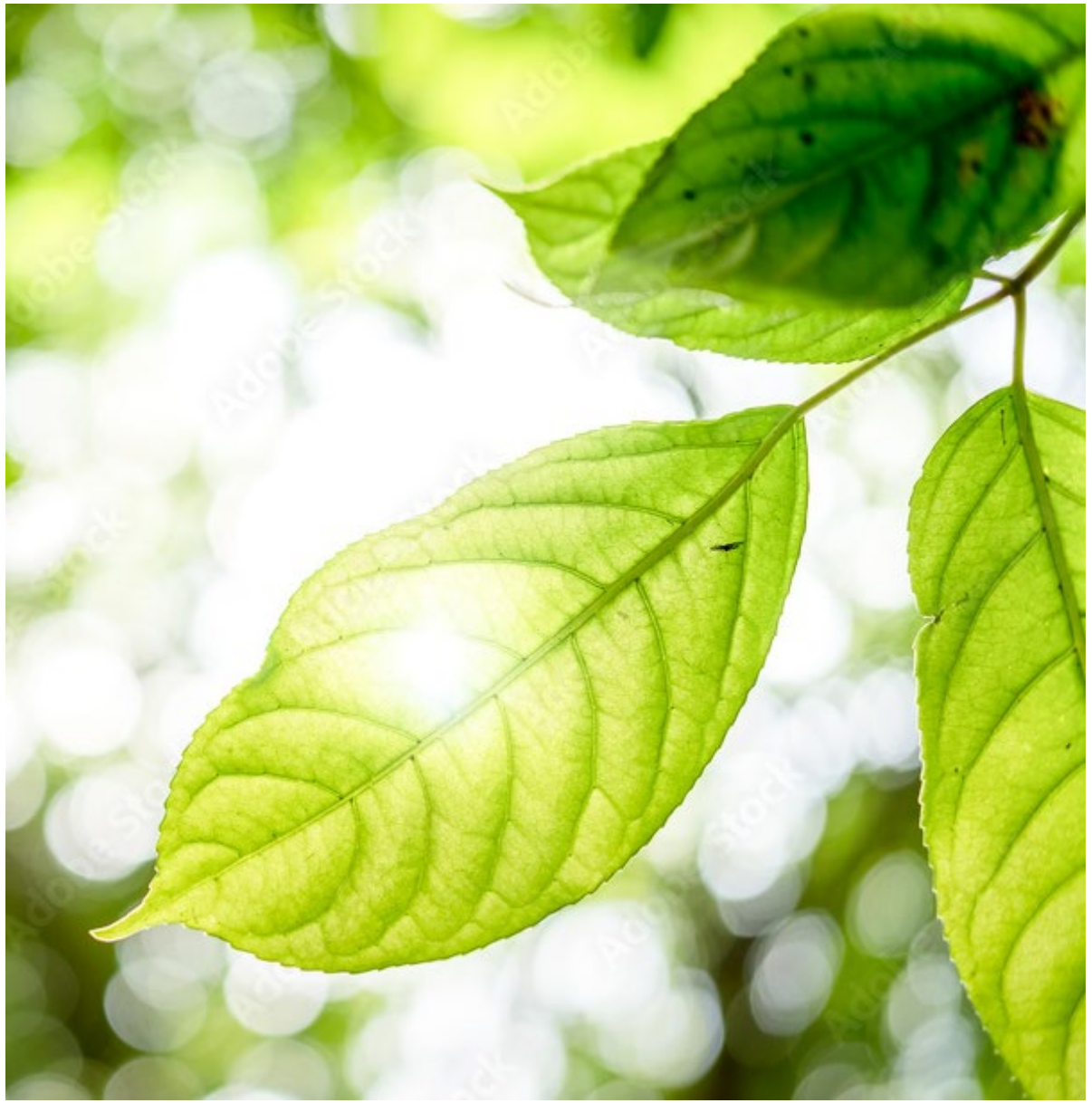
Lesson 5:
Green Energy

BIOL 1441

Cell & Molecular Biology



Learning Objectives (a.k.a. Study Guide)

By the end of this lesson, students will be able to:

1. Explain how autotrophs & heterotrophs obtain their energy.
2. Write the overall chemical equation for photosynthesis.
3. Identify which reaction words (anabolic / catabolic, endergonic / exergonic) accurately describe photosynthesis.
4. Identify the source of energy for photosynthesis.
5. Name the locations of the light reactions & the Calvin Cycle in a plant cell.
6. Describe the general functions of the light reactions & the Calvin Cycle in photosynthesis.
7. Explain how the wavelength of light relates to its color & energy level.
8. Explain why plants are green.
9. Name the structures that are found in a photosystem.
10. Explain how photosystems trap light energy.

Learning Objectives (a.k.a. Study Guide)

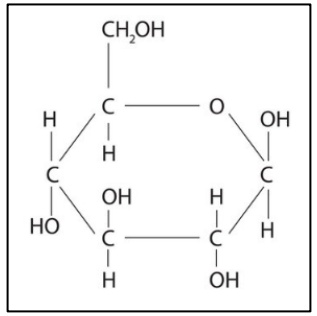
By the end of this lesson, students will be able to:

11. Identify the source of the excited electrons found in Photosystem II & Photosystem I.
12. Explain how the light reactions of photosynthesis generate oxygen.
13. Describe how the proton (H^+) gradient across the thylakoid membrane is generated.
14. Explain how the H^+ gradient is used to generate ATP.
15. List the products & reactants of the light reactions.
16. Explain the relationship between the *products* of photosynthesis' light reactions & the *reactants* of the Calvin cycle.
17. Explain what happens in carbon fixation.
18. Name the enzyme that performs carbon fixation.
19. Explain why 6 turns of the cycle is necessary to make 1 glucose.
20. Explain how photosynthesis & cellular respiration are related to one another.

Where does glucose come from?

Organisms need high energy molecules, such as glucose, to provide energy to make ATP.

GLUCOSE!

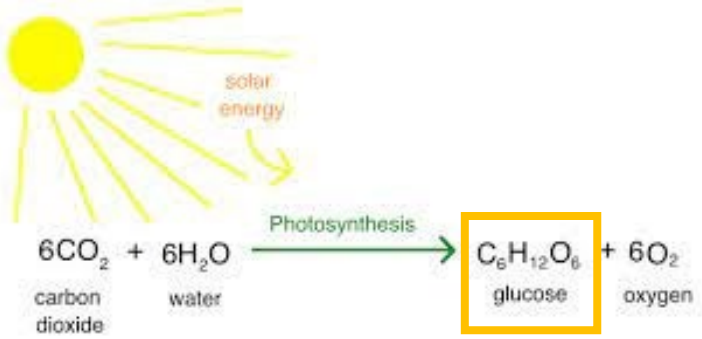


Many organisms (humans included) cannot make their own glucose. It must be consumed as food.

The donut contains glucose and other macromolecules.

Some organisms, called autotrophs, can make their own glucose. Plants are autotrophs that use light energy to make glucose from CO_2 and H_2O.

Sunlight is the ultimate source of energy by which almost all organisms on Earth obtain the energy they need.



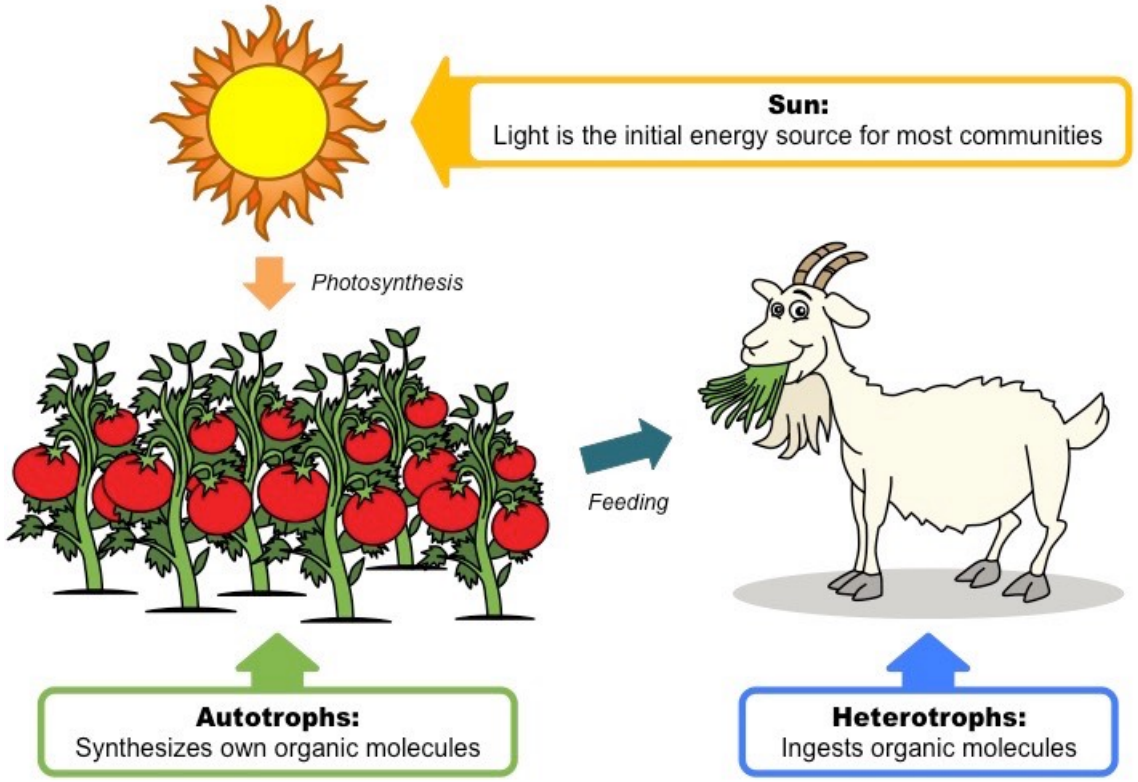
What's Your Source?

Autotrophs ("self feeders") are organisms that CAN build their own energy-rich macromolecules

- **Photo**autotrophs (like plants) use the energy of light to do this
- **Chemo**autotrophs (like some bacteria) use the energy of inorganic molecules (like sulfur or ammonia)

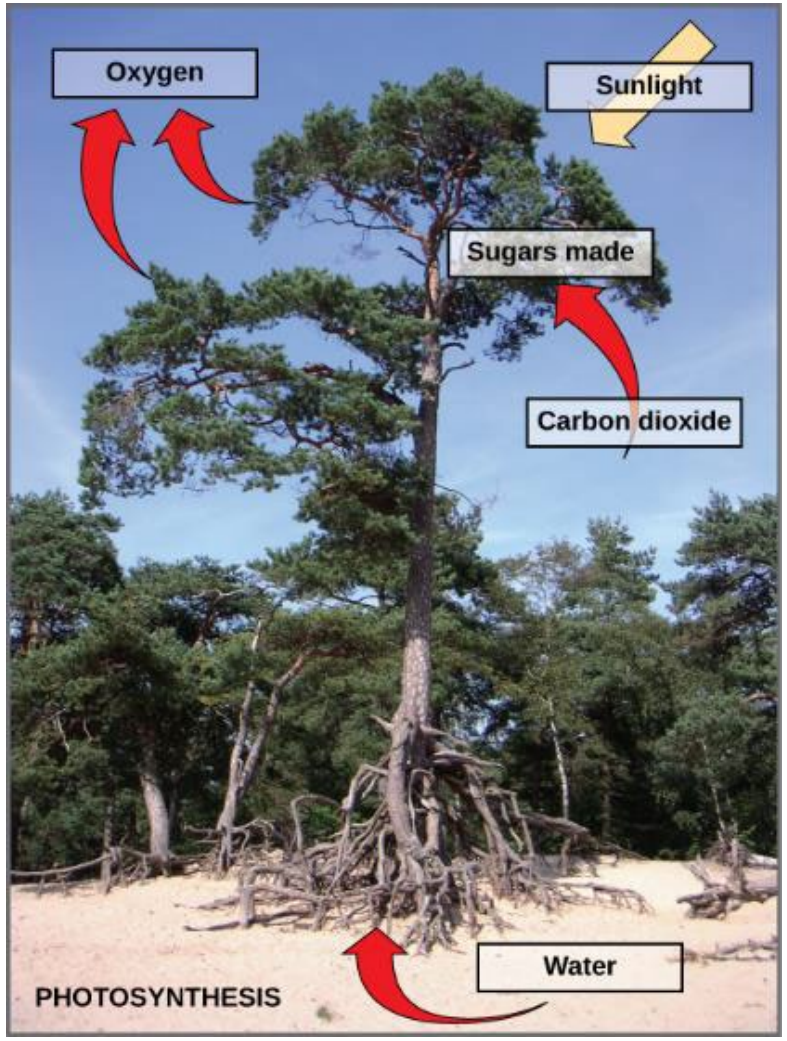
Because humans CANNOT make these molecules themselves, we are considered **heterotrophs** ("other feeders")

- Animals, fungi, and most bacteria are also heterotrophs



Photosynthesis

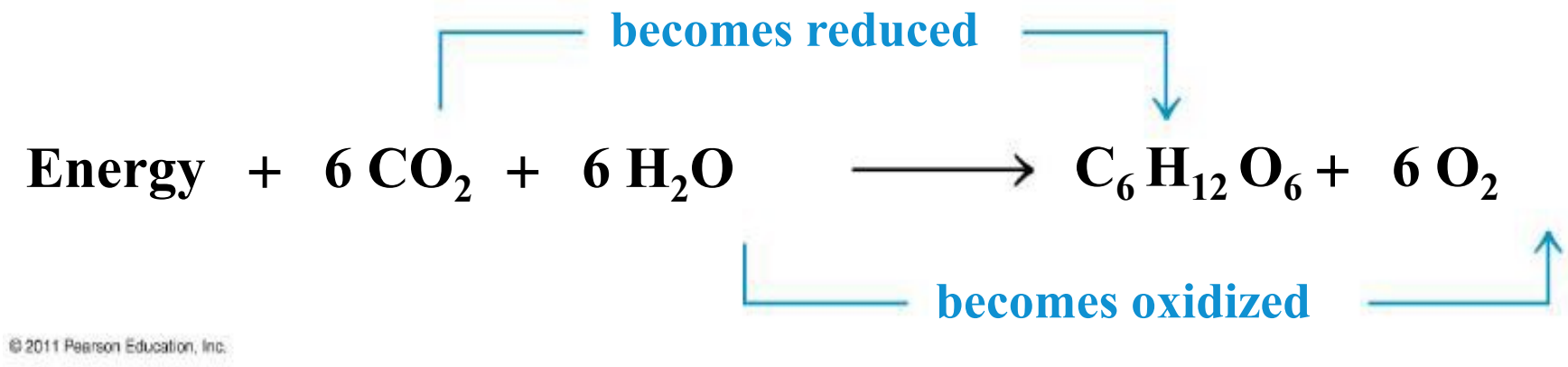
Photosynthesis Equation						
Carbon dioxide	+	Water	SUNLIGHT →	Sugar	+	Oxygen
$6CO_2$		$6H_2O$		$C_6H_{12}O_6$		$6O_2$



Photosynthesis is the process used by plants to transform light energy (and carbon dioxide and water) into glucose

- Based on its equation, is photosynthesis endergonic or exergonic?
- Based on this equation, is photosynthesis catabolic or anabolic?

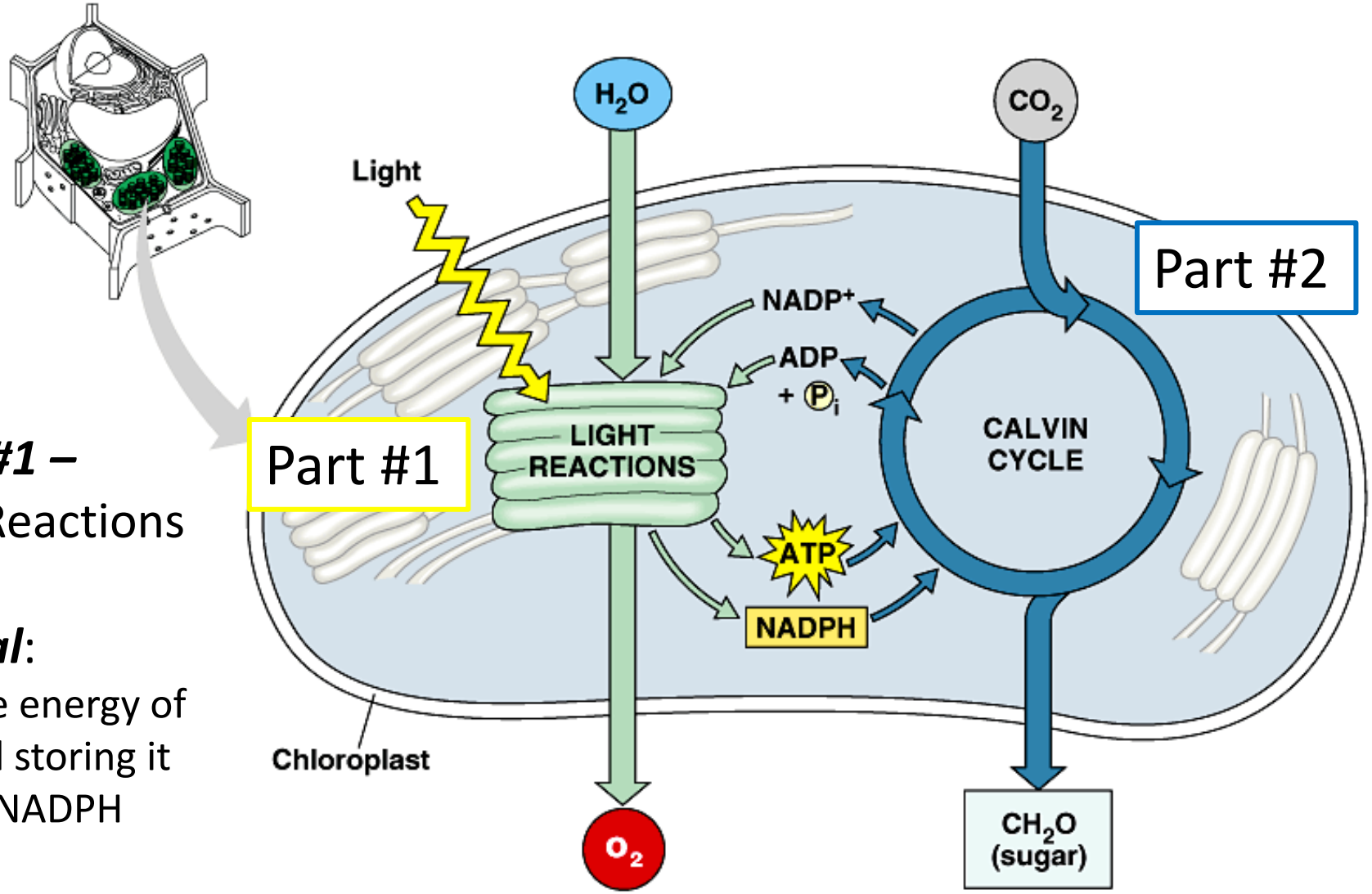
Photosynthesis is also an example of a **redox reaction**.



What does it mean that CO_2 is <u>reduced</u>?

What does it mean that H_2O is <u>oxidized</u>?

The Process of Photosynthesis



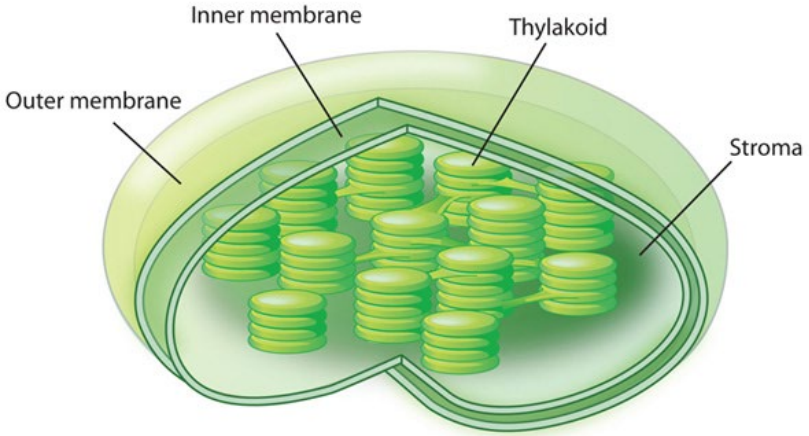
Part #1 –
The Light Reactions

Goal:
capturing the energy of sunlight and storing it in ATP & NADPH

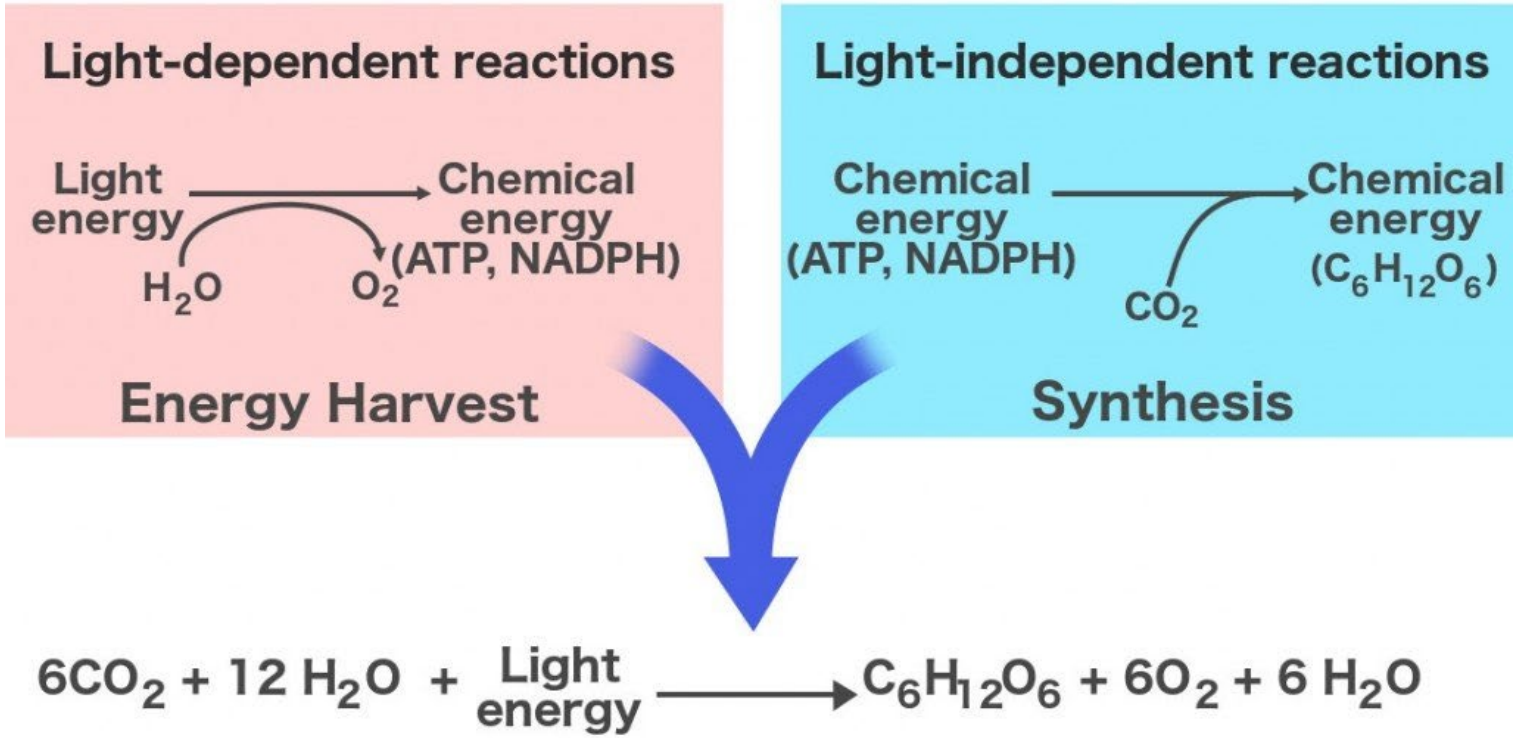
Part #2 –
The Calvin Cycle

Goal:
building sugar using the energy of ATP & NADPH

The light-dependent reactions occur in photosystems that are embedded in the **thylakoid membranes** of the chloroplasts.



The Calvin Cycle (a.k.a. light-independent reactions) occur in the **stroma** of chloroplasts.



Photosynthesis

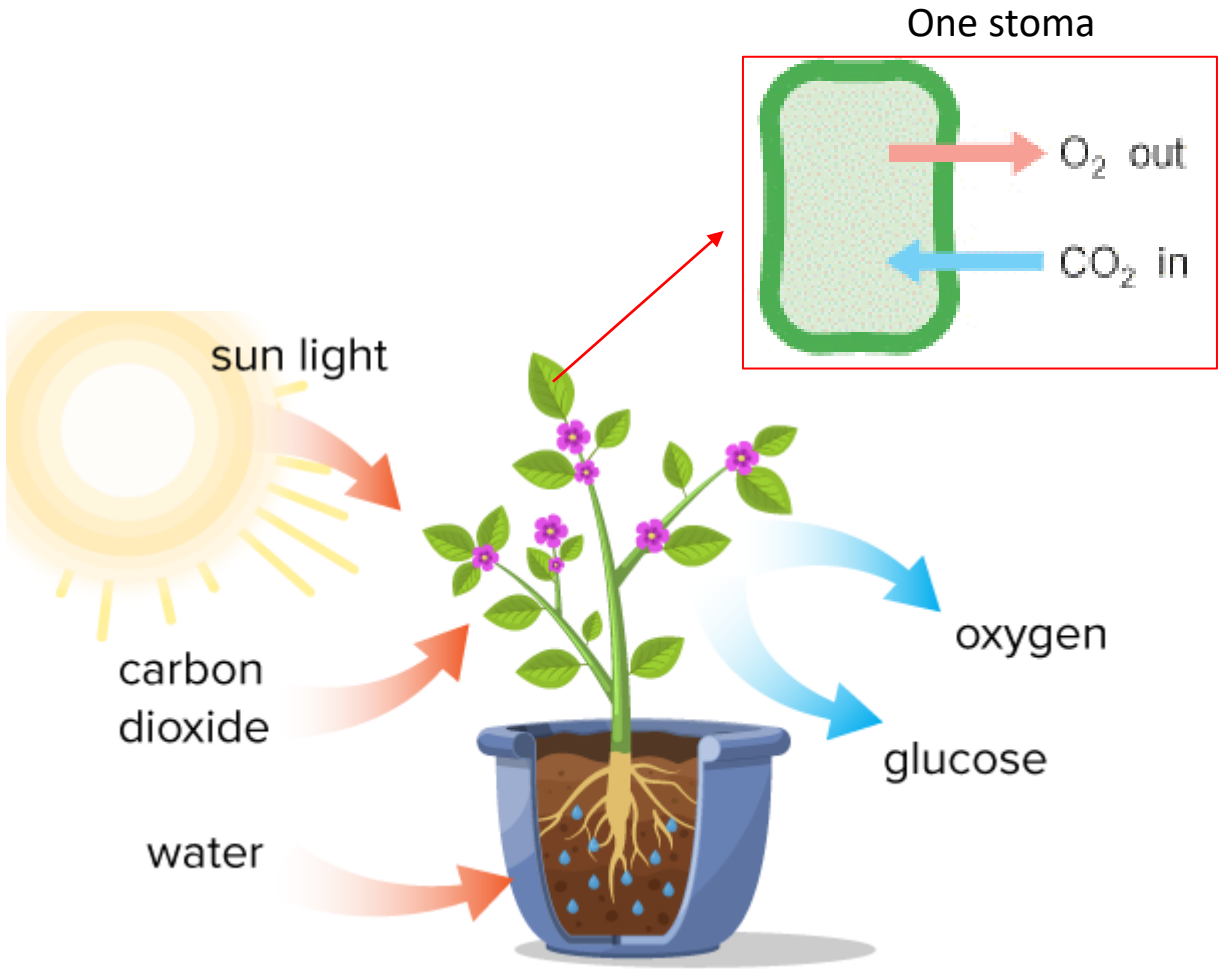
Starting Materials

- CO_2, absorbed through **stomata** (a.k.a. holes) in a plant's leaves
- H_2O, absorbed through the plant's roots
- Sunlight, absorbed by the pigments in the leaves

Ending Materials

- Glucose ($C_6H_{12}O_6$), stored as cellulose & starch
- O_2, released as a waste product

If photosynthesis did NOT occur, there would NOT be any oxygen in the earth's atmosphere!



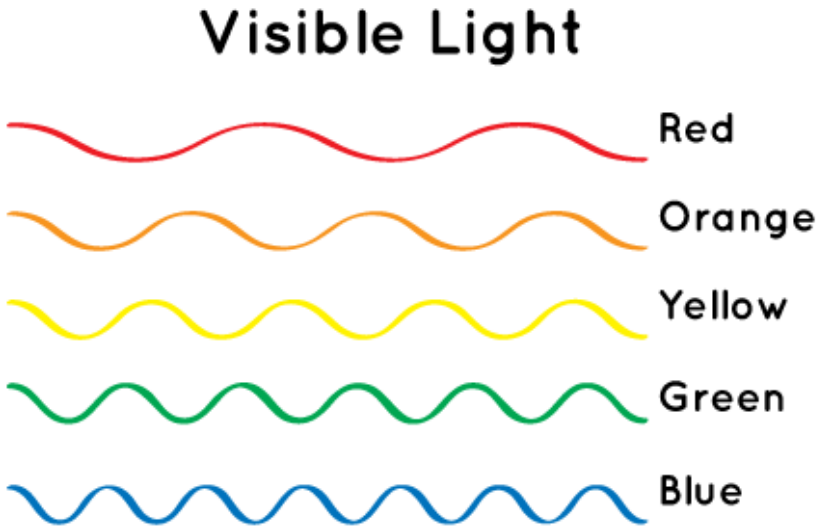
The Energy of Light

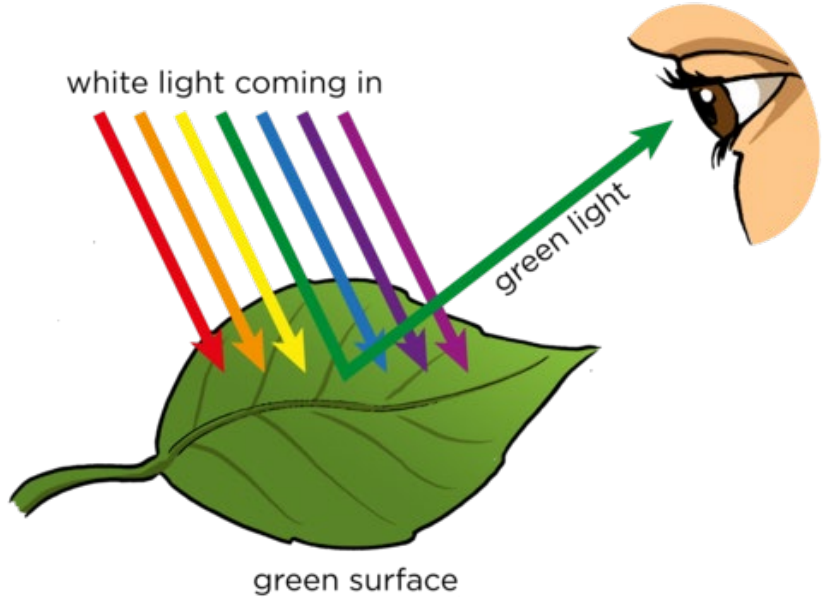
The light reactions of photosynthesis convert light energy into energy stored in chemical bonds

Light energy is made of photons that travel in waves

- Light with *shorter* wavelengths (like blue & purple) has more energy
- Light with *longer* wavelengths (like red) has less energy

The color of an object (like a leaf) is determined by which wavelengths of light are *reflected* off its surface



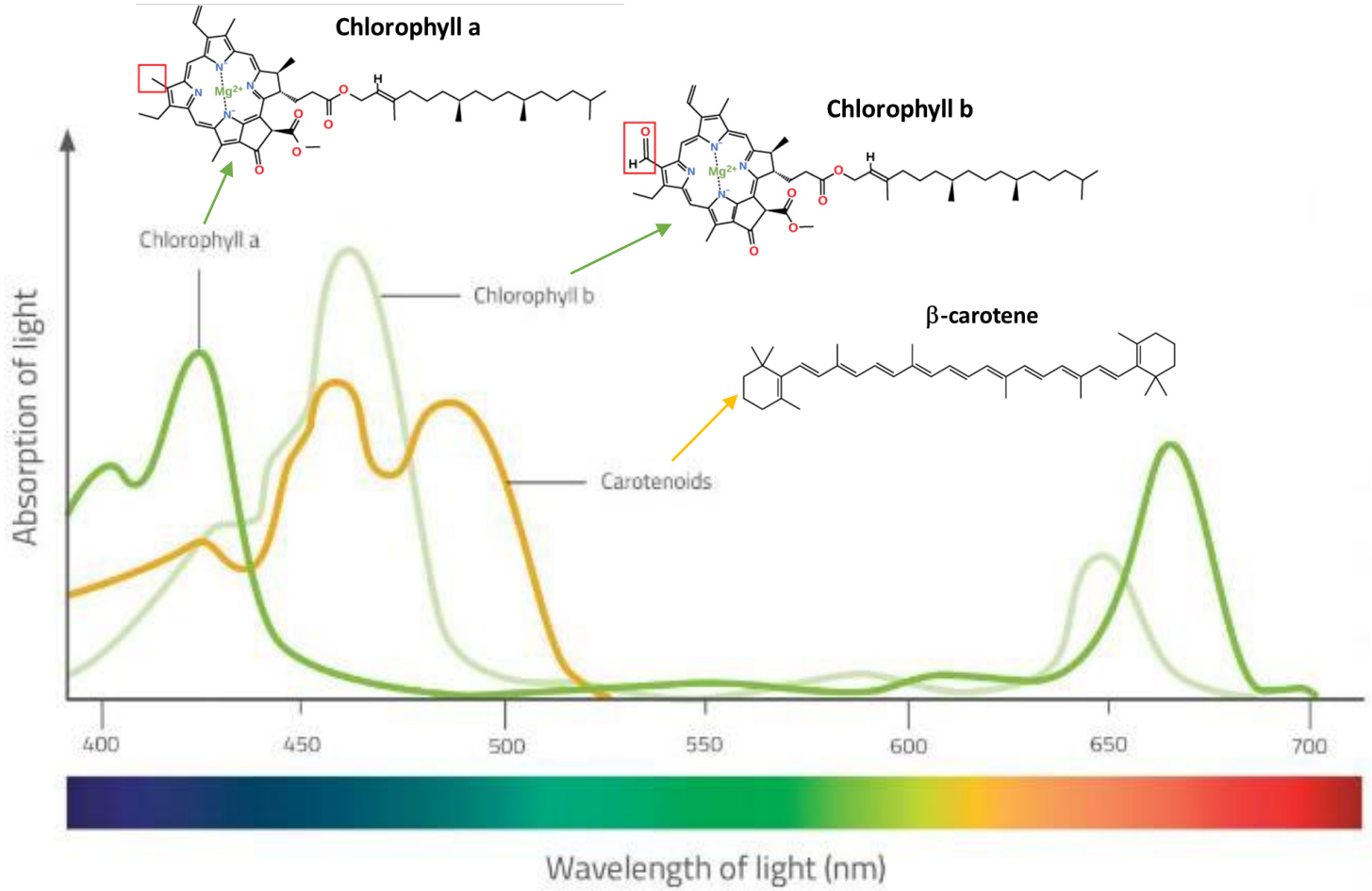


Photosynthetic Pigments

To capture as much light as possible, plants use multiple pigment proteins that each absorb different wavelengths of light

Chlorophyll a is the primary pigment protein in plants

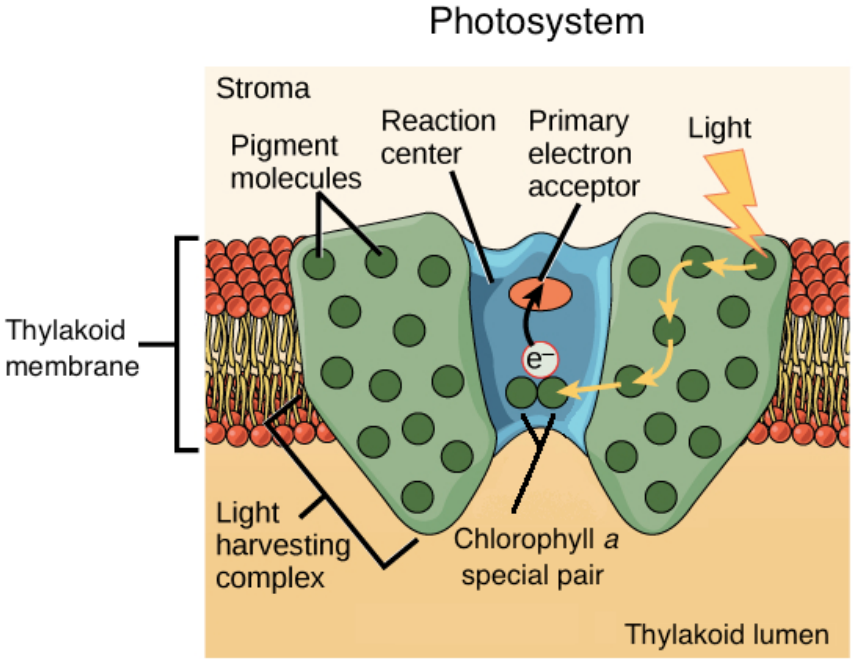
Accessory pigments (like Chlorophyll b & β-carotene) absorb light & transfer that energy to Chlorophyll a



Photosystems

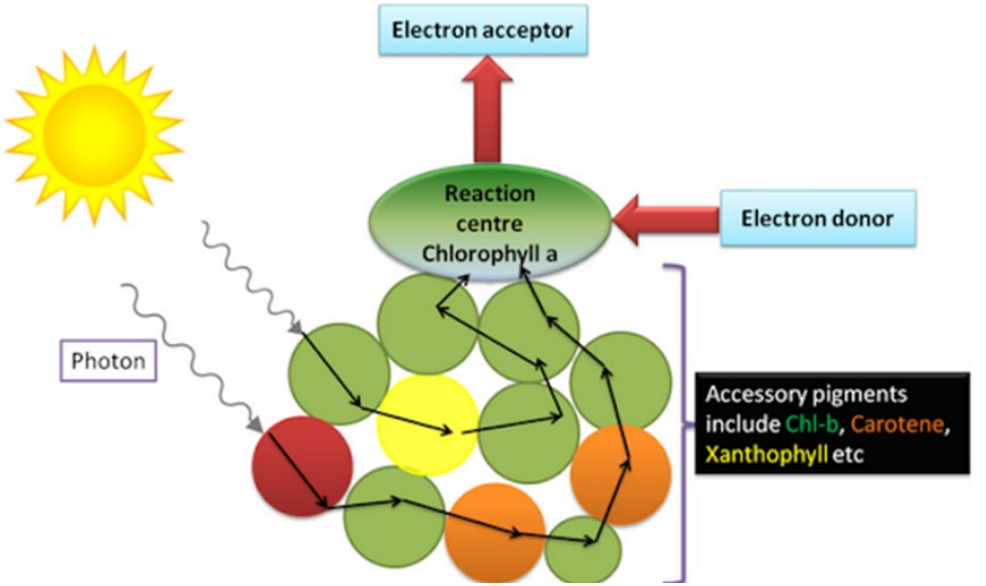
Inside a chloroplast, the photosynthetic pigments group together in **photosystems**

- Photosystems are found in the thylakoid membranes
- Each photosystem has a central reaction center with a Chlorophyll a molecule & a pair of special electrons



During the light reactions, all pigments in the photosystem collect light energy

- This energy is funneled toward the reaction center
- Ultimately, it energizes Chlorophyll a's special electrons
- These energized special electrons then travel through Electron Transport Chain proteins and are ultimately donated to NAD^+

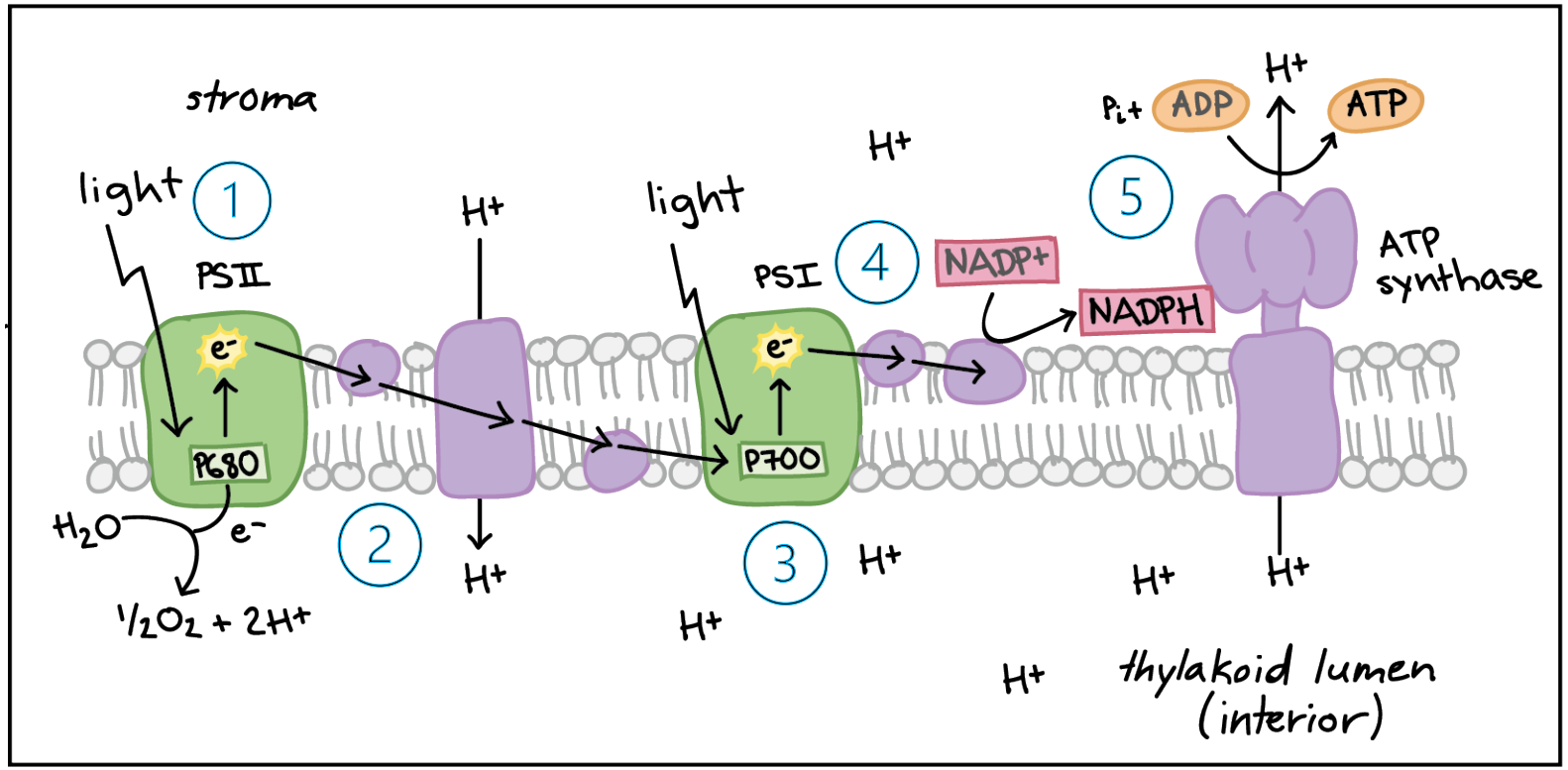


The Light Reactions

1

Light energy entering Photosystem II (PSII) is funneled to the reaction center, energizing the electrons there.

Electron carriers then shuttle these electrons through an Electron Transport Chain.



4

When light energy is absorbed by PSI, these electrons are energized again, and are used to reduce $NADP^+$ to NADPH.

5

ATP Synthase uses the energy of H^+ moving back across the thylakoid membrane to generate ATP (through chemiosmosis).

2

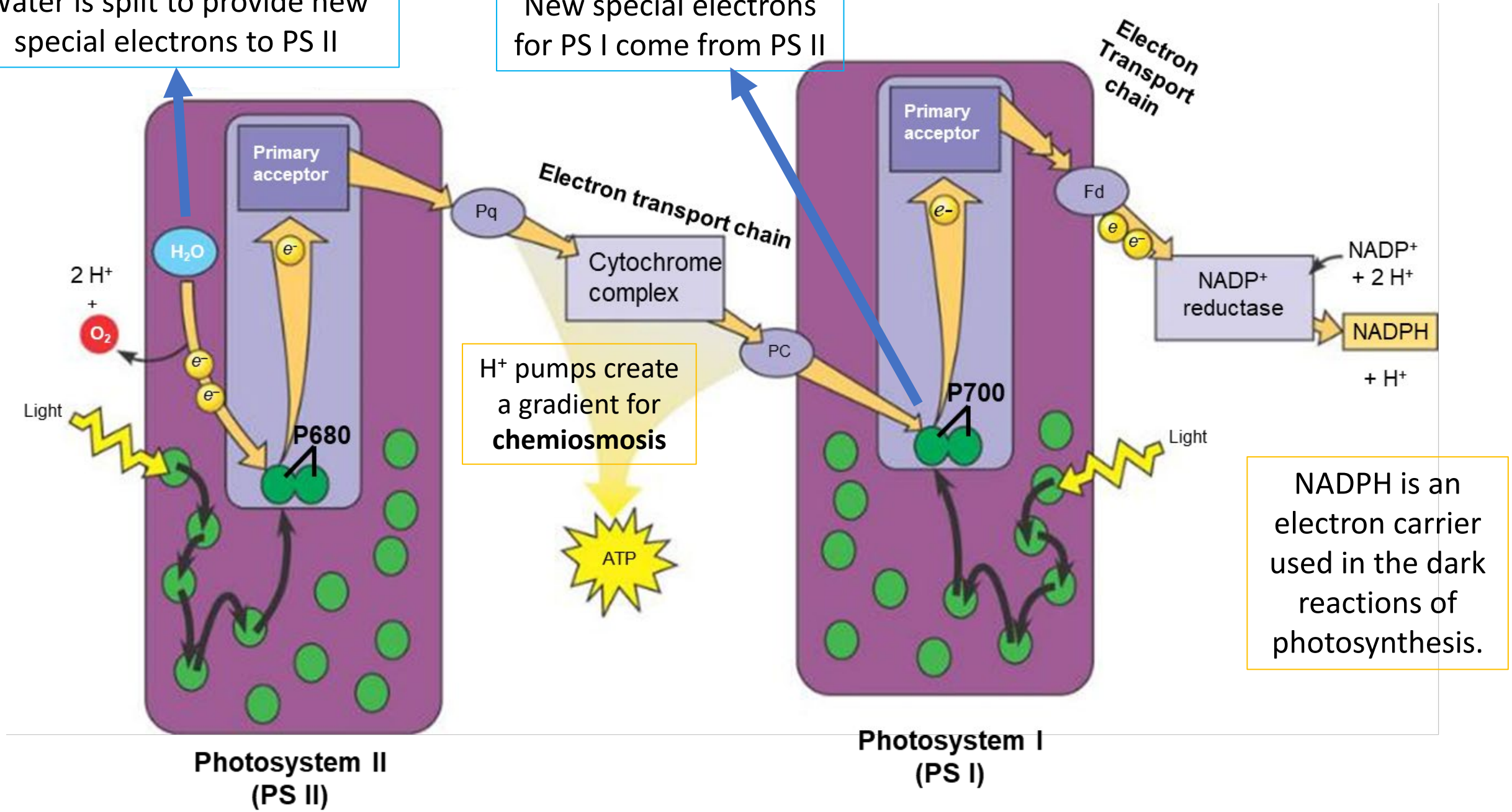
As the electrons move through the chain, their energy helps pump H^+ into the lumen of the thylakoids.

3

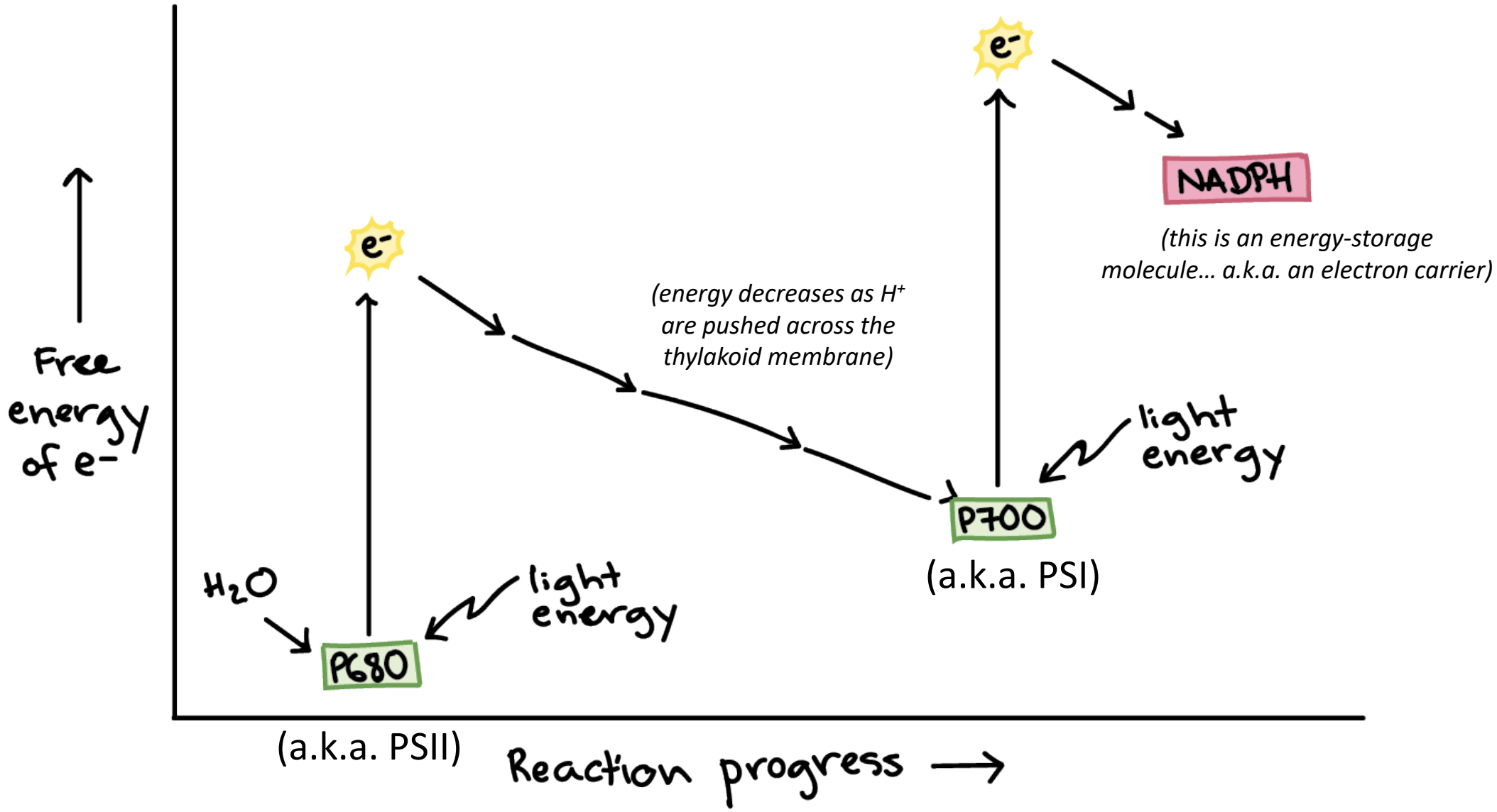
When the electrons reach the end of the ETC they are transferred to Photosystem I (PSI).

Water is split to provide new special electrons to PS II

New special electrons for PS I come from PS II



NADPH is an electron carrier used in the dark reactions of photosynthesis.


Free energy of e⁻
e⁻
(energy decreases as H⁺ are pushed across the thylakoid membrane)
e⁻
NADPH
(this is an energy-storage molecule… a.k.a. an electron carrier)
light energy
P700
(a.k.a. PSI)
H₂O
light energy
P680
(a.k.a. PSII)
Reaction progress

Light Reactions: A Summary

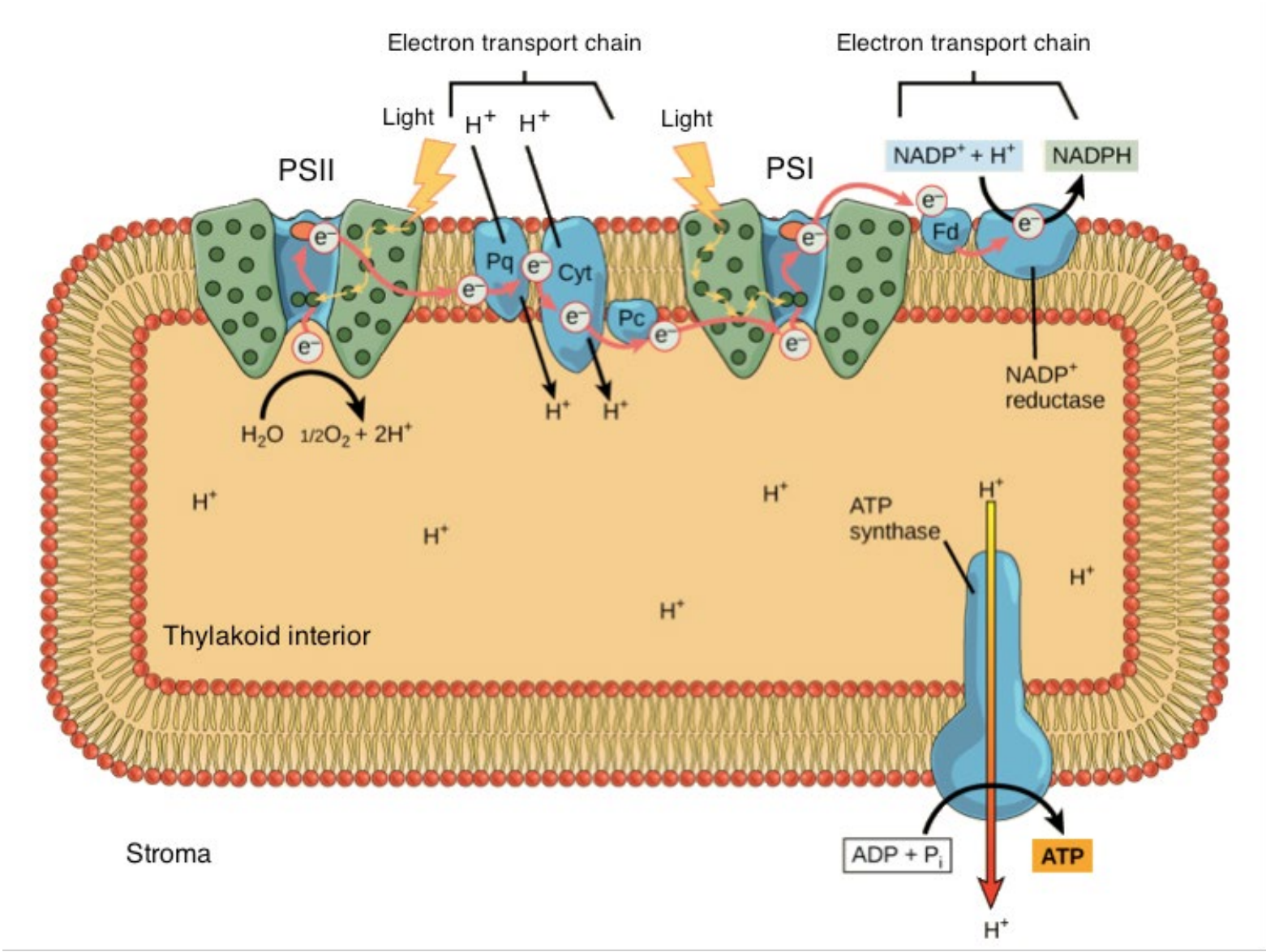
Inputs

Sunlight

H_2O

$NADP^+$

$ADP + P_i$



Outputs

O_2

NADPH

ATP

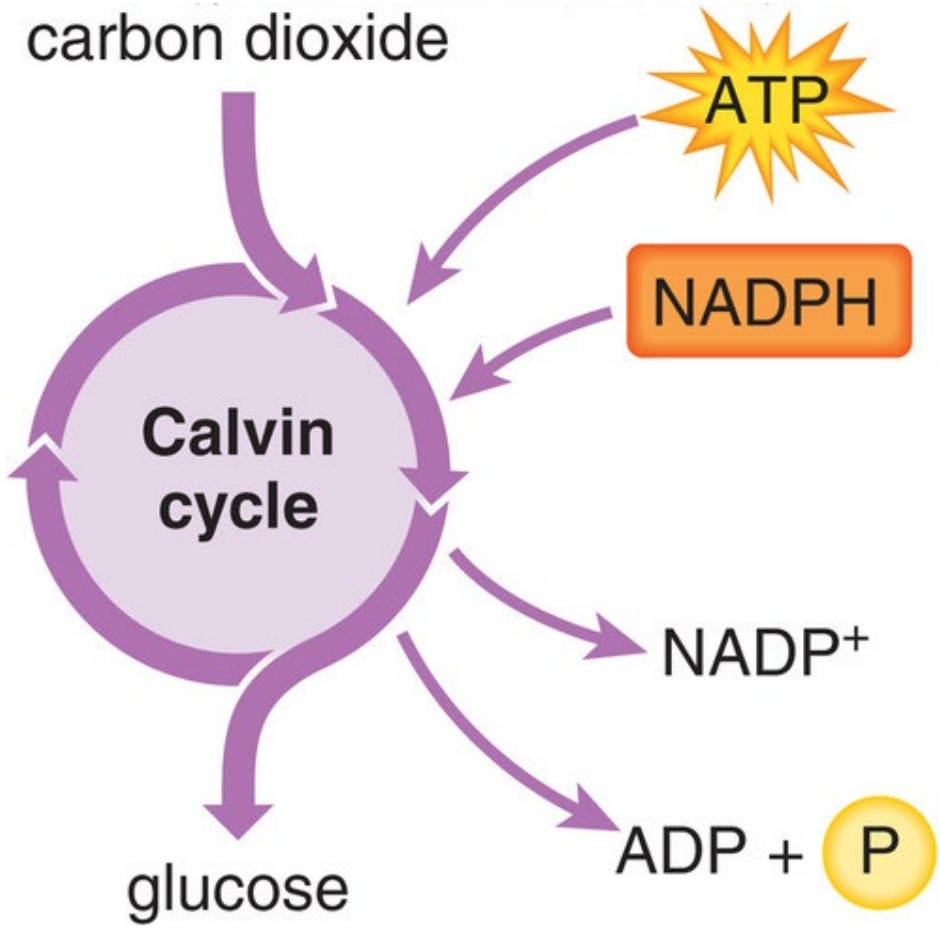
The Calvin Cycle

The goal of the Calvin Cycle is to perform **carbon fixation**

- Definition: attaching carbon atoms to other molecules to generate organic macromolecules

Overview of the Calvin Cycle

- Carbon dioxide (CO_2), with 1 carbon, goes into the cycle
- It is attached to a 5-carbon compound (RuBP)
- The new compound is split into 2 G3P (glyceraldehyde-3-phosphate) molecules, each with 3 carbons
- Combining 2 G3P molecules builds 1 glucose, with 6 carbons



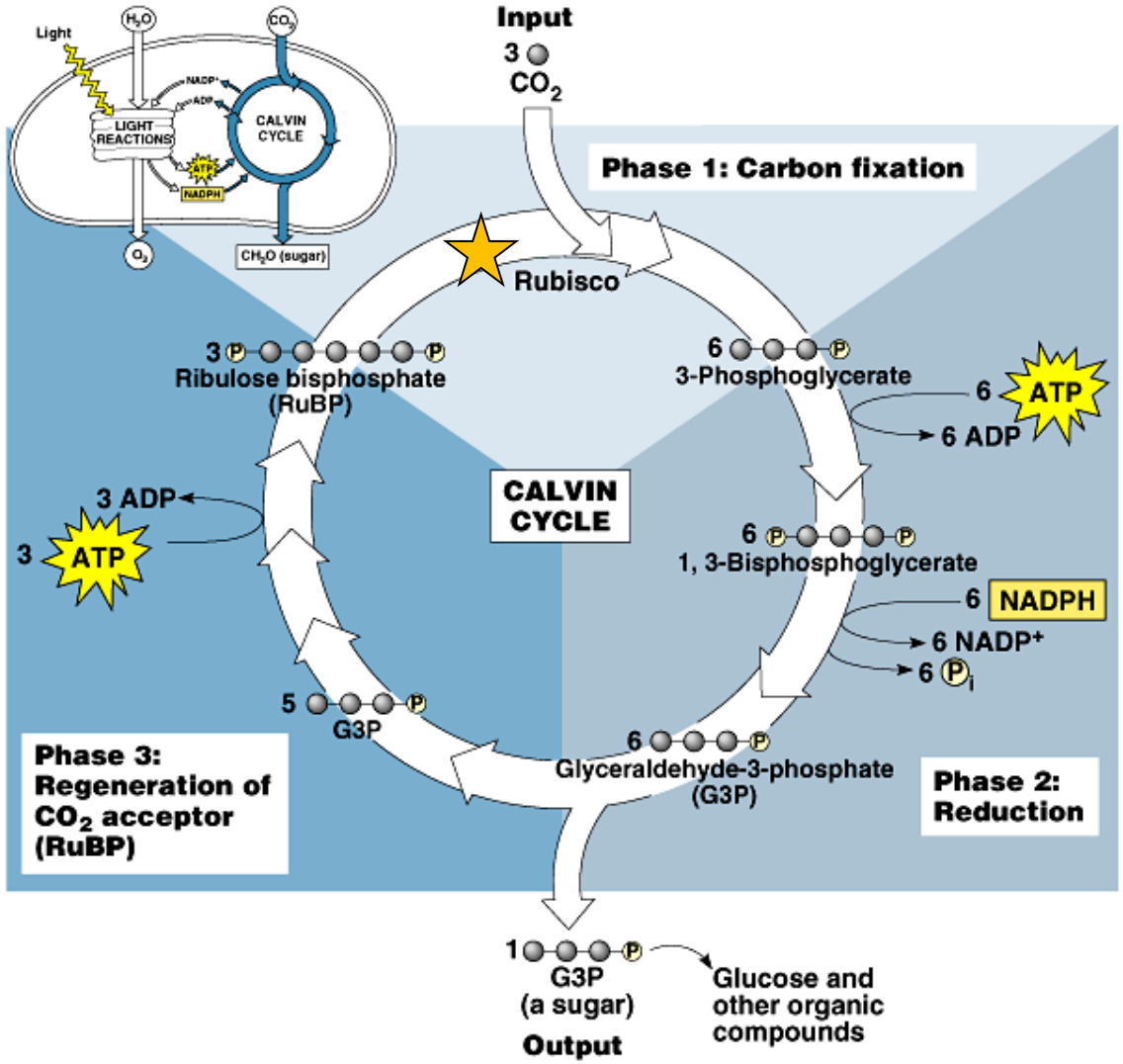
The Calvin Cycle

The process of carbon fixation is done by the enzyme **Rubisco**

Each time all the steps of the Calvin cycle are completed, only **ONE** carbon is fixed

This means:

- The Calvin Cycle must run 3 times to generate one new molecule of G3P
- The Calvin Cycle must run 6 times to generate one new molecule of glucose



Photosynthesis: A Review

What is the function of Rubisco?

What is the function of G3P?

What is the function of Photosystem II?

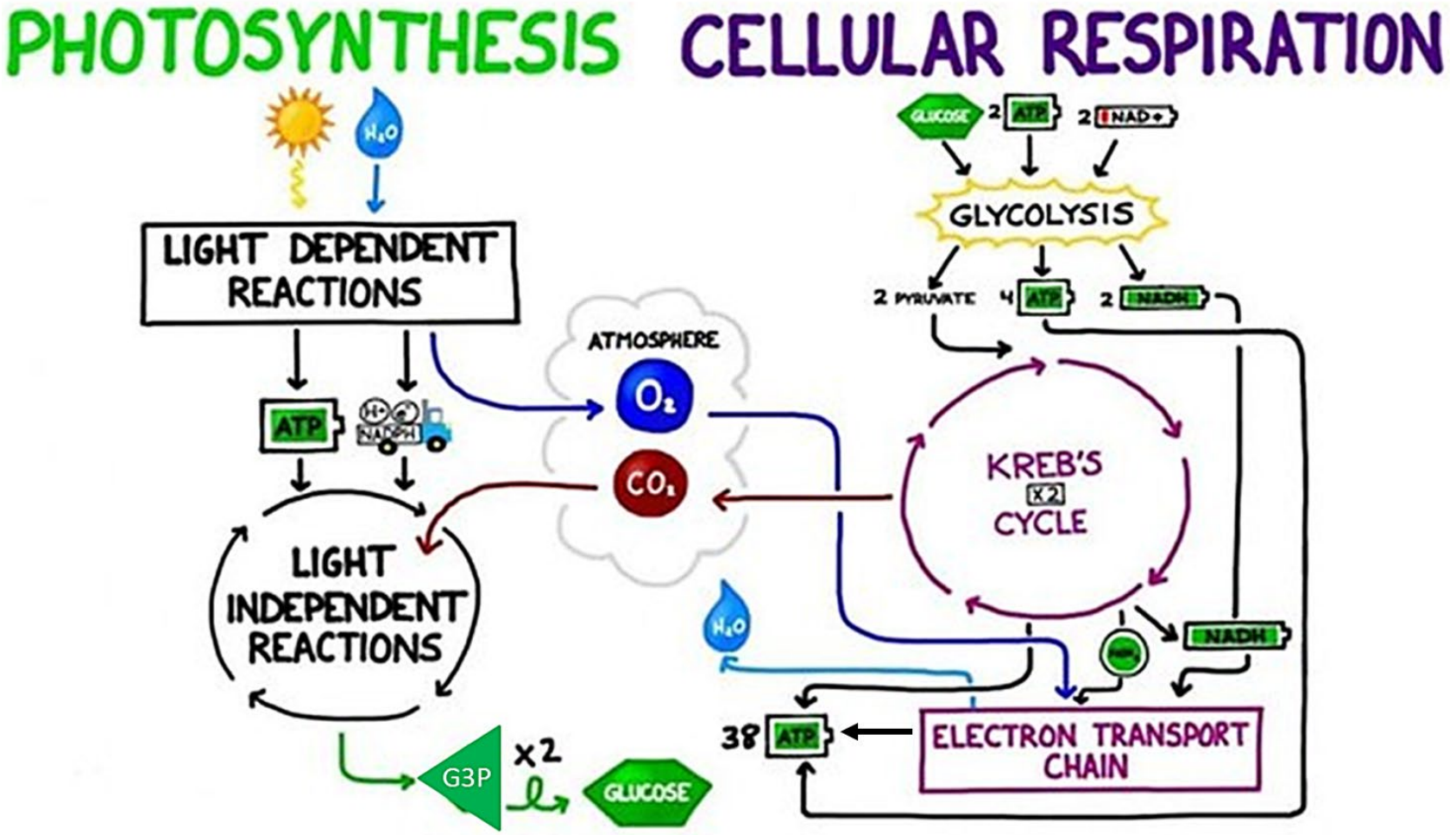
What is the function of Photosystem I?

What is the function of NADPH?

What is the function of ATP Synthase?

	Location	Starts with:	Ends with:
Light reactions			
The Calvin Cycle			

Bringing it Back to You…



The **glucose** in your donut (& the **oxygen** you used to fully **metabolize** it) were made through **photosynthesis**.

To Prepare for Exam #2…

- ❑ Complete the Lesson #5 Homework Assignment
  - This covers all the content from Lesson #5
  - Use the eTextbook & Other Helpful Resources to supplement your lecture notes
  - **Remember**: you can complete this assignment as many times as you need until you earn full credit!

- ❑ Review your notes & assignments for Lesson #4… this will also be on the exam!

- ❑ Make sure Respondus LockDown Browser is fully updated on your laptop… you'll need it for the Practice Exam & Exam #2!