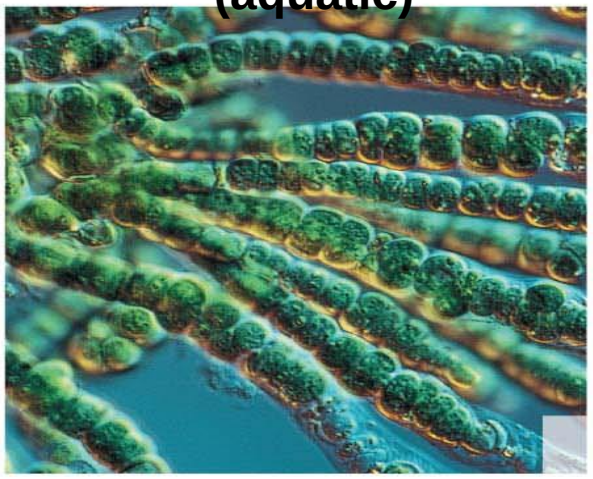
Chapter 7

Photosynthesis

THE BASICS OF PHOTOSYNTHESIS

- Almost all plants are photosynthetic autotrophs, as are some bacteria and protists
  - Autotrophs generate their own organic matter through photosynthesis
  - Sunlight energy is transformed to energy stored in the form of chemical bonds

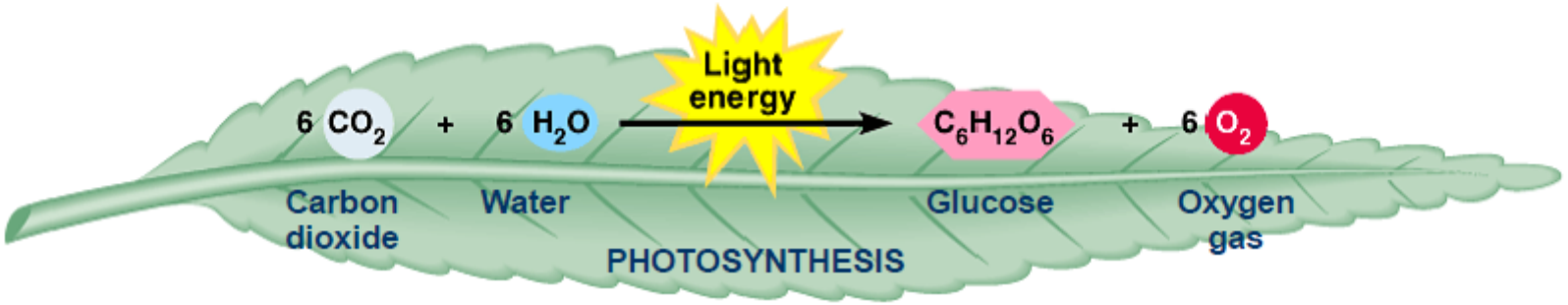
PHOTOSYNTHETIC AUTOTROPHS		
Plants (mostly on land)	**Photosynthetic Protists (aquatic)**	**Photosynthetic Bacteria (aquatic)**
		
Forest plants	Kelp, a large, multicellular alga	Micrograph of cyanobacteria

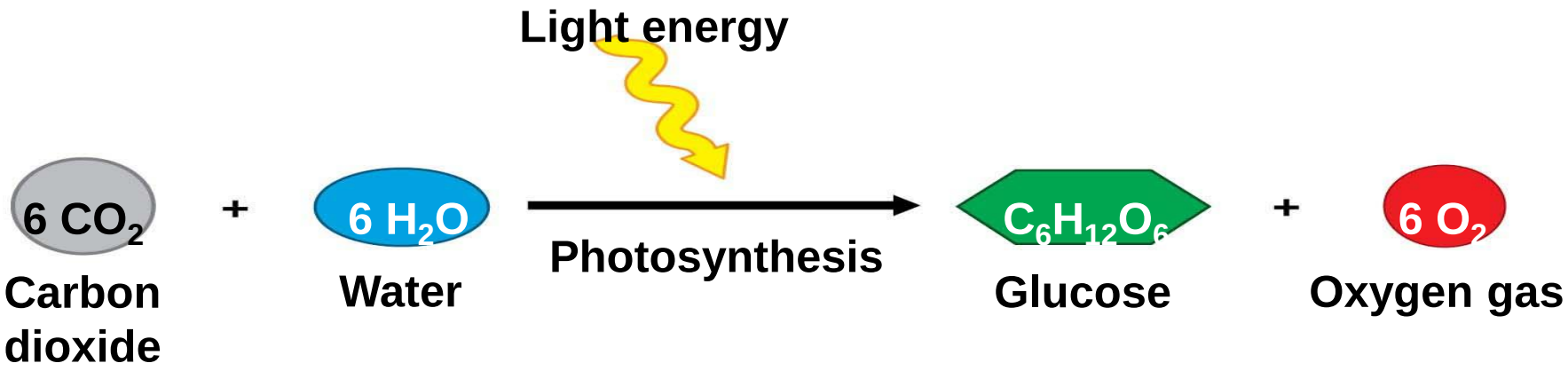
Why is Photosynthesis important?

- Makes organic molecules (glucose) out of inorganic materials (carbon dioxide and water).
- It begins all food chains/webs. Thus all life is supported by this process.
- It also makes oxygen gas!!

AN OVERVIEW OF PHOTOSYNTHESIS

- Photosynthesis is the process by which autotrophic organisms use light energy to make sugar and oxygen gas from carbon dioxide and water





- **During photosynthesis**
  - Organisms use the energy of light to build high-energy organic molecules.
  - Plants, algae and some bacteria can do this.
    - Can make their own food using light
    - Called photosynthetic autotrophs
- **99.9% of all life on earth relies on photosynthesis for their energy.**
  - Heterotrophs eat autotrophs.

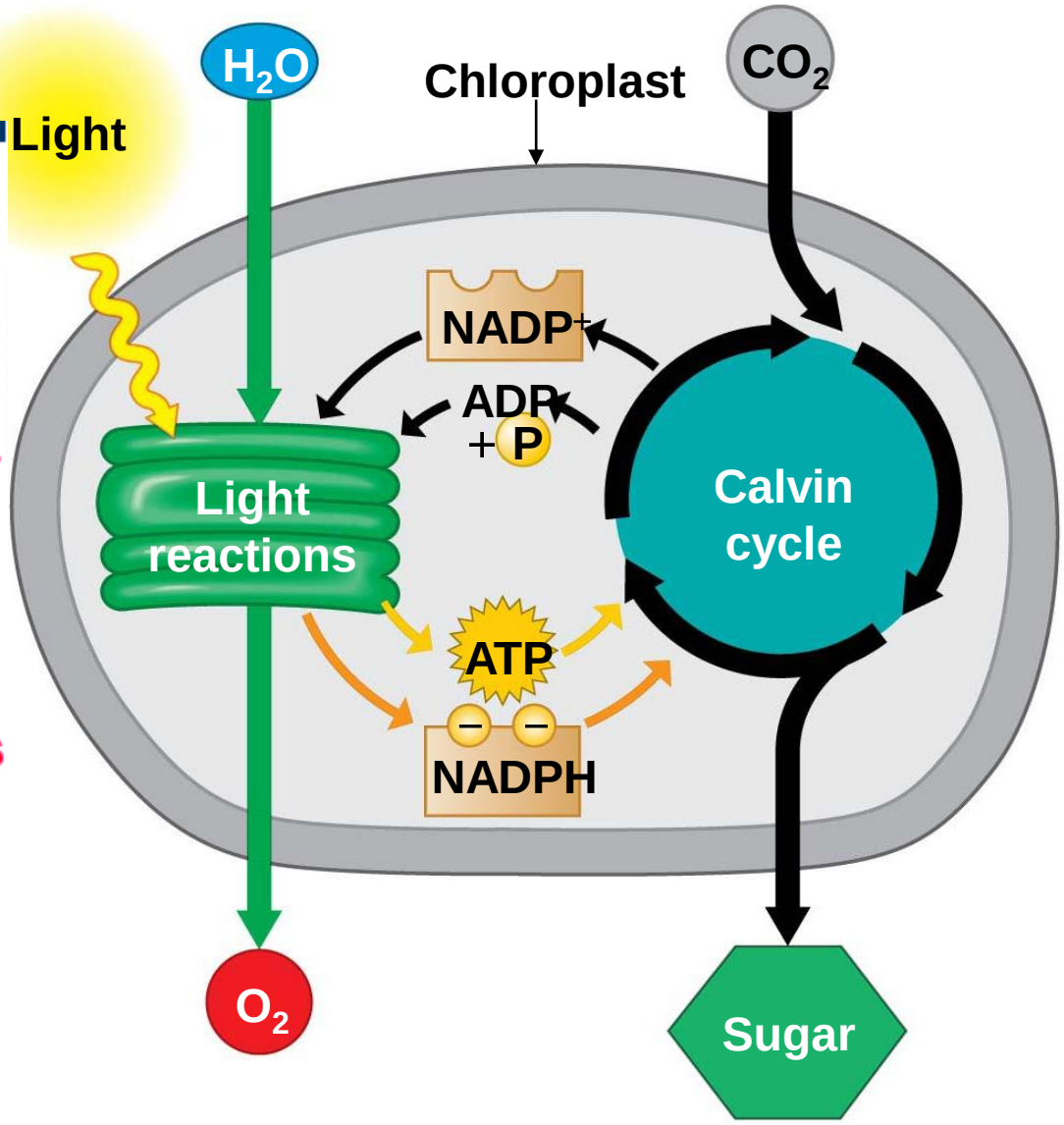
An Overview of Photosynthesis

The light reactions convert solar energy to chemical energy

- Produce ATP & NADPH

The Calvin cycle makes sugar from carbon dioxide

- ATP generated by the light reactions provides the energy for sugar synthesis
- The NADPH produced by the light reactions provides the electrons for the reduction of carbon dioxide to glucose



Chloroplasts are solar-powered sugar factories

Journey into a leaf

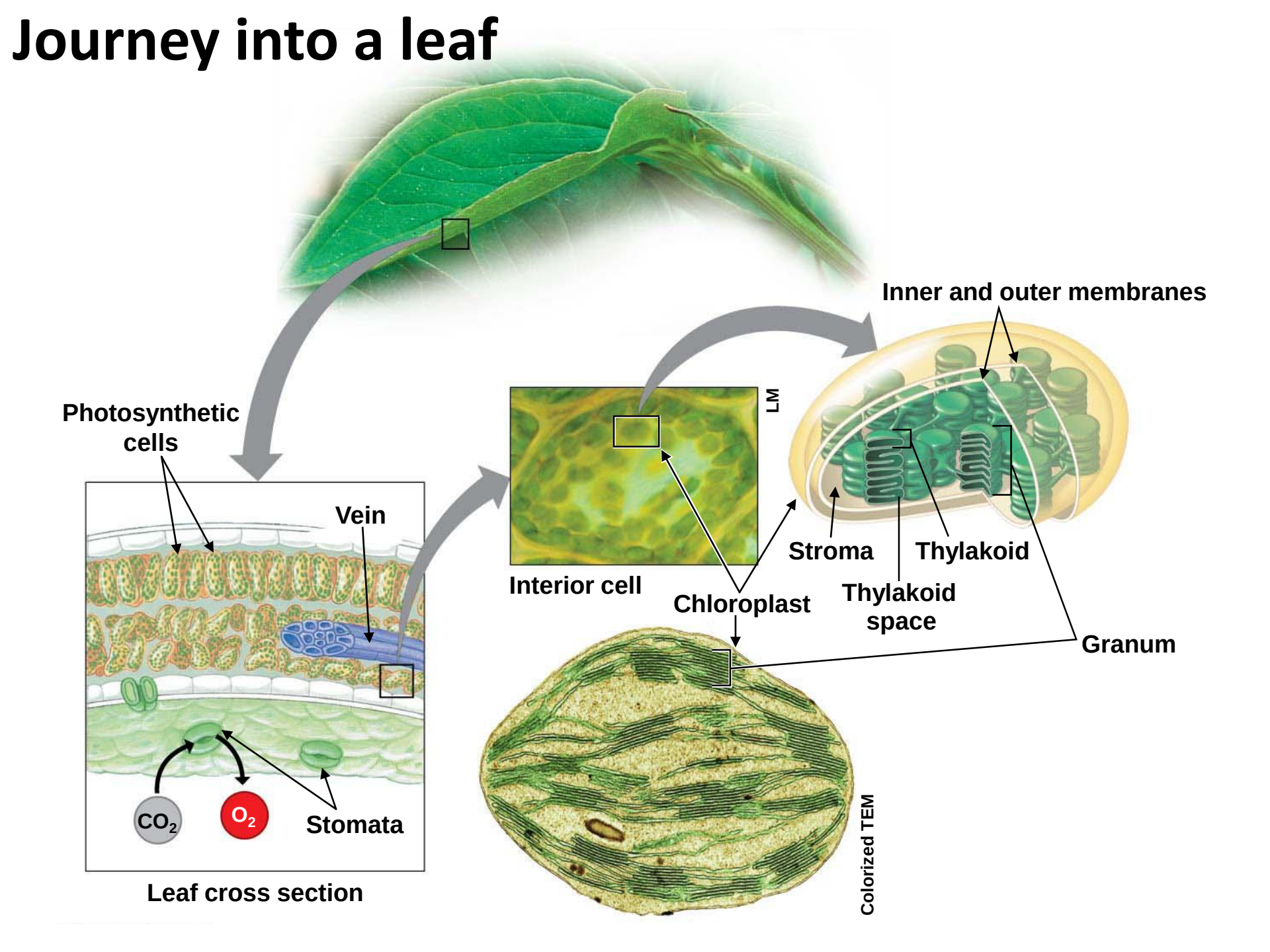
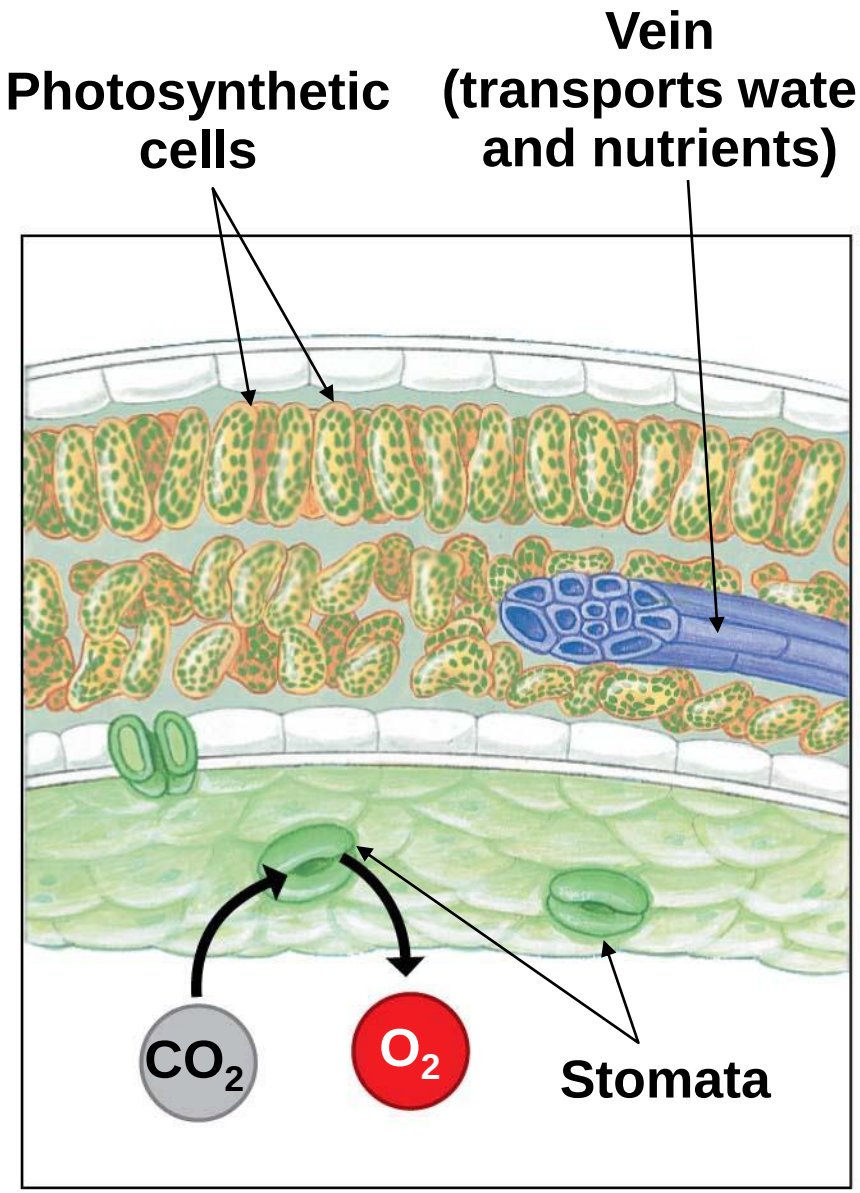


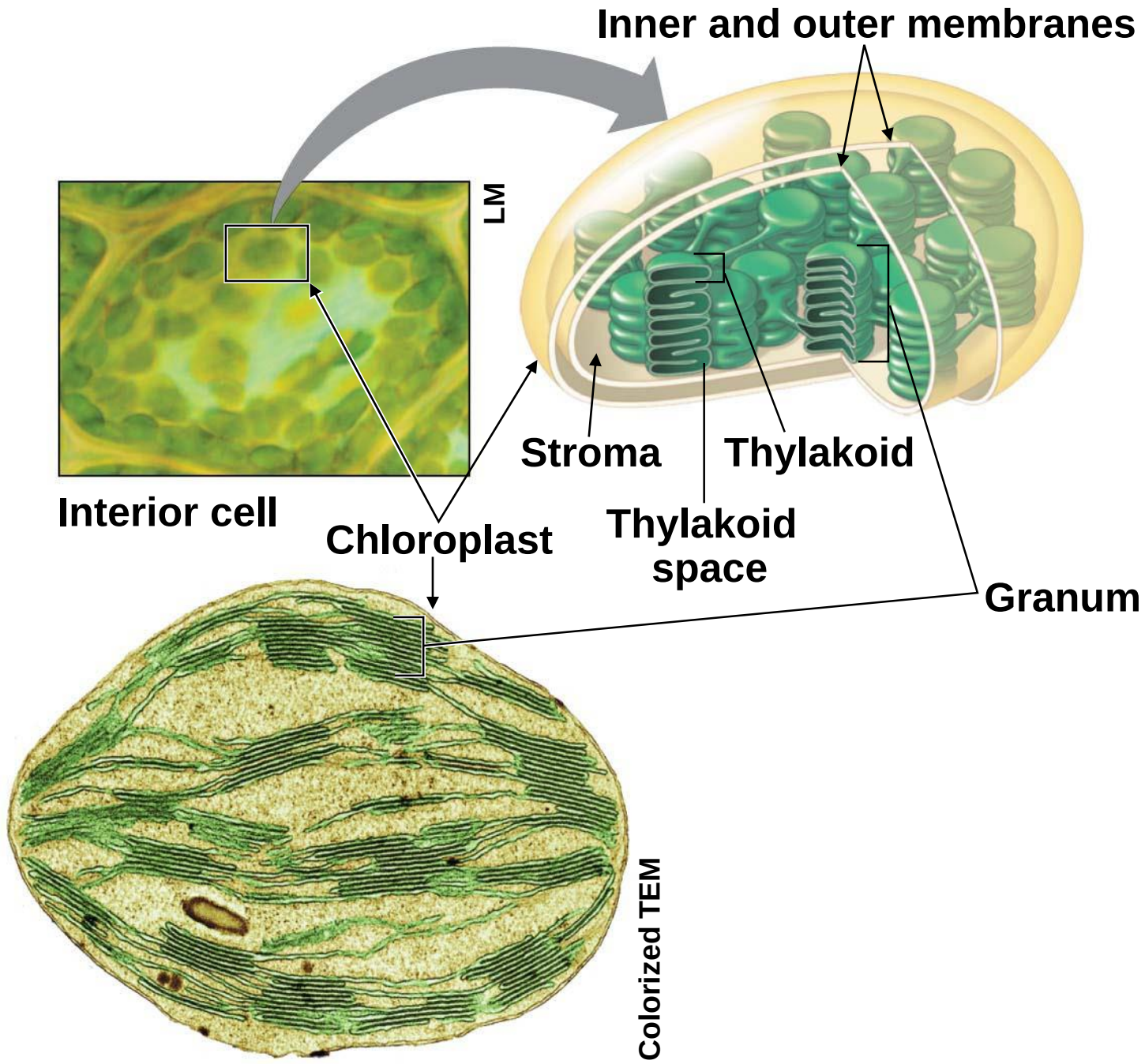
Figure 7.2-1



Leaf cross section

Stomata are tiny pores in leaves where carbon dioxide enters and oxygen exits.

Figure 7.2-2


Inner and outer membranes
LM
Stroma
Thylakoid
Interior cell
Chloroplast
Thylakoid space
Granum
Colorized TEM

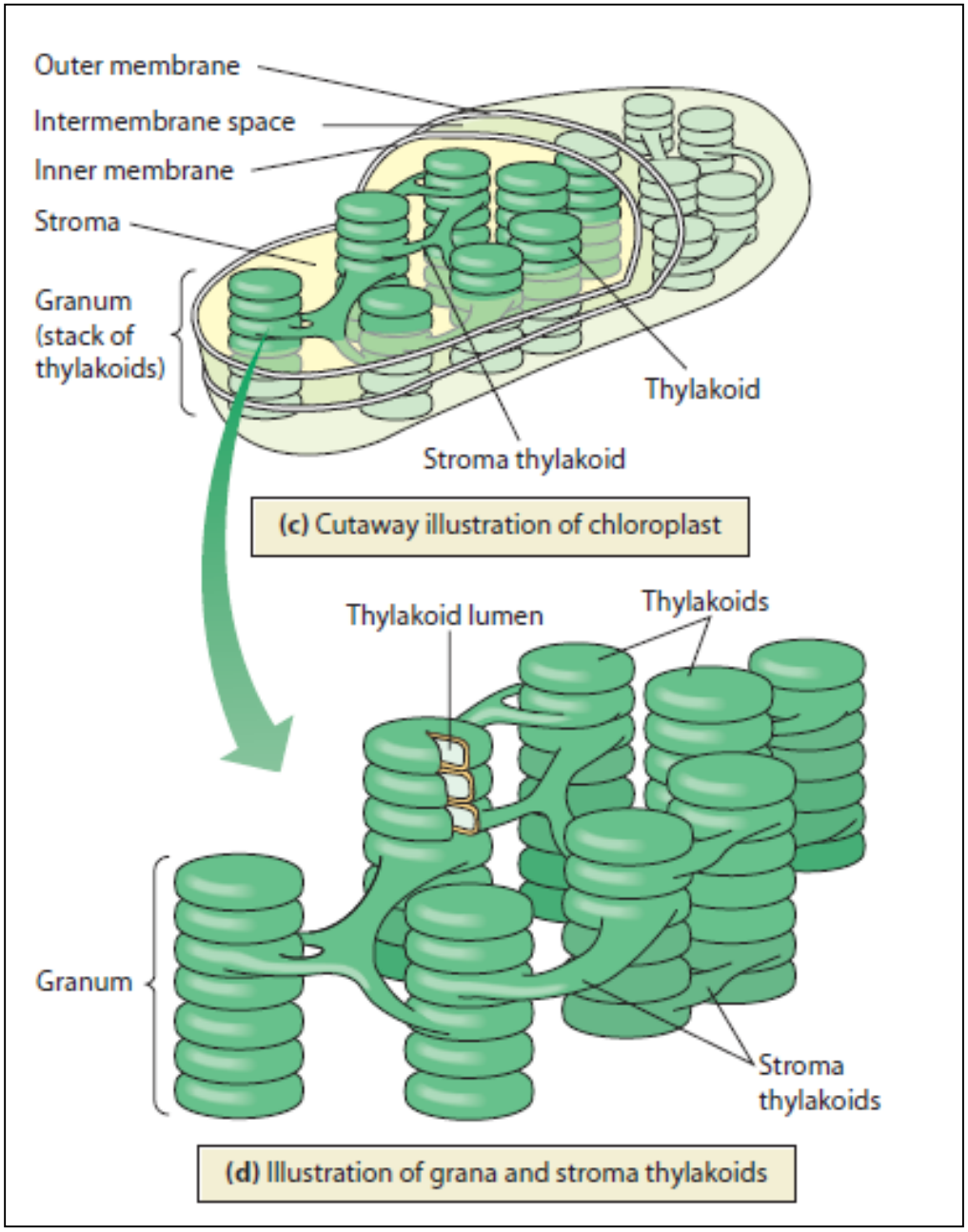
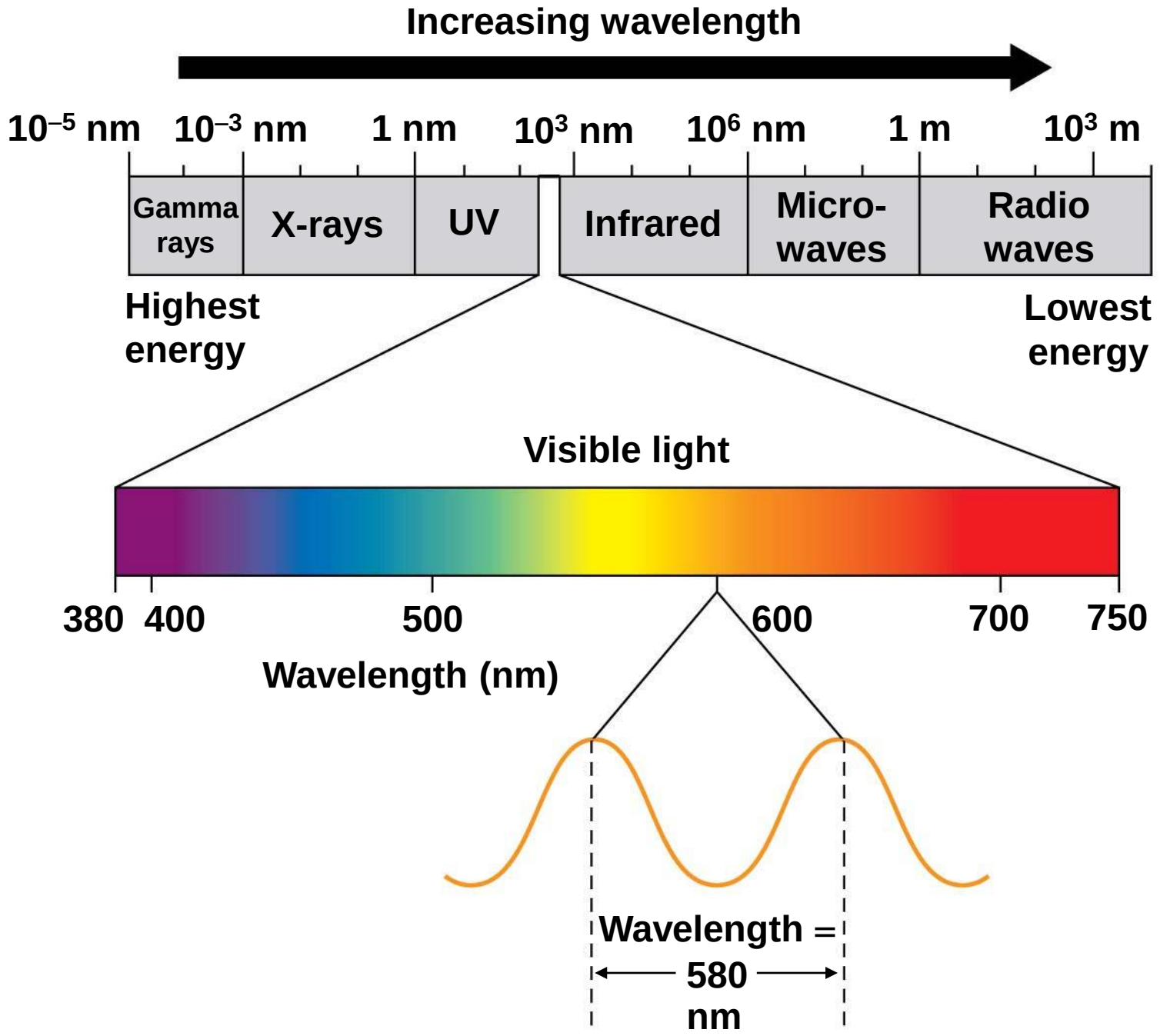
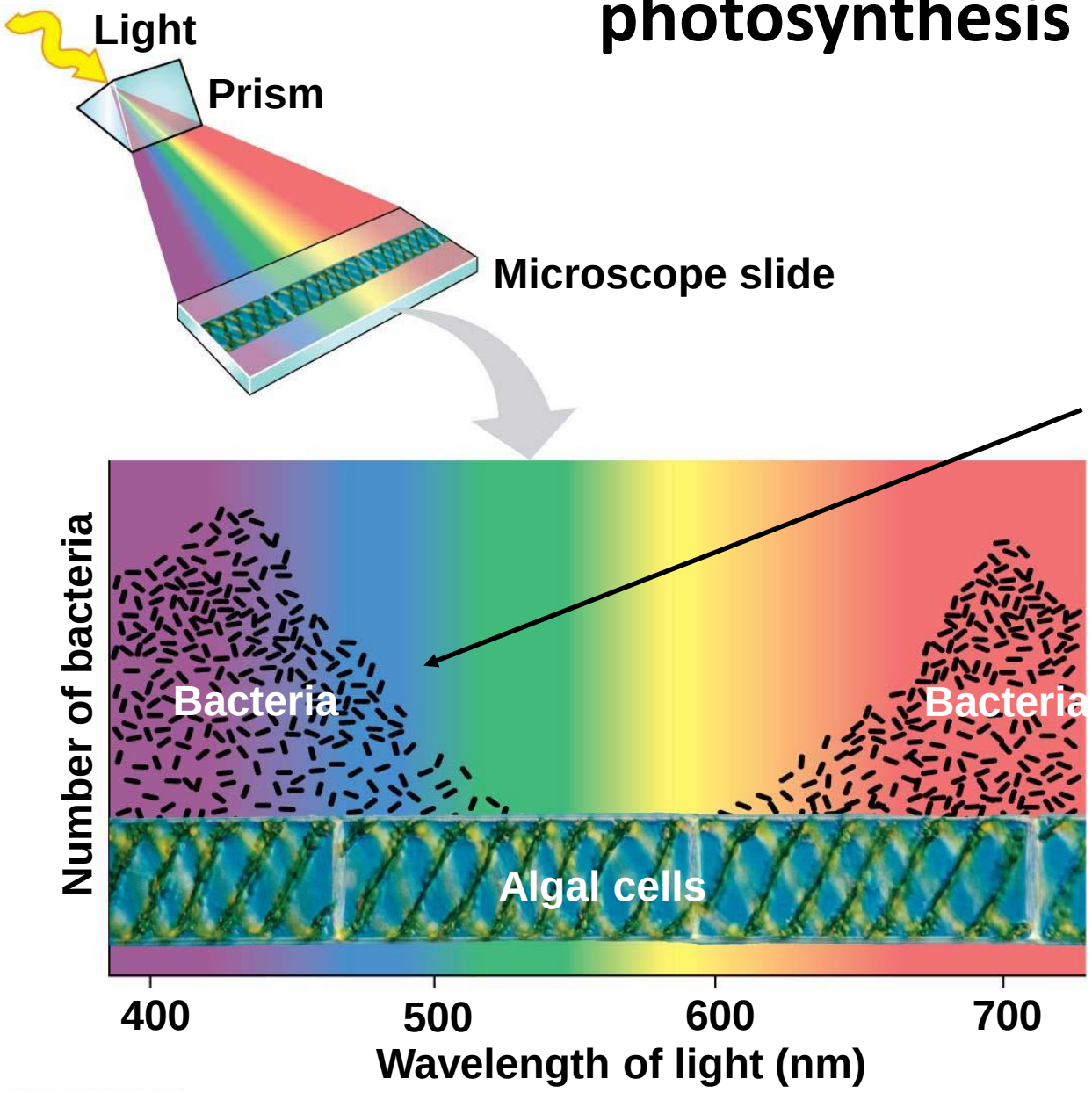

Outer membrane
Intermembrane space
Inner membrane
Stroma
Granum (stack of thylakoids)
Thylakoid
Stroma thylakoid
(c) Cutaway illustration of chloroplast
Thylakoid lumen
Thylakoids
Granum
Stroma thylakoids
(d) Illustration of grana and stroma thylakoids

Figure 7.4


Increasing wavelength
10–5 nm
10–3 nm
1 nm
103 nm
106 nm
1 m
103 m
Gamma rays
X-rays
UV
Infrared
Micro-waves
Radio waves
Highest energy
Lowest energy
Visible light
380
400
500
600
700
750
Wavelength (nm)
Wavelength = 580 nm

Investigating how light wavelength affect photosynthesis



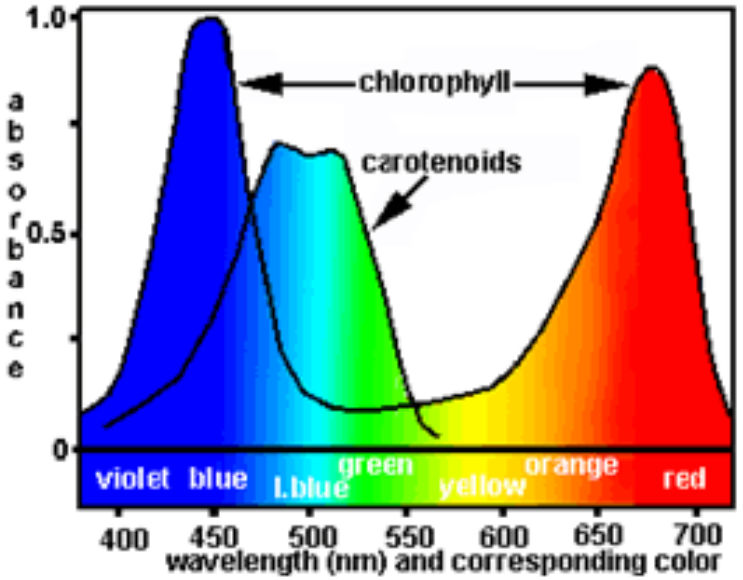
While Violet/Blue and Red lights are absorbed by the photosynthetic organisms, Green light is reflected by them.

Light-capturing Events: Fundamental Concepts

- **Visible light**
  - Combinations of different wavelengths of light
  - Can be seen as different colors
- **Pigments are molecules that absorb light.**
  - Each pigment absorbs certain wavelengths of light.
  - The wavelengths that they do not absorb, they reflect.
    - This is the color we see.
  - In photosynthesis, only the wavelengths that are absorbed can be used to do work.
- Chlorophyll: The main photosynthetic pigment
  - Two forms; a and b
  - Absorb light in the blue and red portions of the spectrum
  - Reflect green wavelengths

Other Types of Pigments

- Accessory pigments
  - Include carotenoids
    - Absorb blue and green wavelengths
    - Reflect orange and yellow
    - Found in leaves, masked by chlorophyll
      - In the autumn, when chlorophyll disintegrates, accessory pigments show through (fall colors).



Light dependent reactions in photosynthesis takes place in **Thylakoid**, whereas the **light independent** reactions take place in **Stroma**

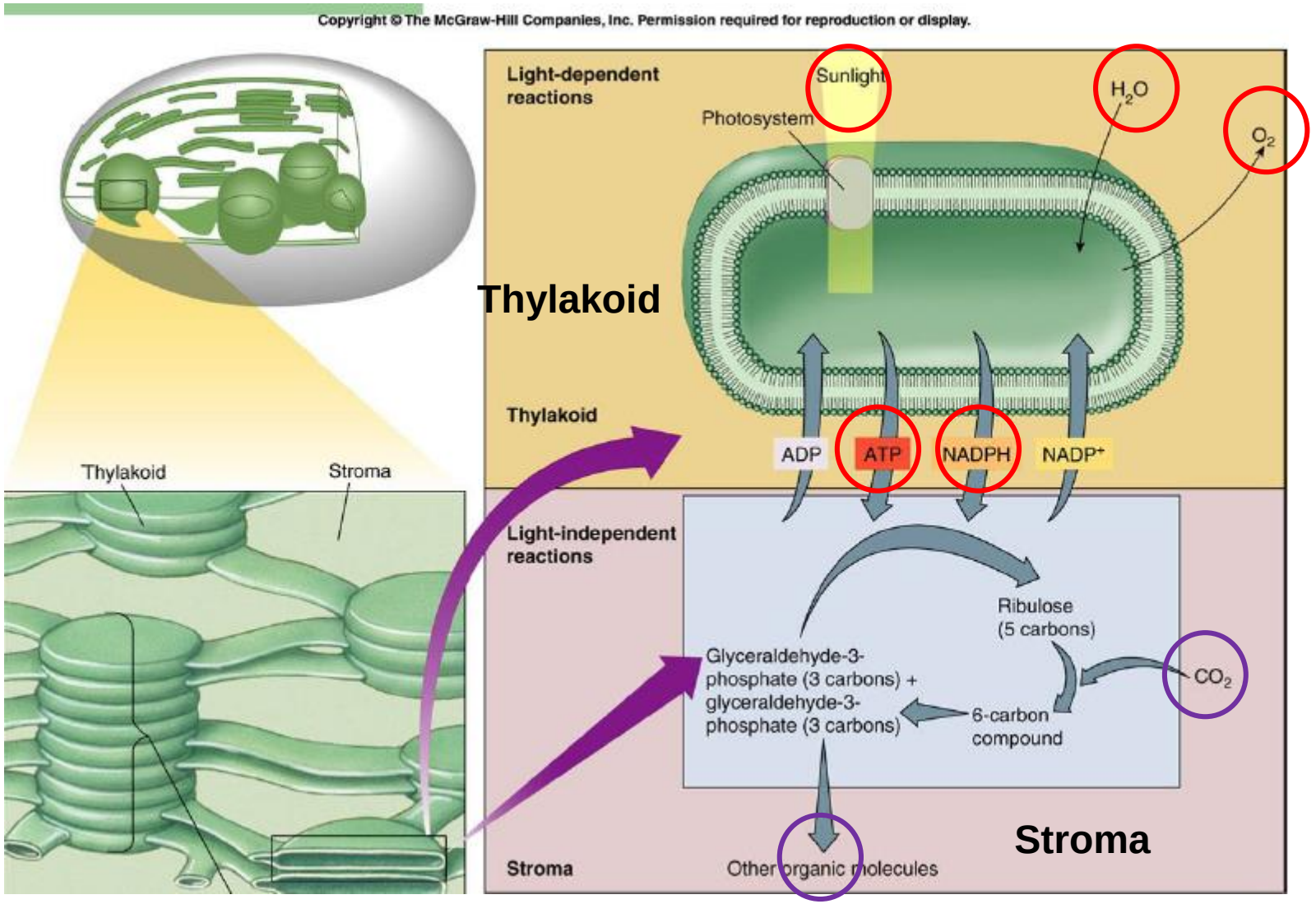
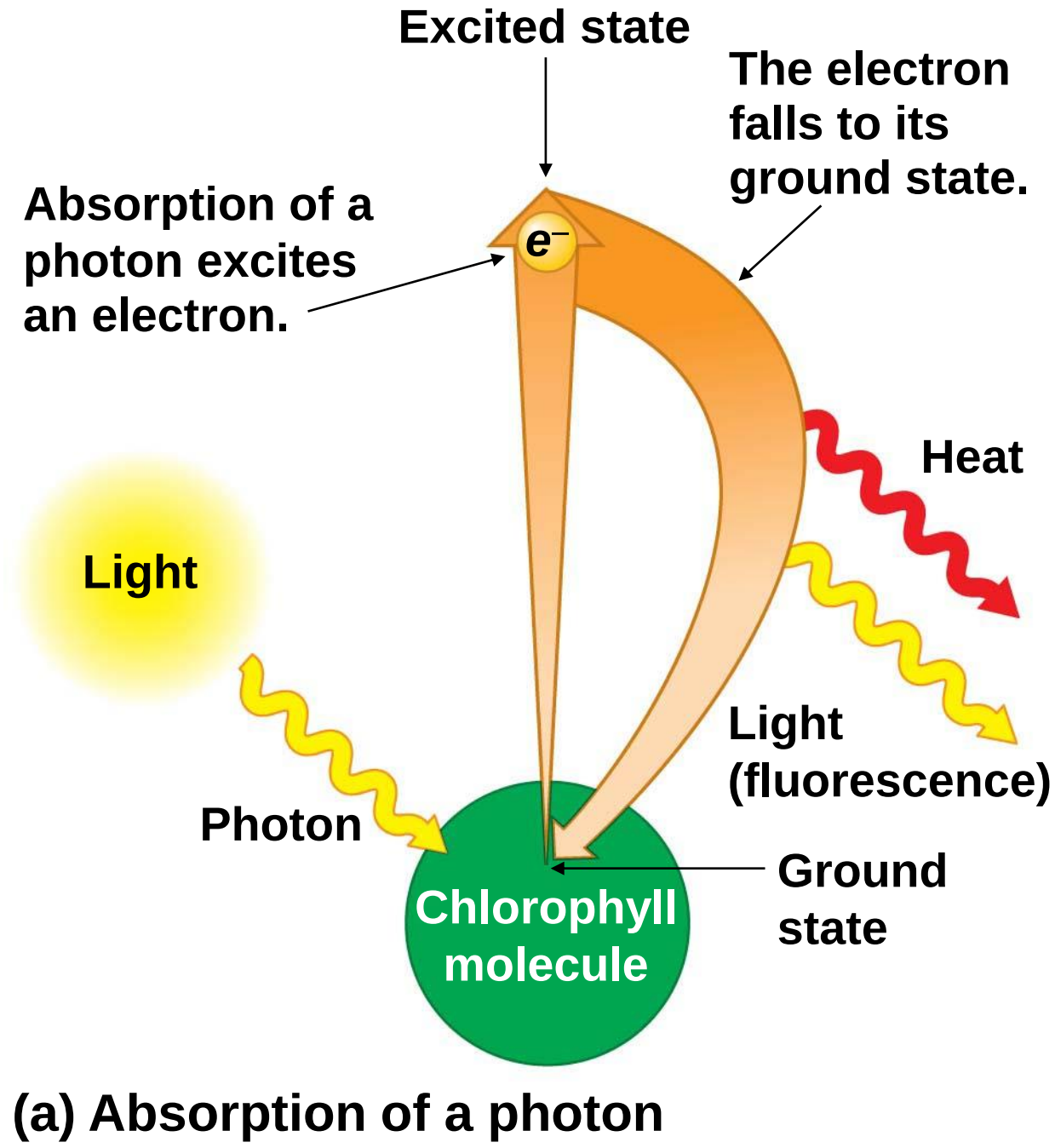


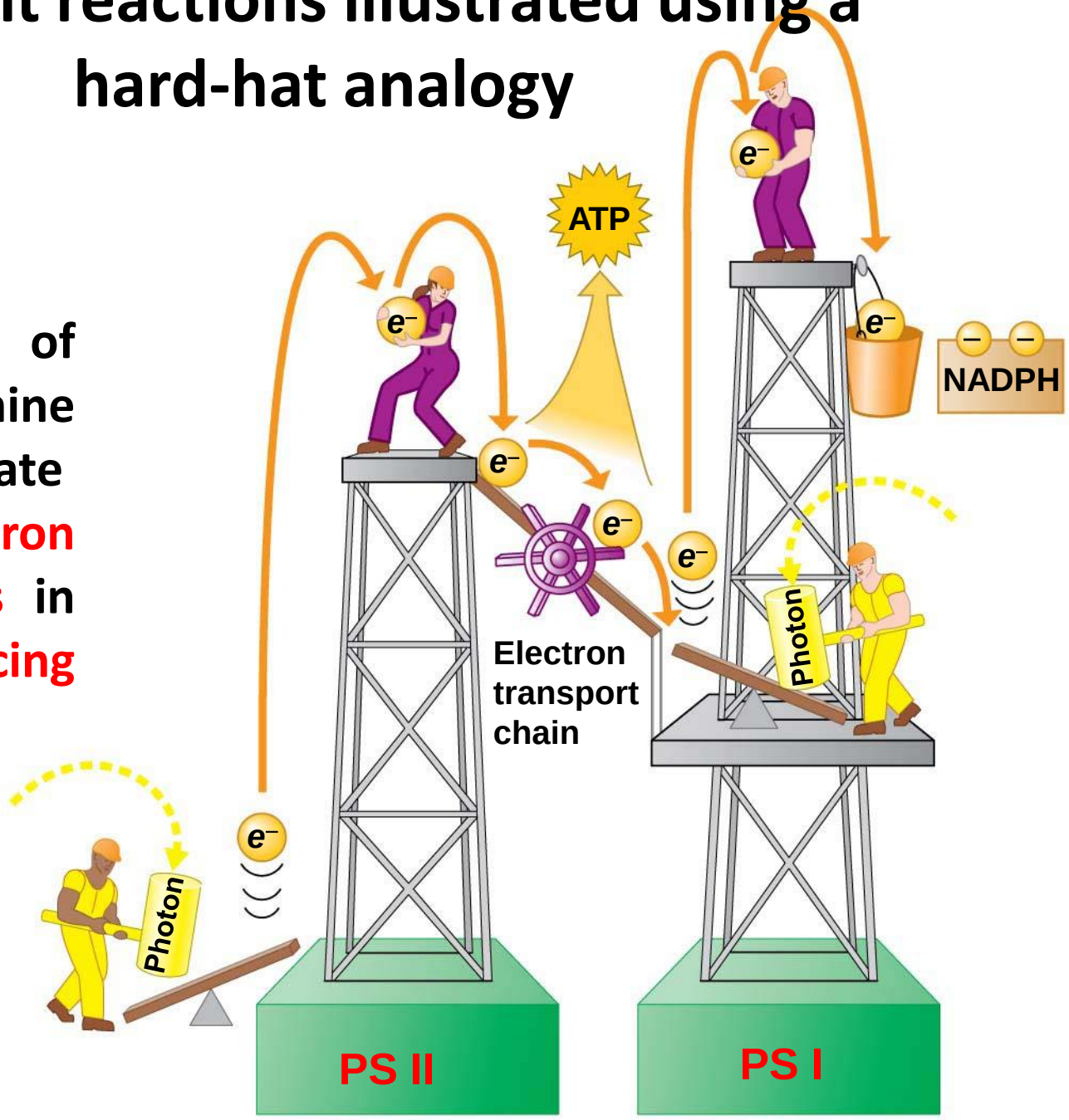
Figure 7.8-1

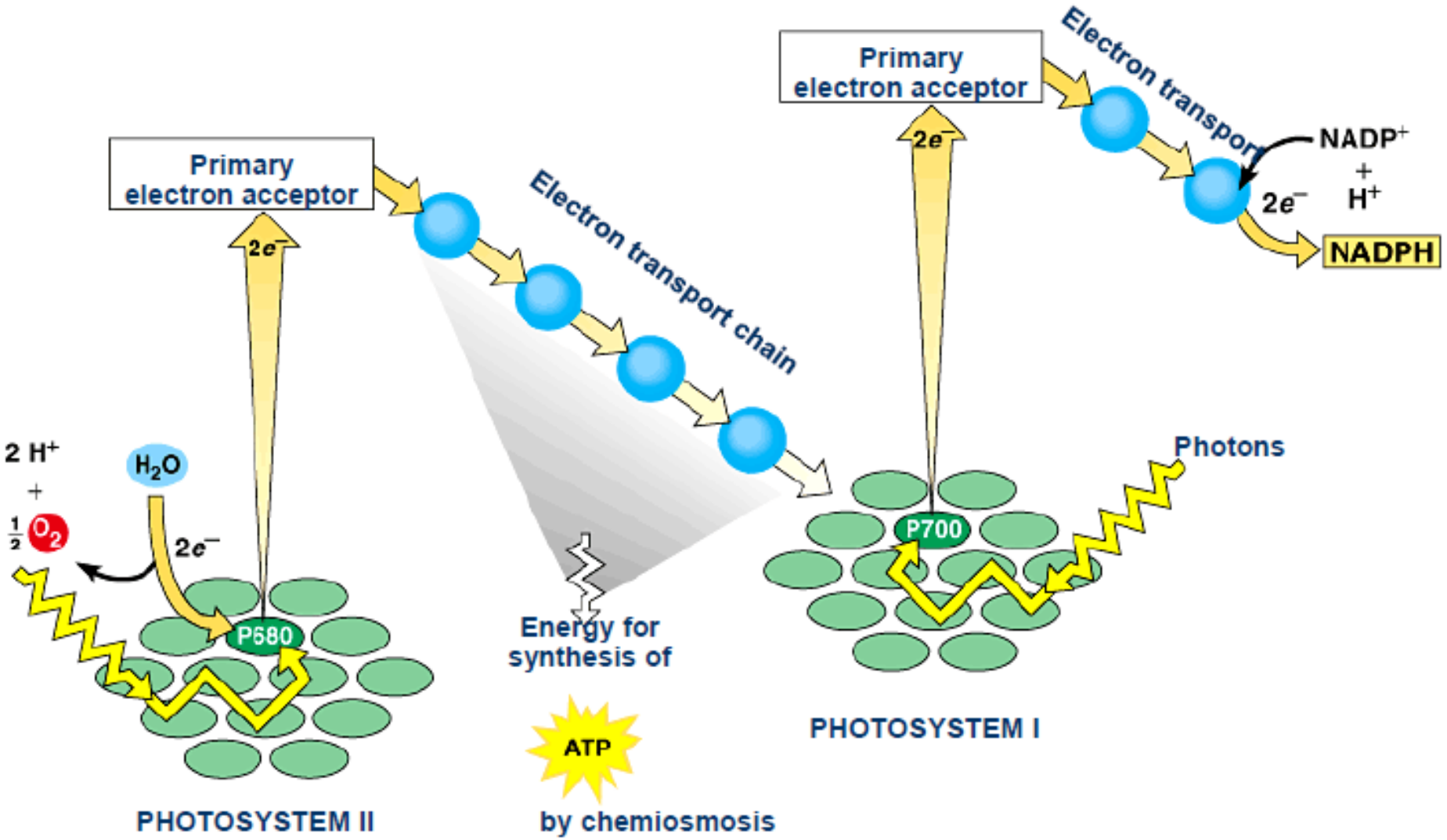


(a) Absorption of a photon

The light reactions illustrated using a hard-hat analogy

The Reduced form of Nicotinamide Adenine Dinucleotide Phosphate **(NADPH)** is an **electron donating coenzymes** in **substrate reducing reactions.**





Light-dependent Reactions:

- The excited electrons from chlorophyll **in Photosystem II**
  - Are passed through an electron transport chain
  - The energy released is used to pump protons up their concentration gradient.
  - When protons diffuse through ATP synthase, ATP is made.

Photosystem II regains electrons by splitting water, leaving O_2 gas as a by-product

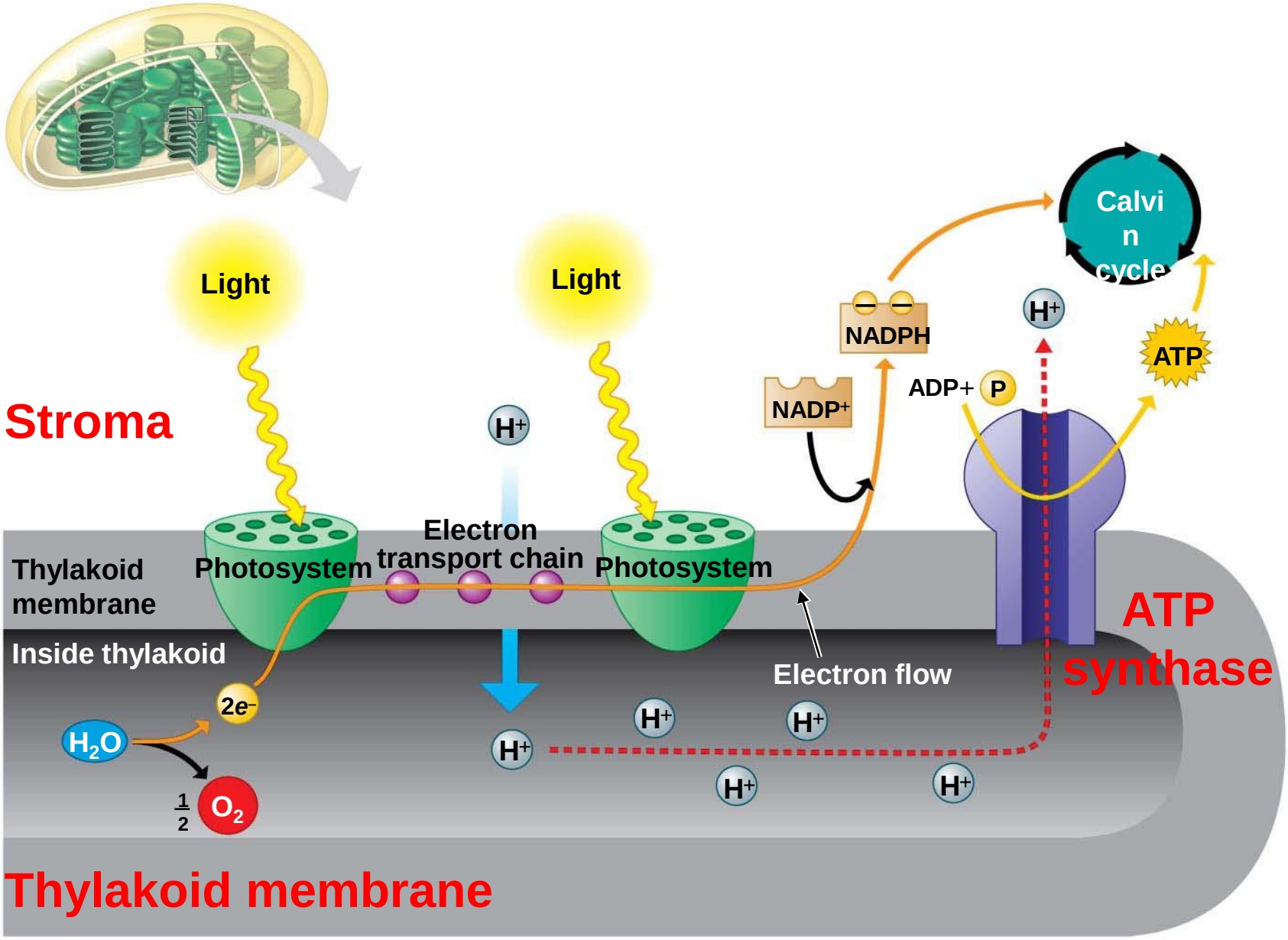
From Photosystem I:

- Excited electrons passed to $NADP^+$ to make NADPH

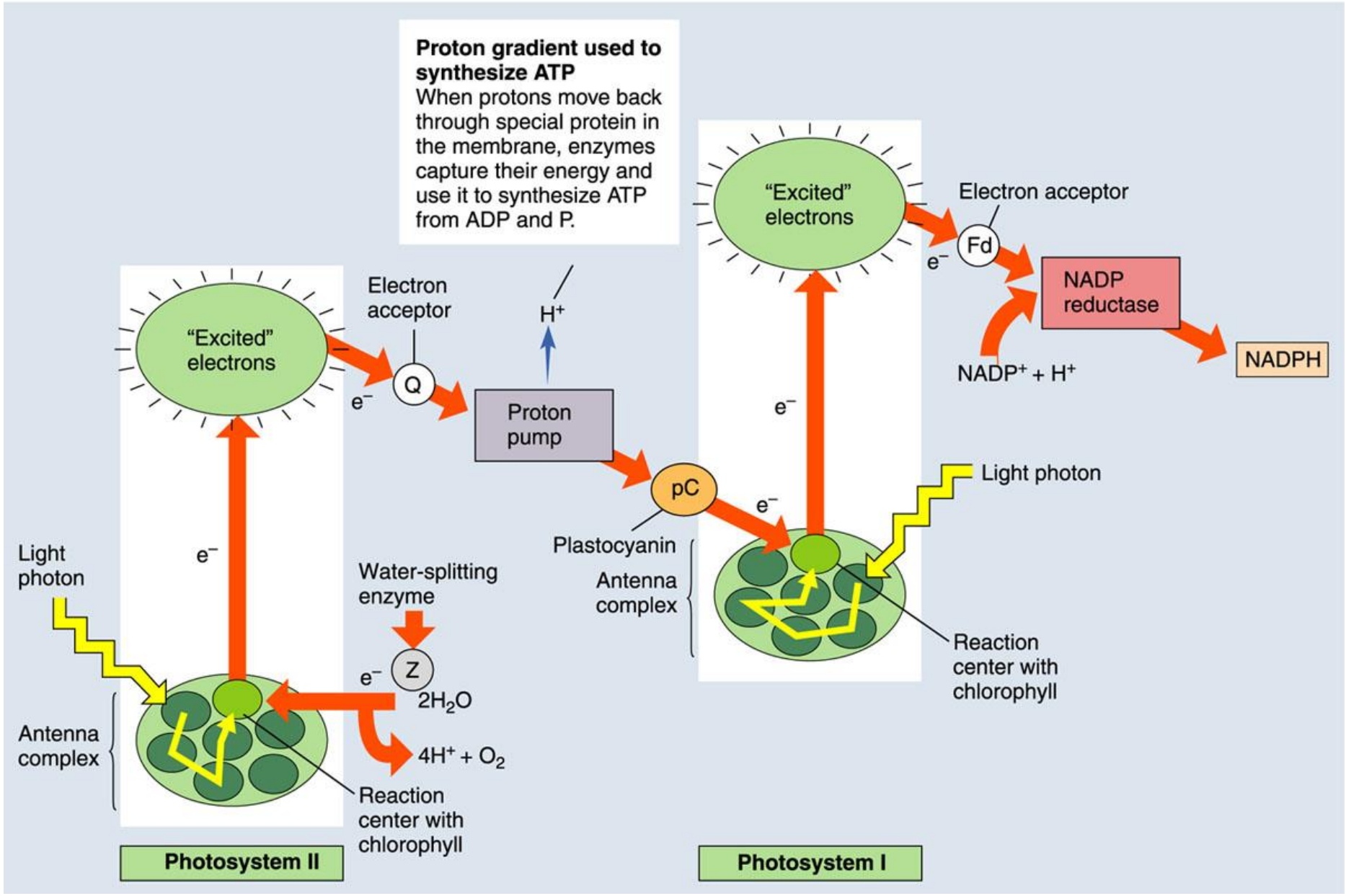
Photosystem I regains electrons from Photosystem II after it donates its energy to pump protons against the concentration gradient

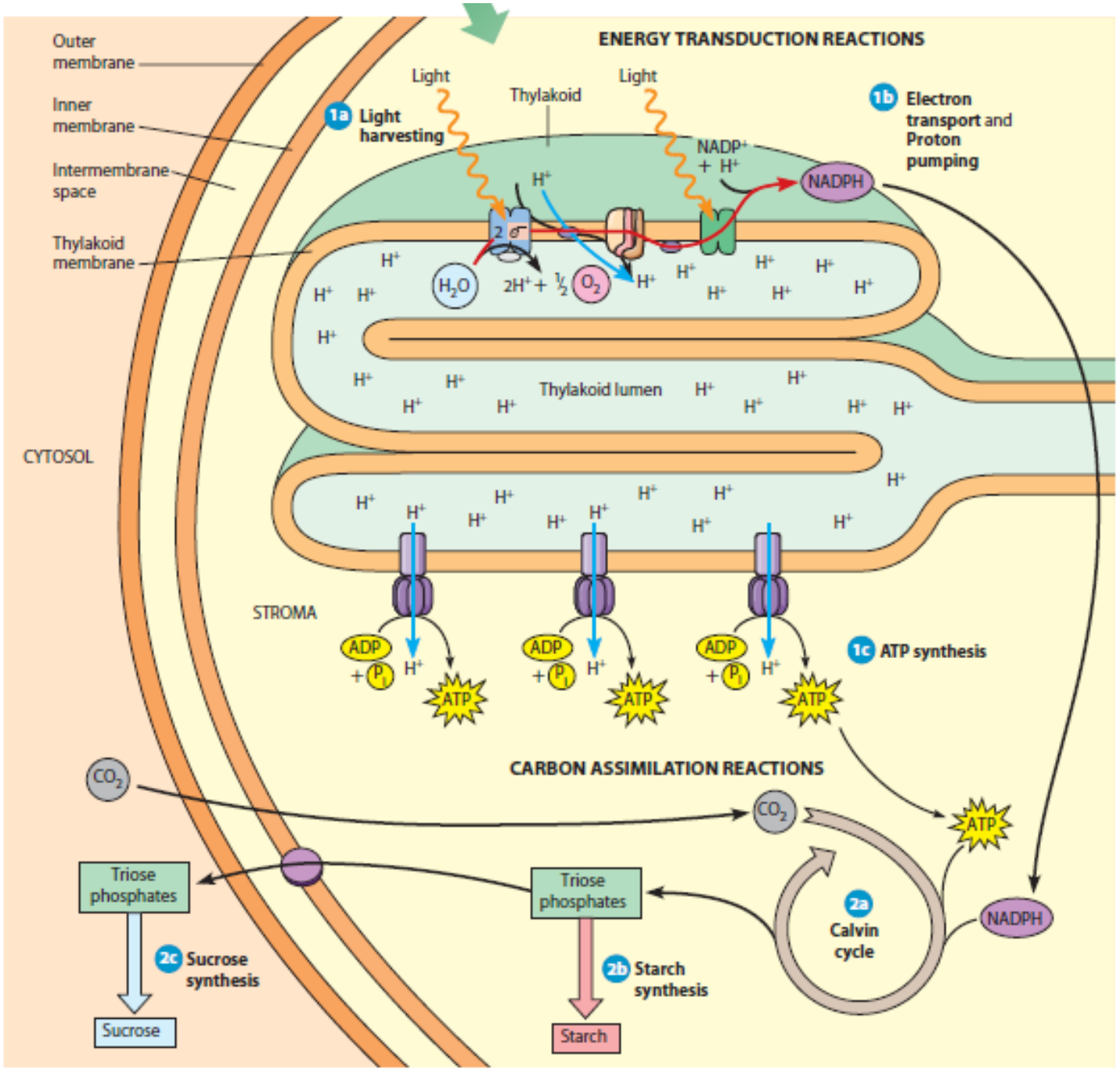
- Occurs in the thylakoid membrane
  - ATP and NADPH move to the stroma to be used in the dark reactions. **(Light independent reactions)**

How the thylakoid membrane converts light energy to the chemical energy of NADPH and ATP



Photosystem I and II



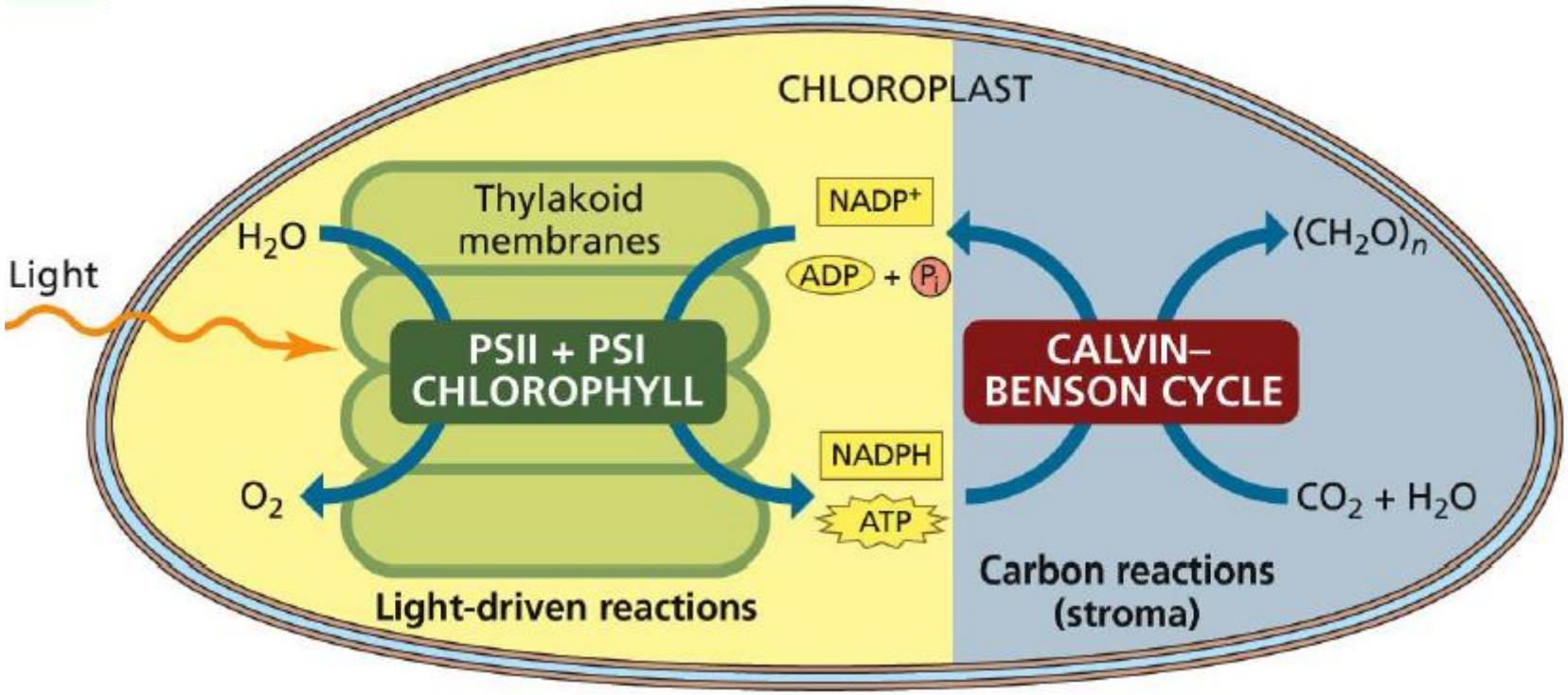

ENERGY TRANSDUCTION REACTIONS
Outer membrane
Inner membrane
Intermembrane space
Thylakoid membrane
CYTOSOL
Light
Thylakoid
Light
1a Light harvesting
1b Electron transport and Proton pumping
NADP+ + H+
NADPH
H+
2 σ
H2O
2H+ + ½ O2
Thylakoid lumen
STROMA
ADP + Pi
ATP
1c ATP synthesis
CARBON ASSIMILATION REACTIONS
CO2
Triose phosphates
2c Sucrose synthesis
Sucrose
2b Starch synthesis
Starch
2a Calvin cycle

Light-independent Reactions: Fundamental Concepts

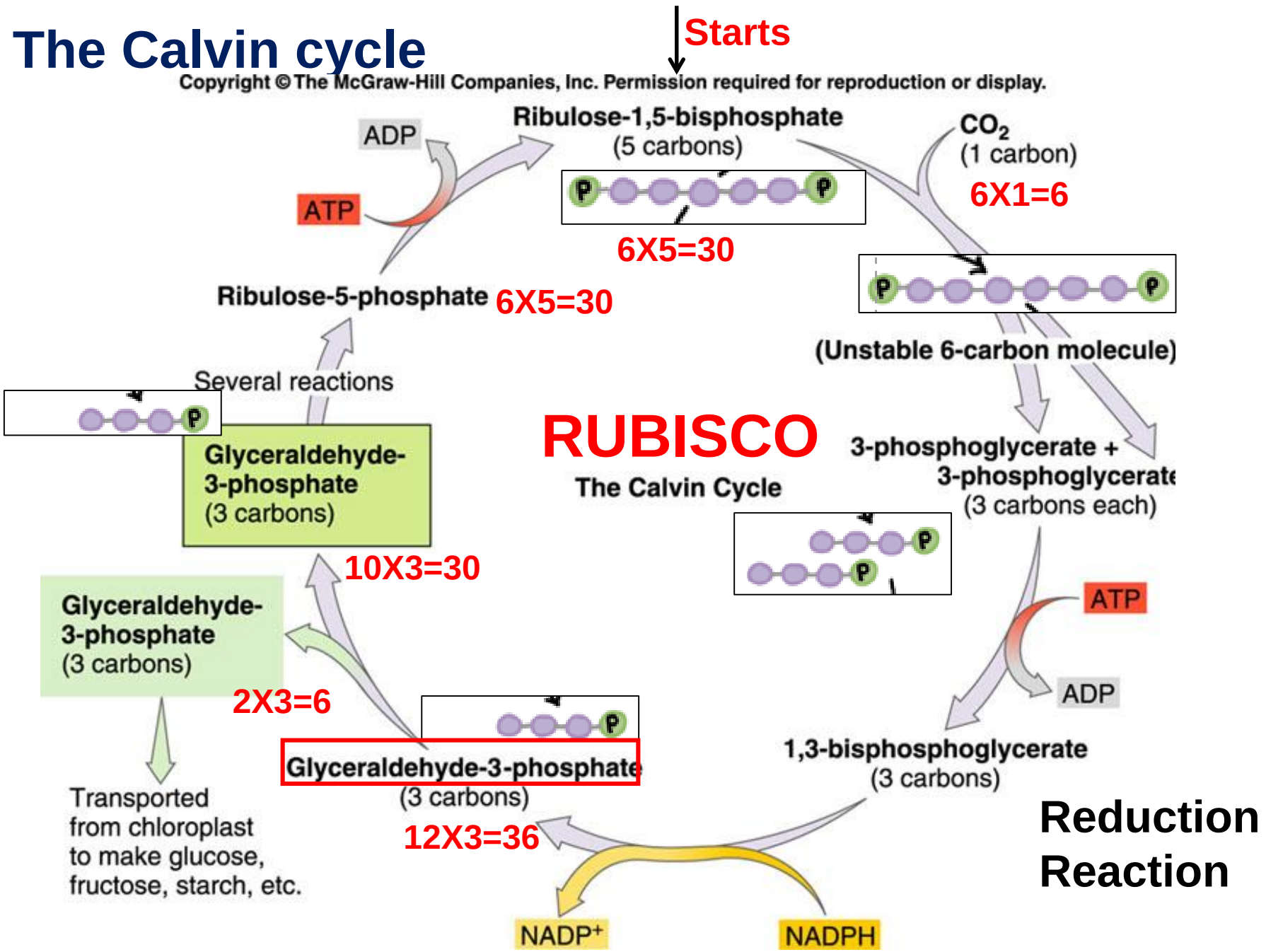
- The ATP and NADPH from the light-dependent reactions
  - Provide the energy and electrons needed to build sugar from carbon dioxide
- CO_2 is captured by an enzyme called RuBisCO
  - Combines CO_2 with ribulose to form a 6-carbon molecule
    - This is immediately split into two 3-C molecules.
- NADPH is used to reduce these molecules.
- Glyceraldehyde-3-phosphate is formed.
  - Can be used to make sugars, proteins or fats

Light Independent Reactions: The Details

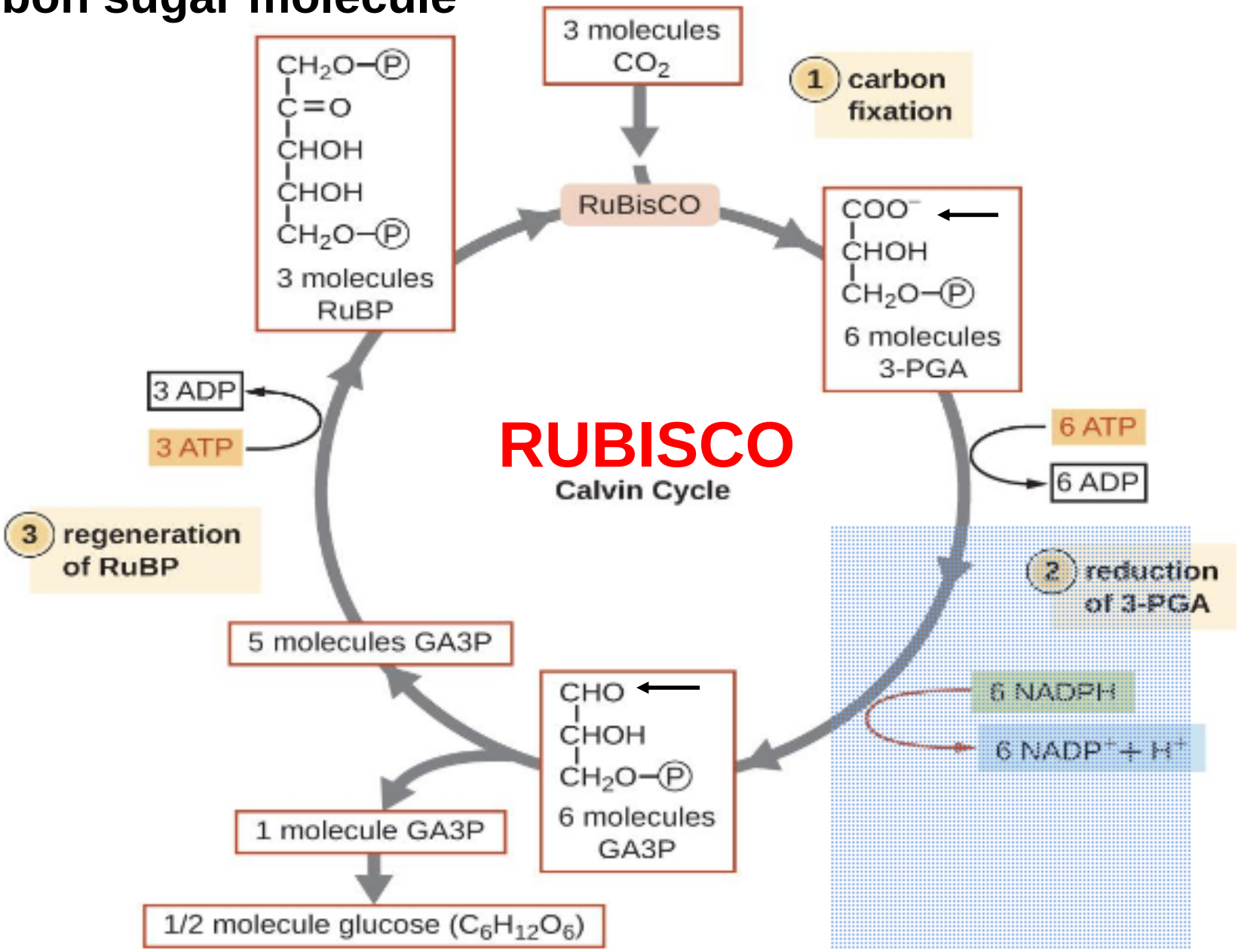
- Takes place in the stroma of the chloroplast
- Uses
  - CO_2 (from the atmosphere)
  - ATP and NADPH (from the light-dependent reactions)
  - Ribulose (recycled)
- Also called the dark reactions
- Also called the Calvin cycle

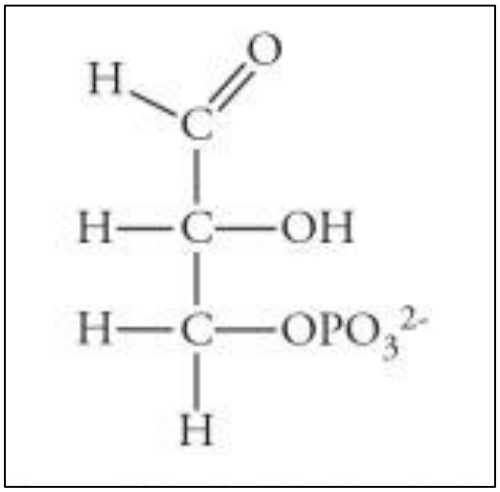


The Calvin cycle



Multiply each reaction by a factor of 2 to produce a 6 carbon sugar molecule





Glyceraldehyde-3-phosphate

NH_3

Regenerate ribulose in calvin cycle

Sugars and complex carbohydrates

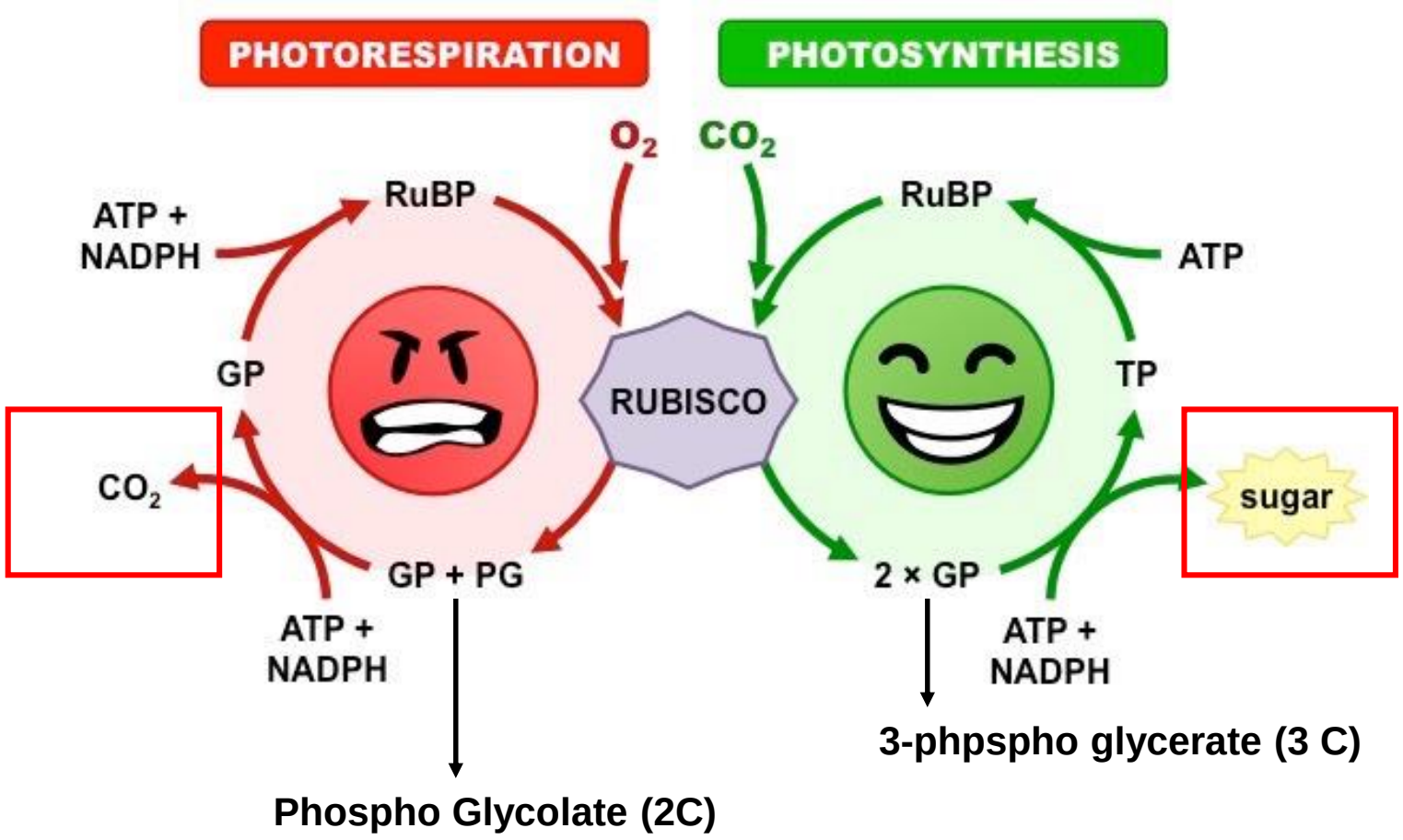
Fats

Broken down to release energy

Protein

Photorespiration and Rubisco

Photorespiration is a wasteful process that occurs when RUBISCO acts on oxygen instead of carbon dioxide.



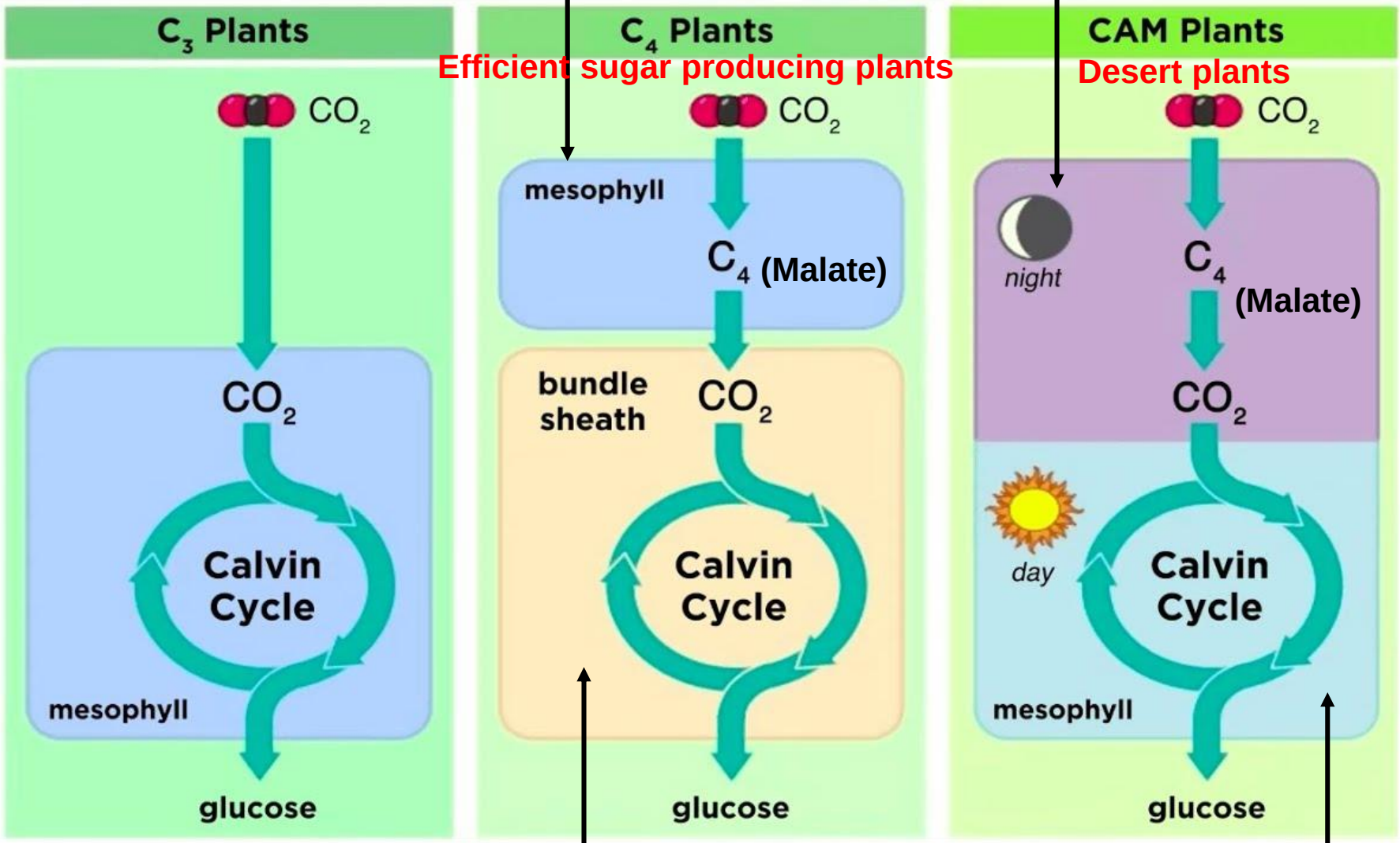
C4 and CAM plants battle against photorespiration:

C4 plants convert CO_2 to **Malate (C4)** in **mesophyll cells** near stromata and convers the C4 back to CO_2 for RUBISCO in the **bundle sheath** cells deep inside the tissue, where there is **no direct access to O_2.** These plants are very efficient in producing sugar.

CAM plants mostly found in the desert, open their stromata **only in the night** to prevent water loss. CO_2 gets inside at the **night** and get **converted to C4**. During the **day time**, when **stromata is closed and thus no O_2 can get in**, the **C4 converts back to CO_2.** This effectively increases the concentration of CO_2 for RUBISCO over O_2.

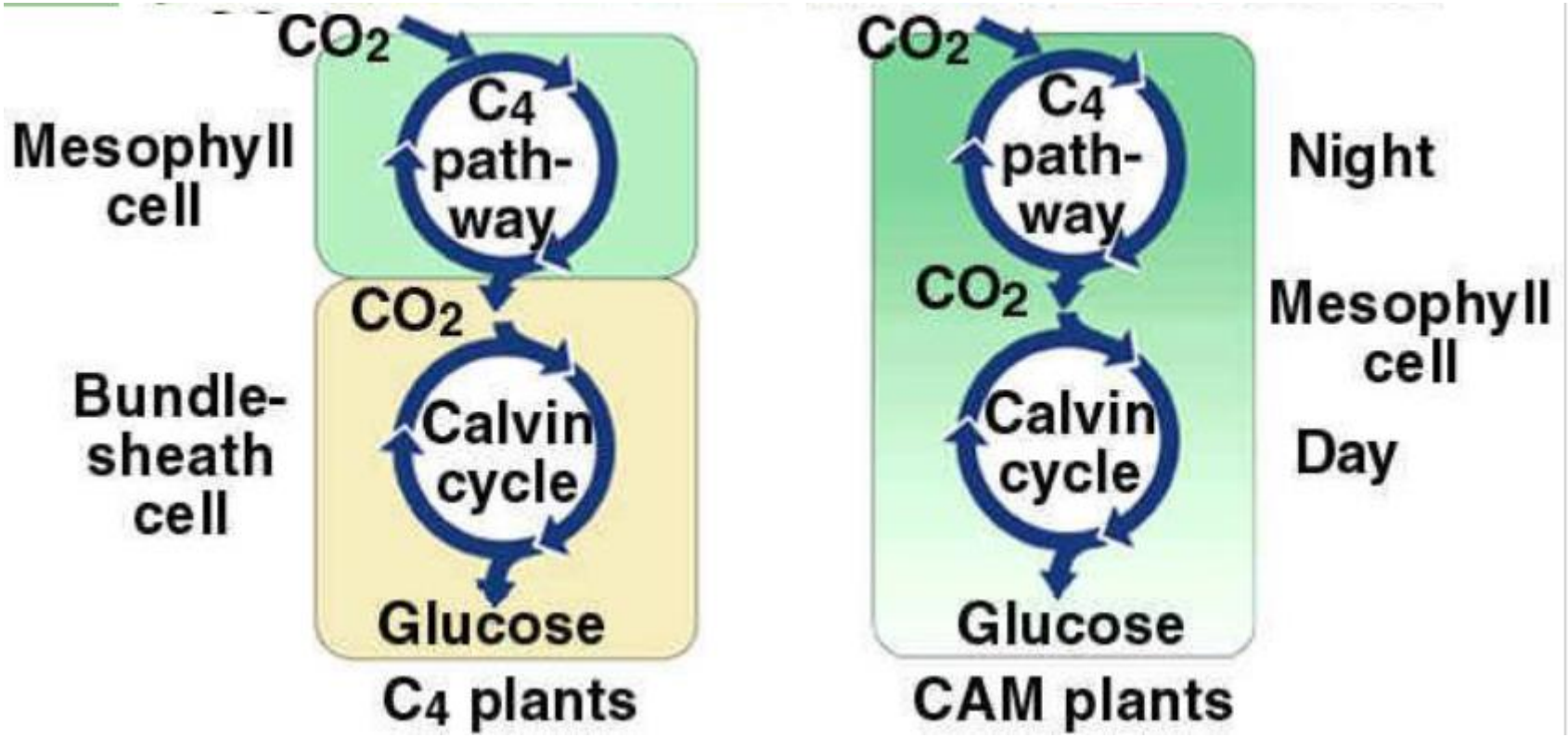
Close to Stomata, Direct access to both CO_2 and O_2; CO_2 gets converted into C4

Stomata open only during night time, CO_2 gets converted into C4



Deep inside the tissue, no direct access to O_2

C4 gets converted to CO_2 during day time, effectively increasing the concentration of CO_2 for RUBISCO



1. Which best describes light-independent reactions?

a. They are the first stage of photosynthesis.
b. They utilize the energy stored in ATP and NADPH.
c. They use carbon dioxide to synthesize proteins.
d. They create energy-rich ATP and NADPH.

2. Why do we perceive chlorophyll as being green?

a. Because it is green.
b. Because it absorbs green light.
c. Because it reflects green light.
d. Because it absorbs yellow light.

3. During what stage of photosynthesis are ATP and NADPH converted to ADP + Pi and $NADP^+$?

A)the light-dependent reactions
B)the light-independent reactions
C)both of the above
D)none of the above

4. Photosynthesis takes place in the membranes of small sacs called

A)Thylakoids B)stroma C)photosystems D)photons

5. During what stage of photosynthesis O_2 is produced?

A)cyclic photophosphorylation
B)the light-dependent reactions involving photosystems I and II
C)carbon fixation
D)the Krebs cycle
E)O_2 is not produced during photosynthesis

6. During photosynthesis, photons raise electrons to higher energy levels. These excited electrons belong to what compound?

A) H_2O **B)** ATP **C)** RuBP **D)** glucose **E)** chlorophyll

7. The oxygen that is released during photosynthesis came from _____ molecules.

A) carbon dioxide **B)** water **C)** glucose **D)** chlorophyll **E)** ATP

8.Which of the following statements about photosynthesis is true?

A)the light-dependent reactions can occur only in the light, the light-independent reactions only in the dark

B)photorespiration is more efficient at producing glucose than is photosynthesis

C)the light-dependent reactions produce the energy-rich compounds that are used to run the light-independent reactions

D)all of the above are true

9. Which of the following statements accurately describes the relationship between photosynthesis and cellular respiration?

A)photosynthesis occurs only in autotrophs; cellular respiration occurs only in heterotrophs

B)photosynthesis uses solar energy to convert inorganics to energy-rich organics; respiration breaks down energy-rich organics to synthesize ATP

C)the primary function of photosynthesis is to use solar energy to synthesize ATP; the primary function of cellular respiration is to break down ATP and release energy

D)photosynthesis and cellular respiration occur in separate, specialized organelles; the two processes cannot occur in the same cell at the same time

10.Light-driven electron transport in the chloroplast pumps H^+ inside the _____ . When high concentration of proton gushes out in the _____ by _____, ATP is produced.

11. CO_2 fixation occurs within the stroma.
A)True **B)**False

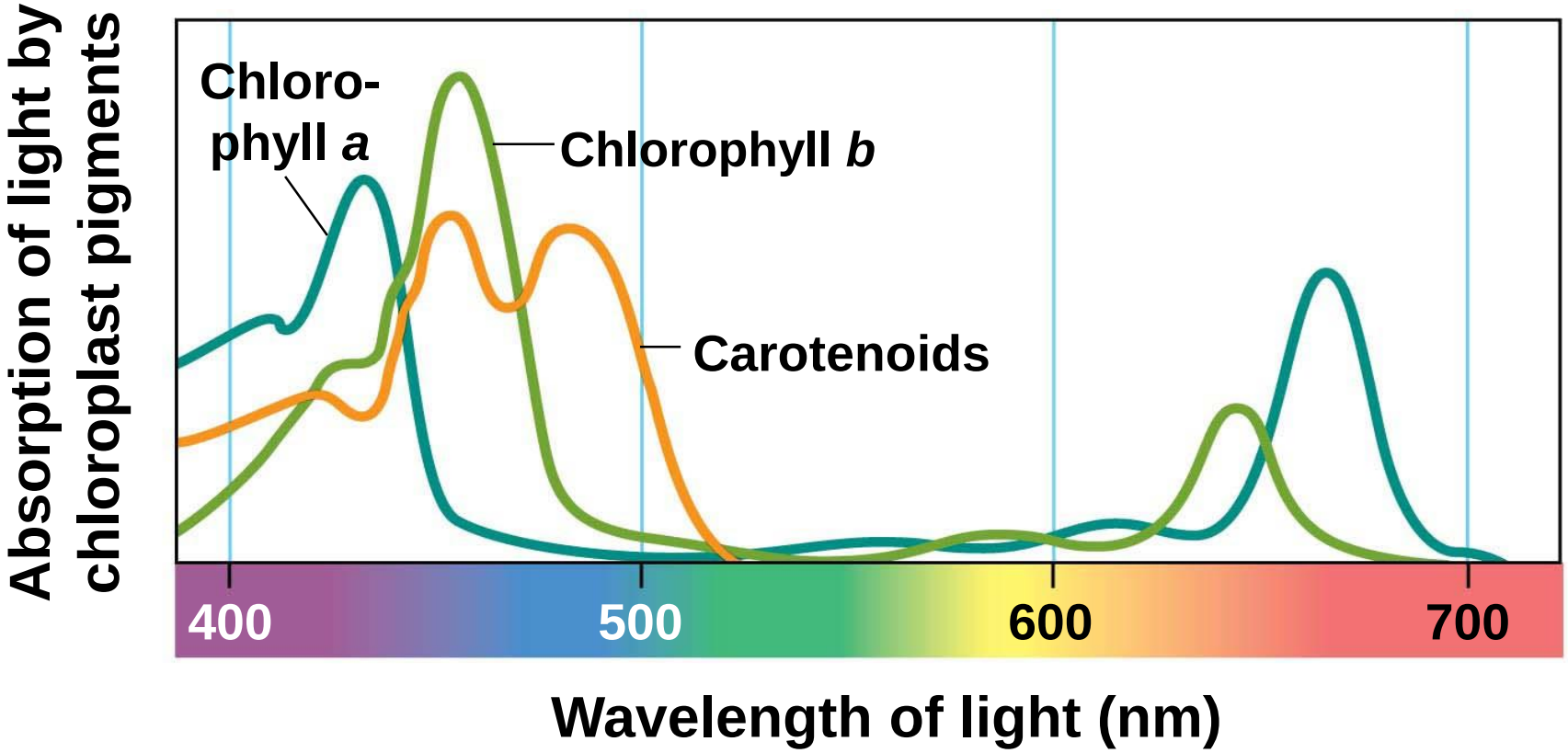
12. Light is required for the light dependent reactions because

A)it is the source for electrons
B)it splits the water molecule
C)it energizes electrons in the reaction center
D)it splits ATP molecules which generates the energy necessary to power the light independent reactions
E)none of the above

Extra slides

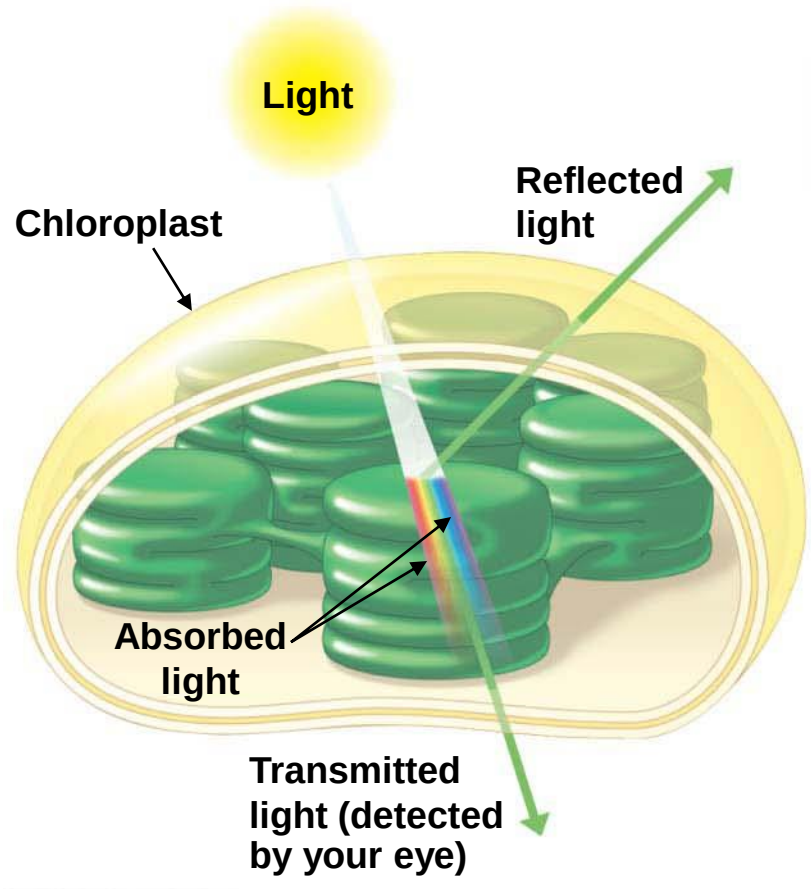
The Nature of Sunlight

- When sunlight shines on a pigmented material, certain wavelengths (colors) of the visible light are absorbed and disappear from the light that is reflected by the material.



In the 19th century, botanists discovered that only certain wavelengths of light are used by plants.

Figure 7.6

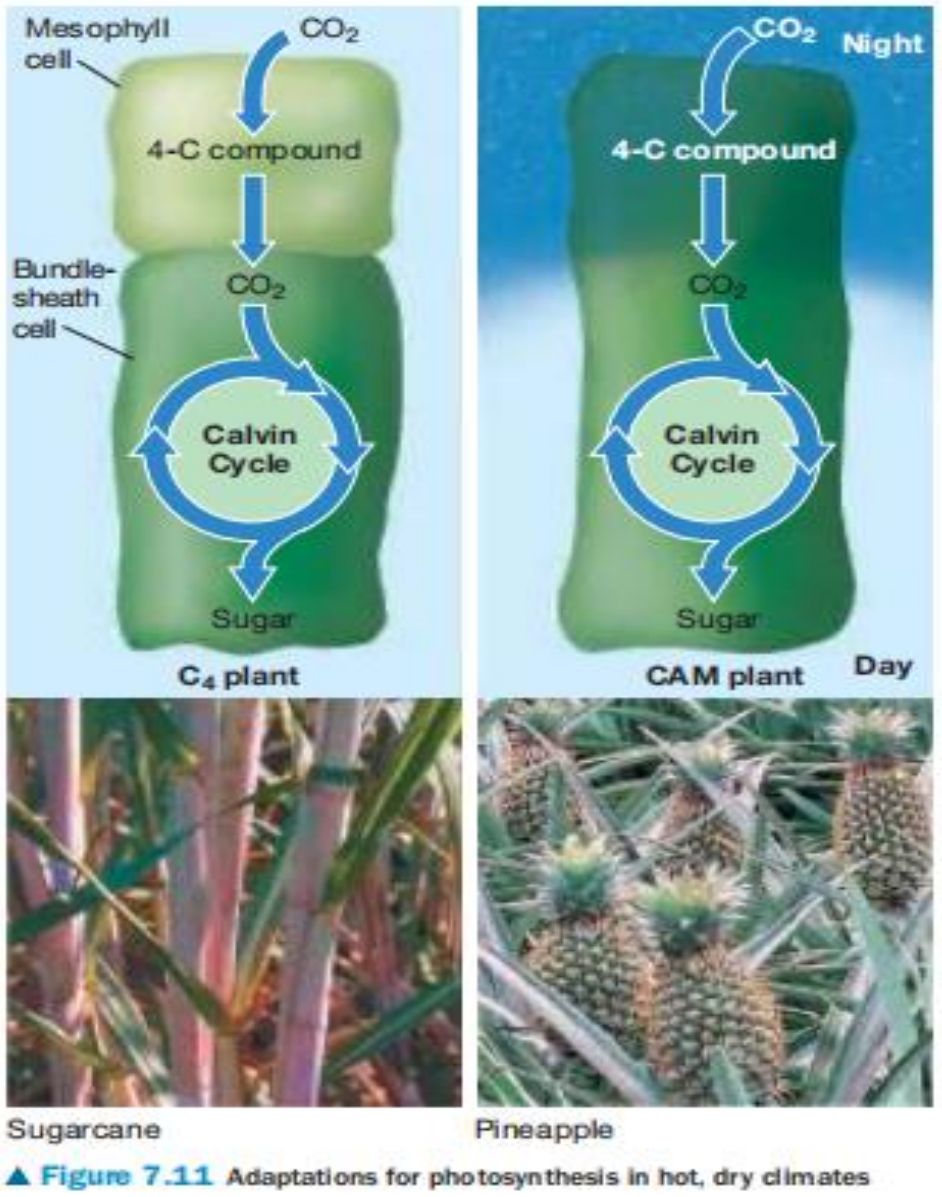

Light
Reflected light
Chloroplast
Absorbed light
Transmitted light (detected by your eye)

Carbon Concentrating Mechanisms

C4:

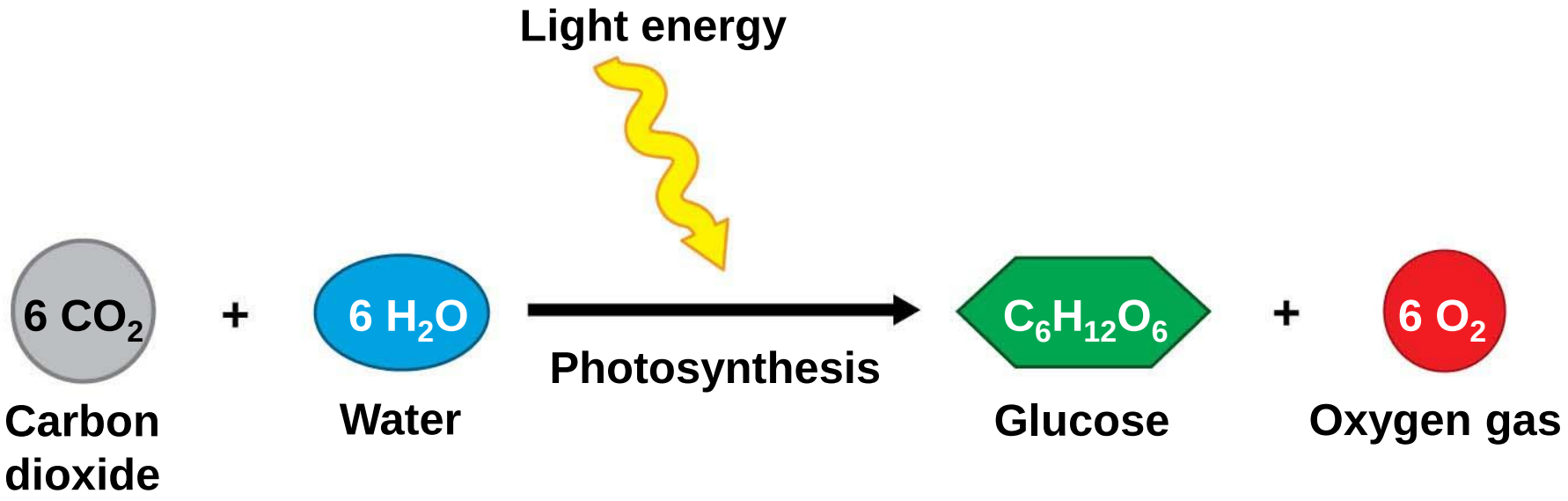
Because the **mesophyll cells** constantly pumps CO2 into neighboring bundle-sheath cells in the form of **malate**, there's always a high concentration of CO2 relative to O2 around rubisco. This strategy minimizes photorespiration.

CAM:

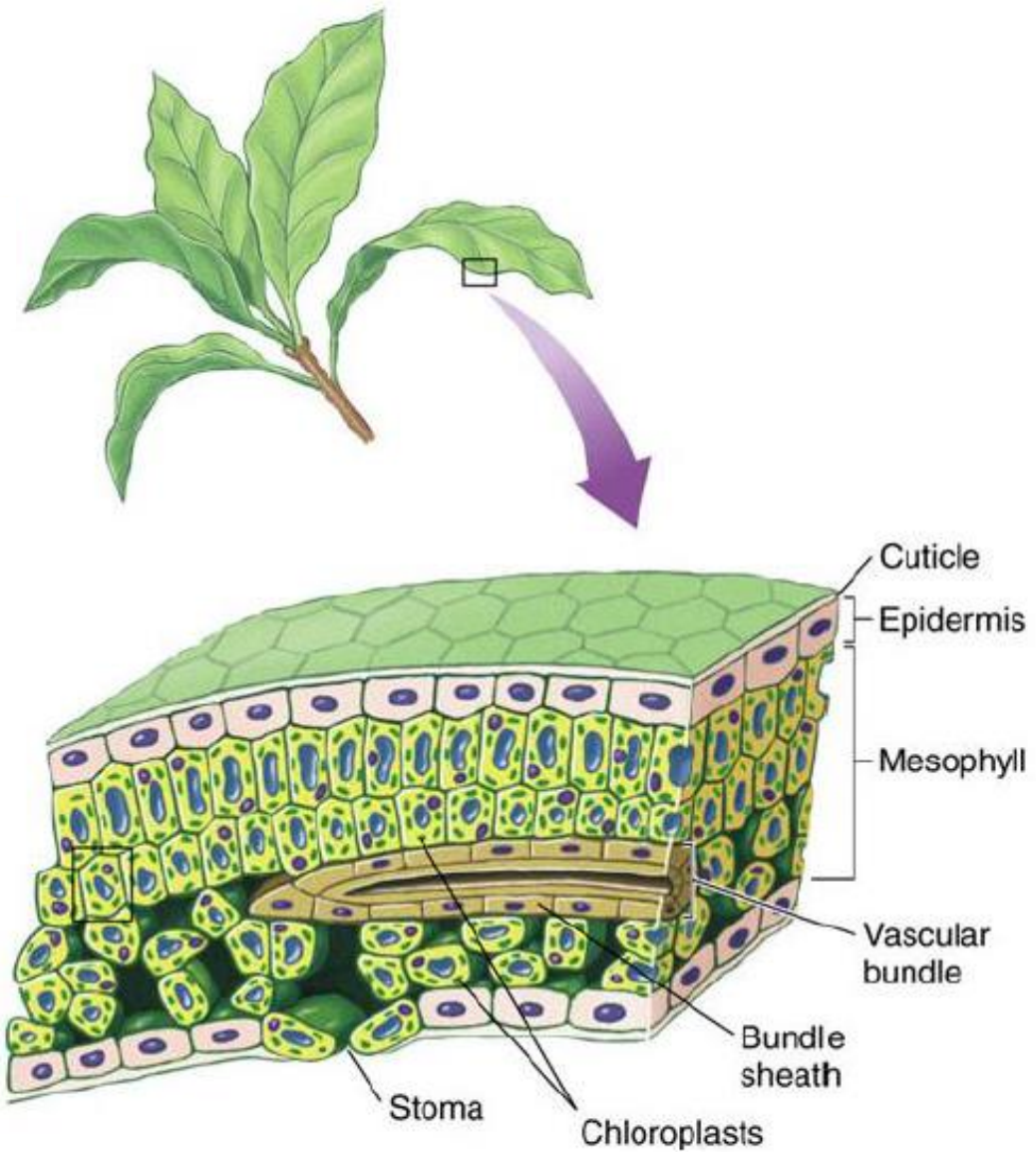


▲ Figure 7.11 Adaptations for photosynthesis in hot, dry climates

- In the overall equation for photosynthesis, notice that the reactants of photosynthesis, carbon dioxide (CO_2) and water (H_2O), are the same as the waste products of cellular respiration, and photosynthesis produces what respiration uses—



Structure of a Leaf



Chloroplast

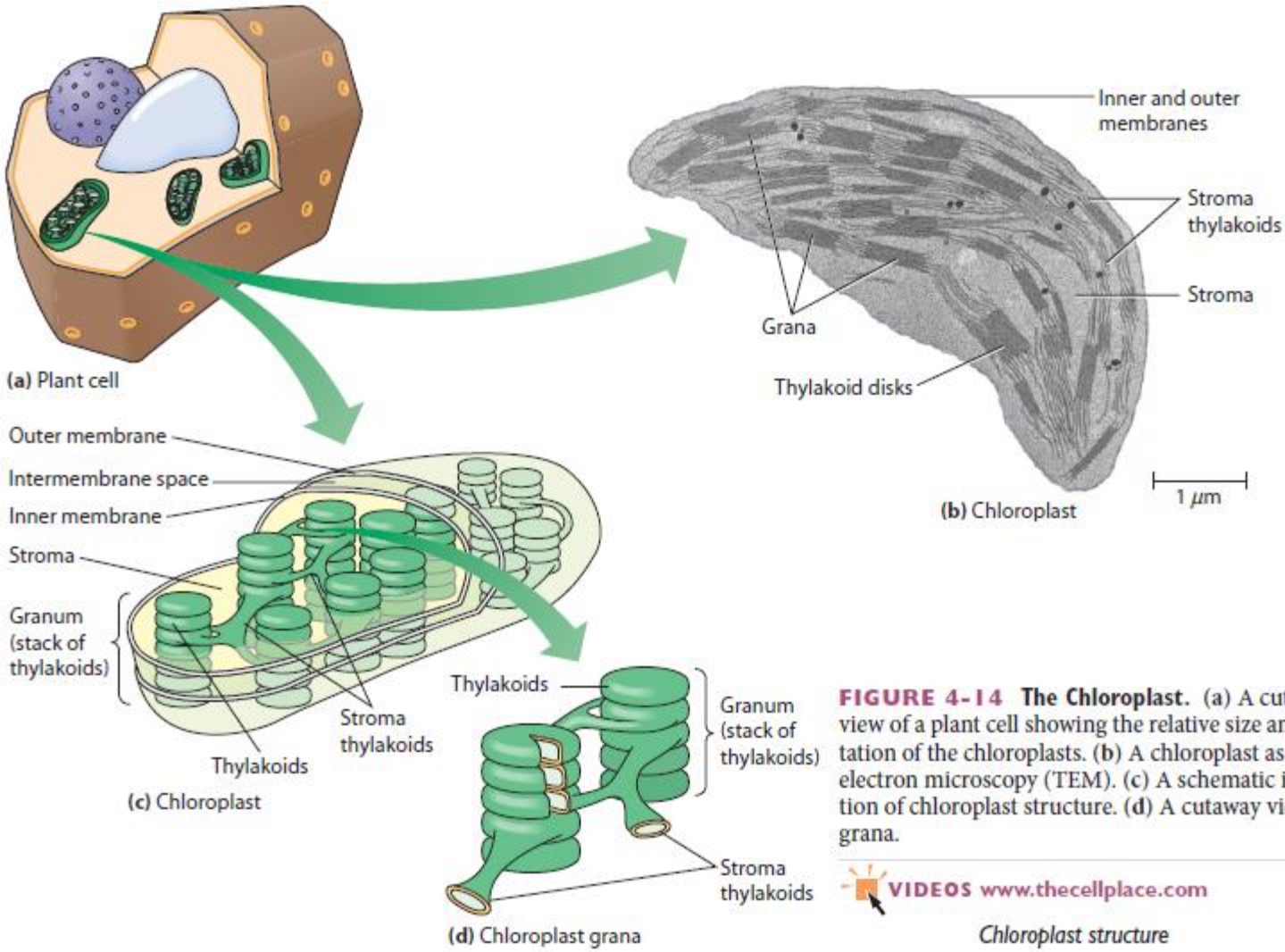


FIGURE 4-14 The Chloroplast. (a) A cutaway view of a plant cell showing the relative size and orientation of the chloroplasts. (b) A chloroplast as seen by electron microscopy (TEM). (c) A schematic illustration of chloroplast structure. (d) A cutaway view of two grana.

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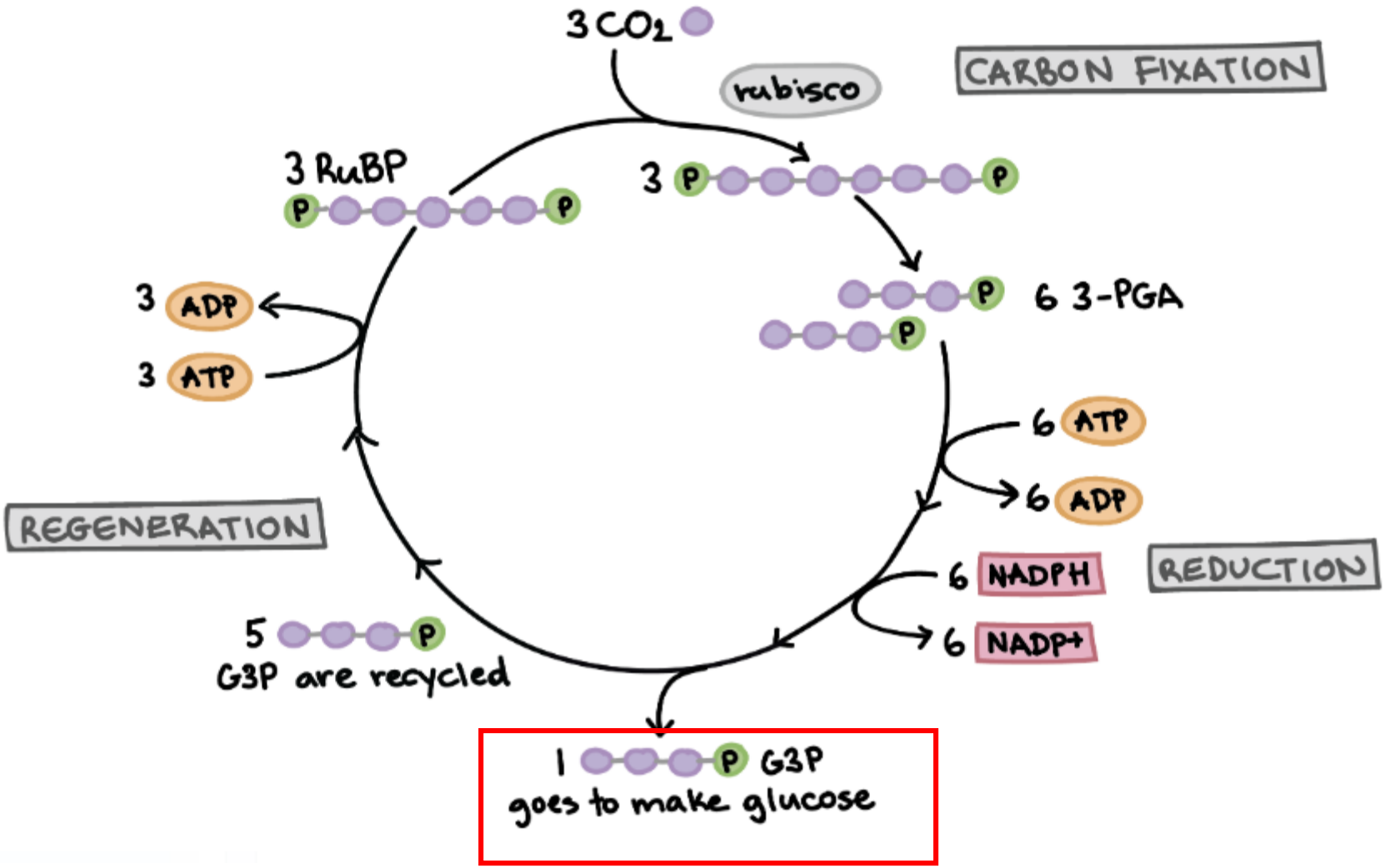
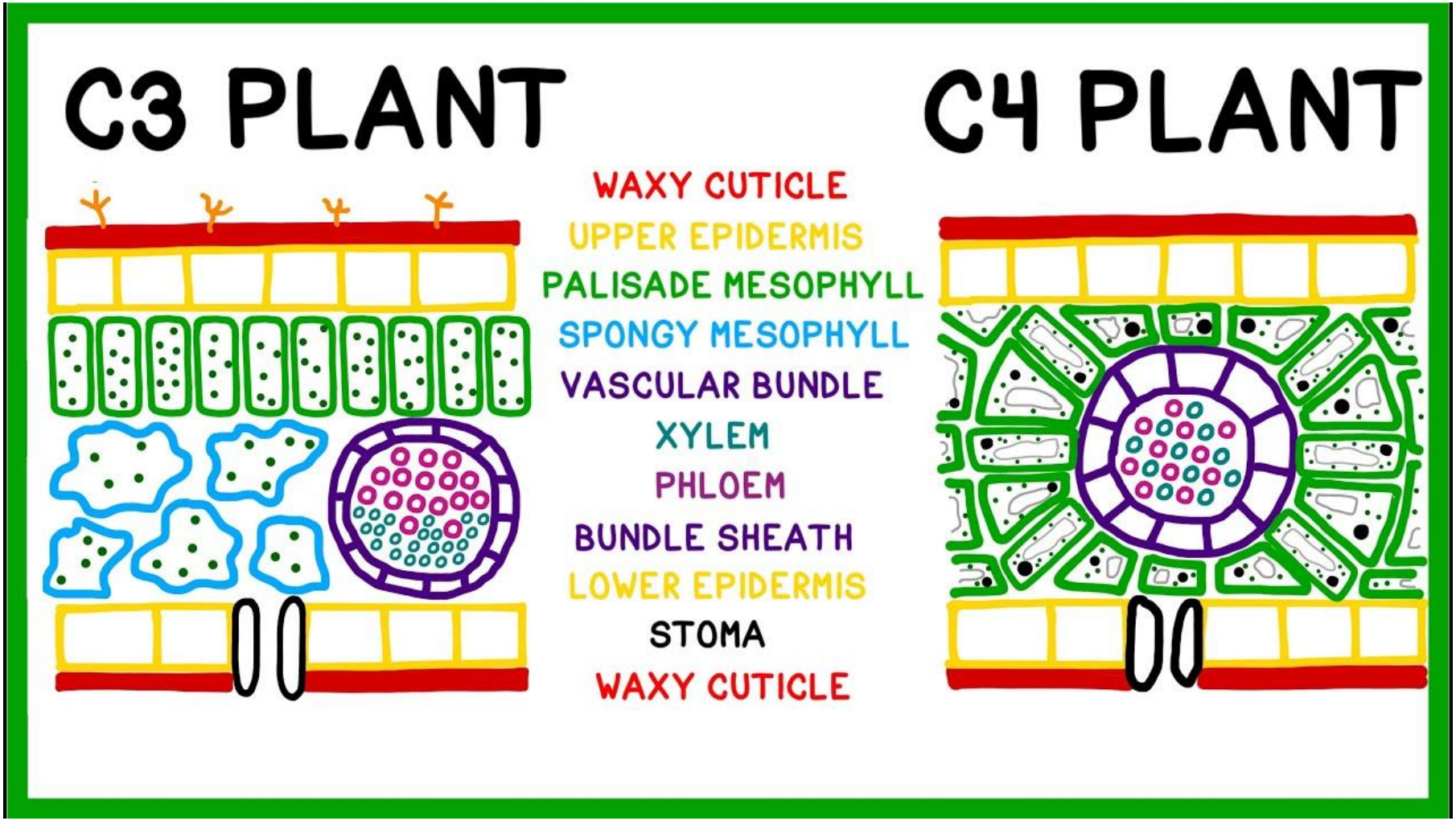
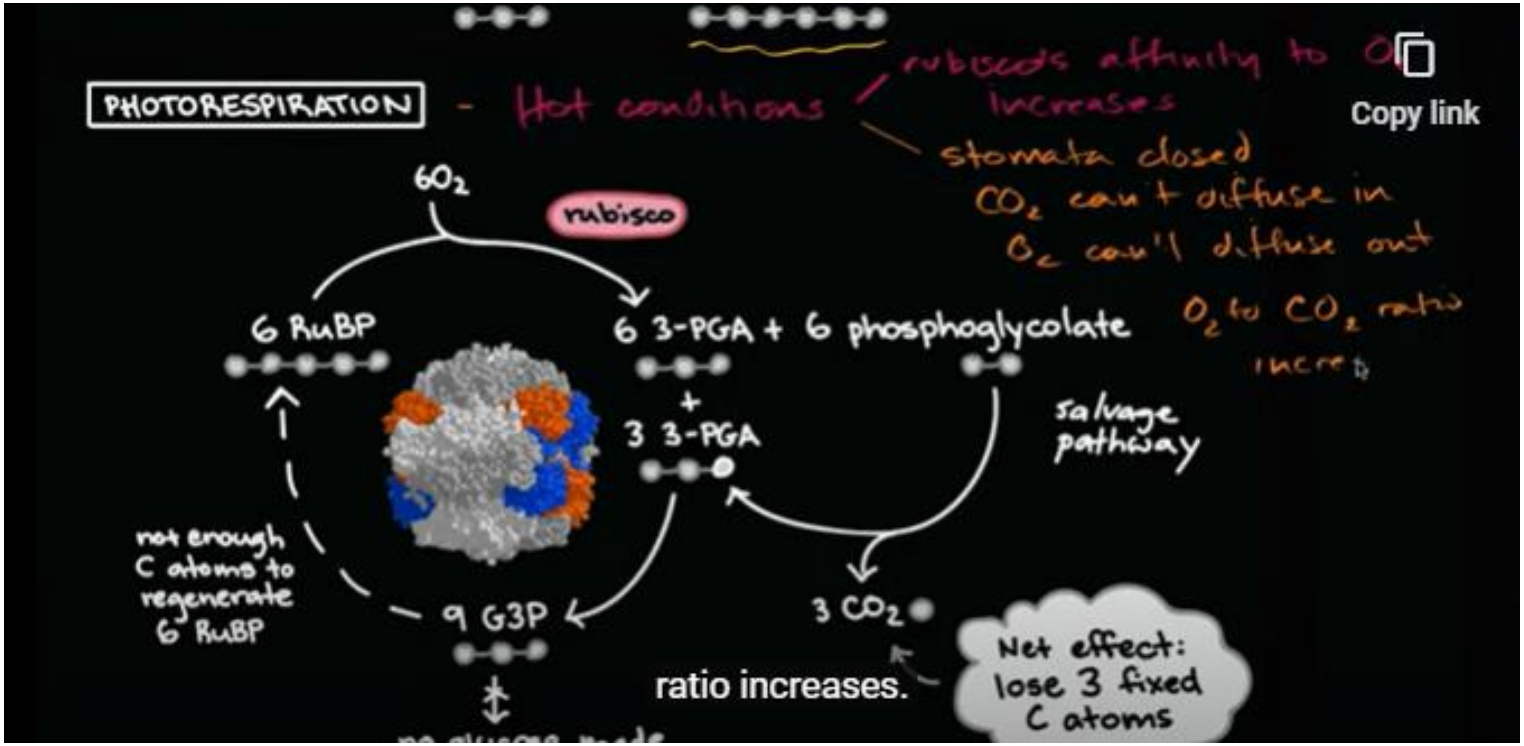
Chloroplast structure



Multiply each reaction by a factor of 2 to produce a 6 carbon sugar molecule




PHOTORESPIRATION
- Hot conditions
rubisco's affinity to O increases
stomata closed
CO_2 can't diffuse in
O_2 can't diffuse out
O_2 to CO_2 ratio incre
Copy link
$6O_2$
rubisco
6 RuBP
6 3-PGA + 6 phosphoglycolate
+
3 3-PGA
salvage pathway
not enough C atoms to regenerate 6 RuBP
9 G3P
3 CO_2
Net effect: lose 3 fixed C atoms
ratio increases.