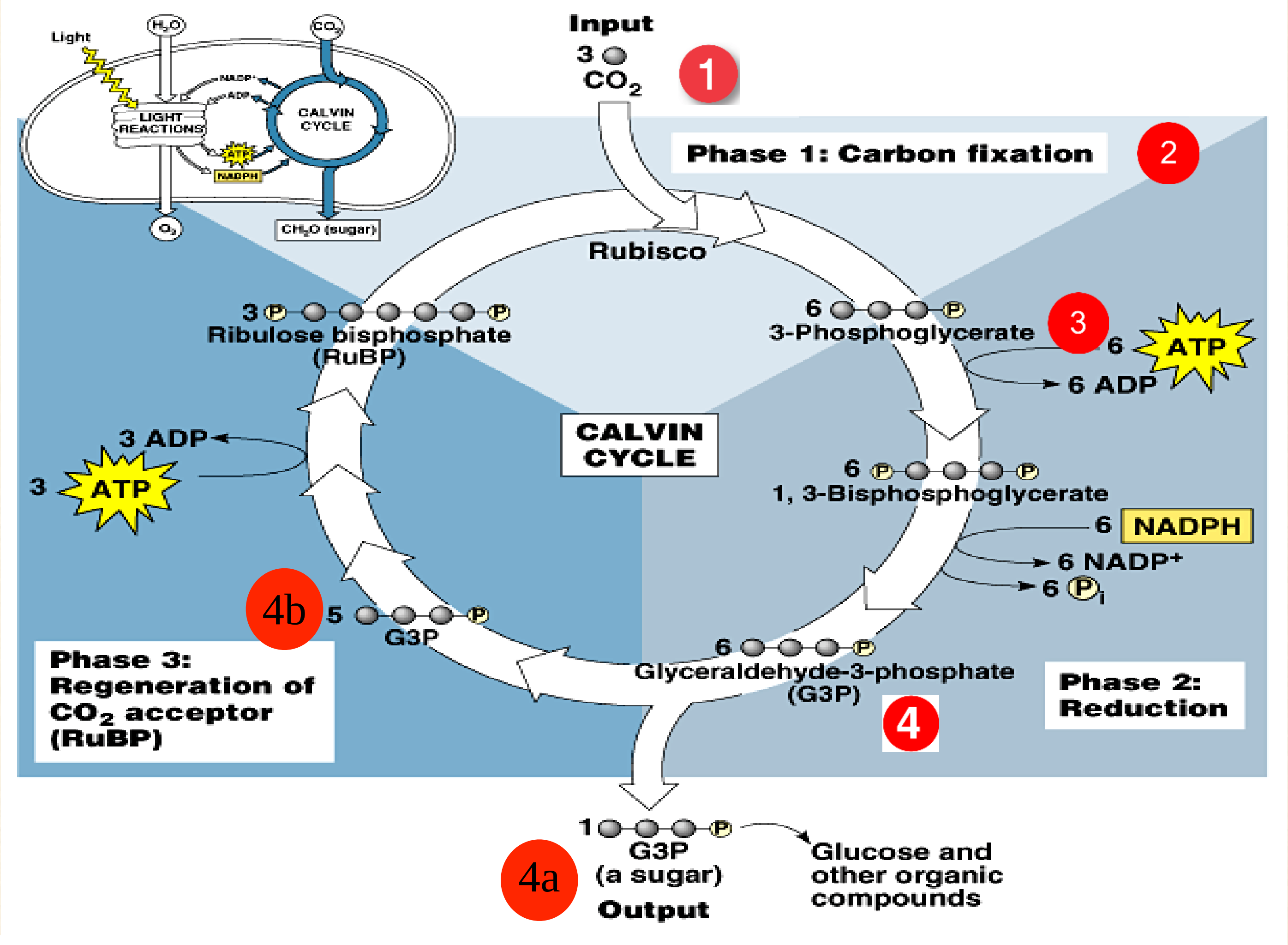
Steps of the Calvin Cycle



4 A series of reactions involving ATP and NADPH converts this molecule into two molecules of G3P, which is a three-carbon compound [REDUCTION].

(Glyceraldehyde-3-phosphate)

Steps of the Calvin Cycle



There are 2 possibilities for **G3P**:

4a **Two molecules of G3P** are combined together to form a molecule of **Glucose**.

4b Some of the **G3P** is converted by a series of reactions into more **RuBP** so that the reaction can occur again.

Dark Reaction

TRY IT

1. Why is it called this?

   - Doesn't depend on light in order to occur

2. Alternative names for the Dark Reaction

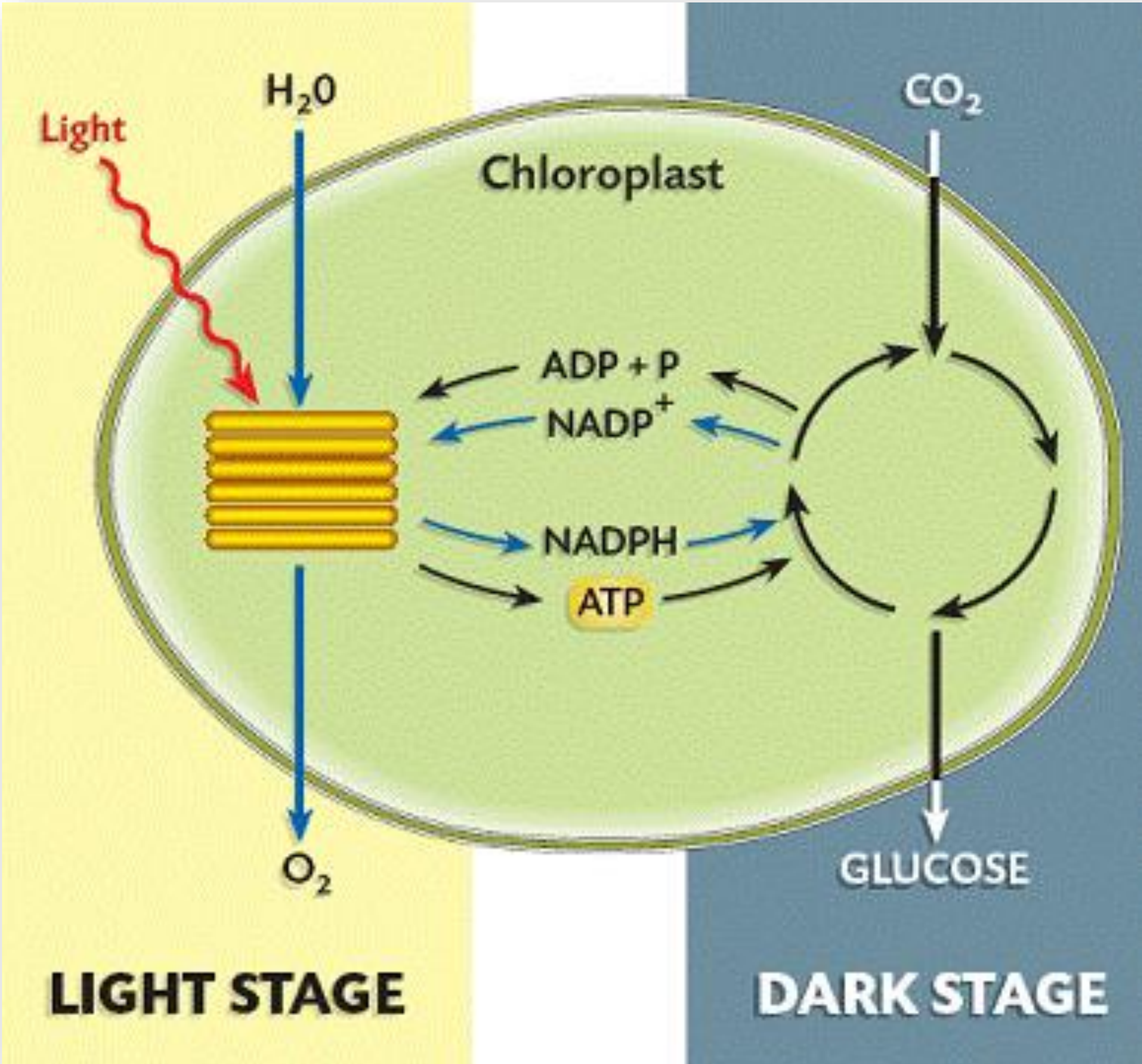
   1. Light Independent Reaction
   2. Carbon Fixation

      - Plants take Carbon Dioxide (inorganic) molecules and convert them into Glucose molecules (organic)

   3. C3 Pathway
   4. Calvin-Benson Cycle

3. Where does it occur?

   - Stroma


H$_2$0
Light
Chloroplast
CO_2
ADP + P
NADP$^+$
NADPH
ATP
O_2
GLUCOSE
LIGHT STAGE
DARK STAGE

Photosynthesis Overview

http://somup.com/c3eOIgTPqI (3:06)

Calvin Cycle of Photosynthesis

Dark Reaction

QUICK CHECK

1. Where does it occur?

   Stroma

2. What is produced?

   Glucose and water

3. What is used?

   Carbon Dioxide

4. What is the energy source?

   ATP

5. What are the by-products?

   ADP and NADP

To Sum It All Up:

Solar Energy has been stored as Chemical Energy in Glucose

Comparing Photosynthesis with Respiration

TRY IT

Event	?	?
Function	Energy capture	Energy release
Reactants	?	?
Products	?	?
Where it takes place	Cells with Chlorophyll	ALL Cells
What happens to glucose	Synthesized	Broken down
What happens to energy	Energy from ? is used; Stored in Glucose	Energy from ? is used; Stored in ATP
Overall reaction	$6CO_2 + 6H_2O ==> C_6H_{12}O_6 + 6O_2$	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy (36 ATP)

Comparing Photosynthesis with Respiration

TRY IT

Event	Photosynthesis	Respiration
Function	Energy capture	Energy release
Reactants	CO_2 + H_2O	Glucose + O_2
Products	Glucose + O_2	CO_2 + H_2O
Where it takes place	Cells with Chlorophyll	ALL Cells
What happens to glucose	Synthesized	Broken down
What happens to energy	Energy from sunlight is used; Stored in Glucose	Energy from glucose is used; Stored in ATP
Overall reaction	$6CO_2 + 6H_2O ==> C_6H_{12}O_6 + 6O_2$	$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + Energy (36 ATP)