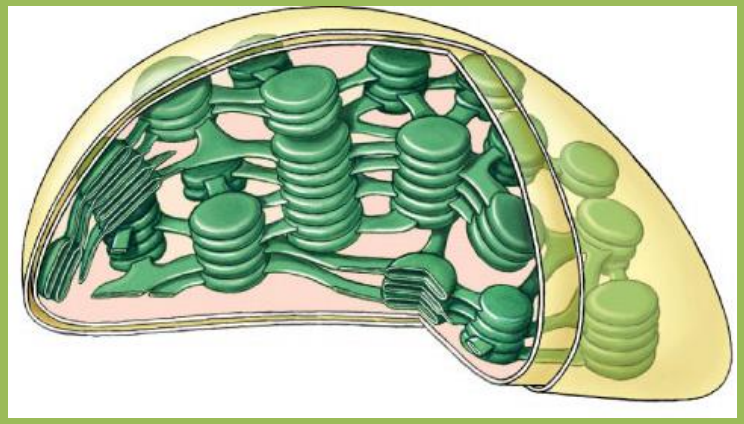
PHOTOSYNTHESIS

Dr. Bertolotti



Photosynthesis:

Life from Light and Air

Essential Question

- **How do plants and other organisms capture energy from the sun?**

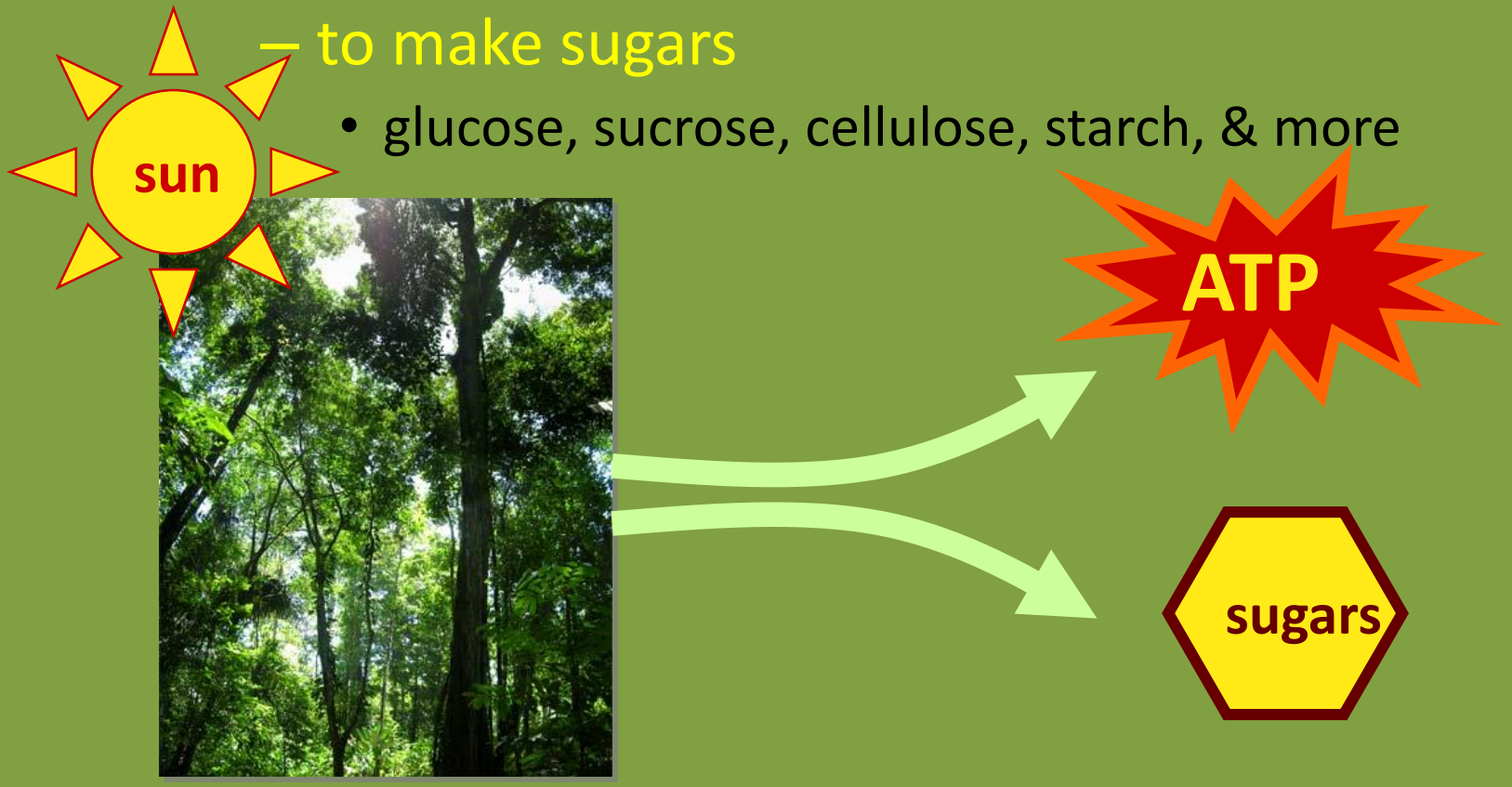
What is ATP and why is it useful in cells?

Plants are energy producers

- Like animals, plants need energy to live
  - unlike animals, plants don't need to eat food to make that energy
- Plants make both FOOD & ENERGY
  - animals are consumers (heterotrophs)
  - plants are producers (autotrophs or photoautotrophs)

How do plants make energy & food?

- Autotrophs (plants and Cyanobacteria) use the energy from the sun
  - to make ATP energy
  - to make sugars
    - glucose, sucrose, cellulose, starch, & more



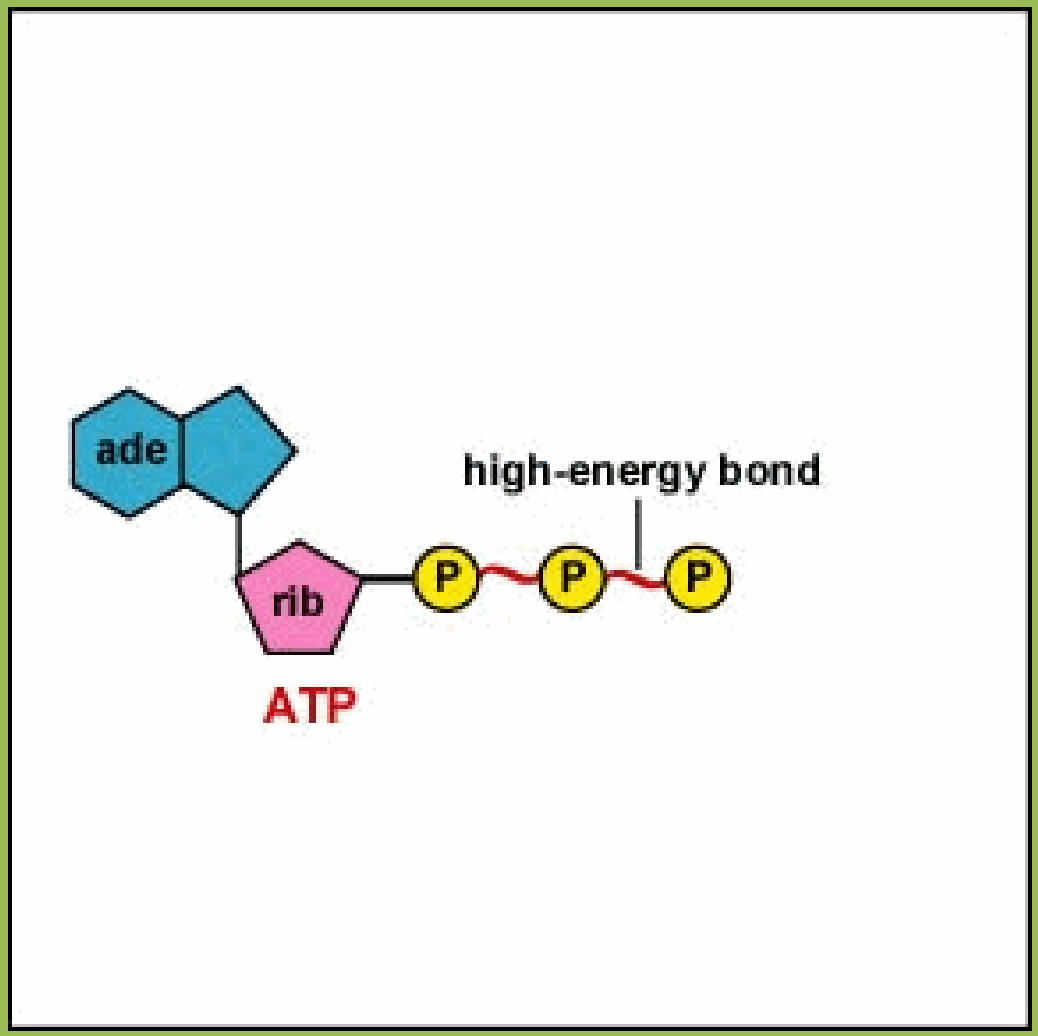
Chemical energy and ATP

- Energy is available in many forms including light, heat, and electricity

•**<u>Adenosine triphosphate</u> (ATP)** is the principal chemical compound that cells use to store and release energy for all metabolic activities.

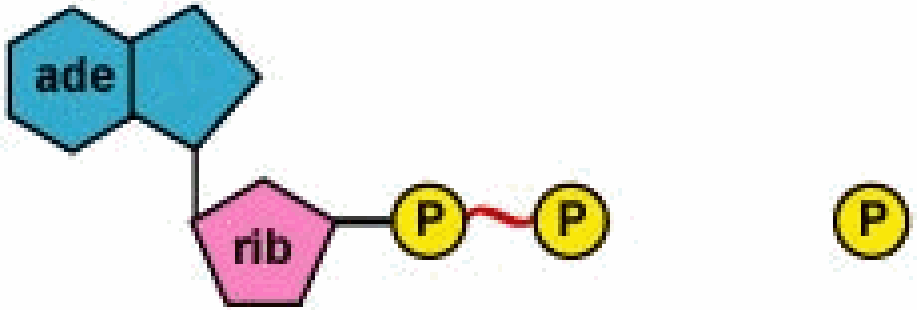
- •Consists of adenine, a 5 carbon sugar called ribose, and 3 phosphate groups (these 3 phosphate groups are key to ATP's ability to store and release energy)

The ATP molecule



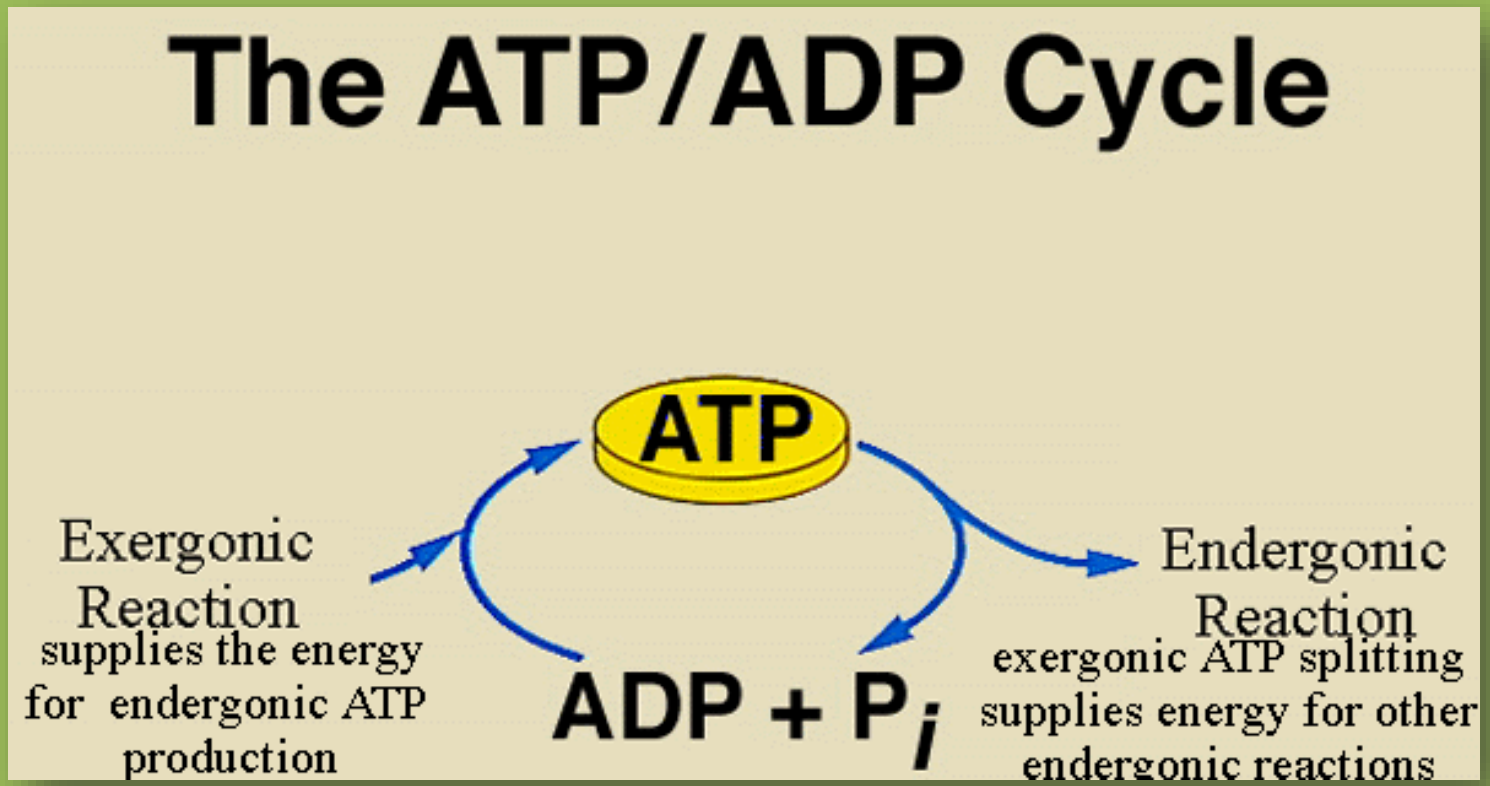
Storing energy

- **Adenosine diphosphate or ADP**
  - Has 2 phosphate groups instead of ATP's 3
  - When a cell has energy available, it can store small amounts of it by phosphorylation (the addition of a phosphate group) to the ADP molecule, thus producing ATP


ade
rib
P
P
P

Releasing energy

- Energy is released by breaking the chemical bond between the 2nd and 3rd phosphates in ATP



ATP vs. glucose

- ATP is a useful source of ***short term*** energy
  - ATP is great for transferring energy but not storing large amounts of energy for the long term
    - A single glucose molecule stores more than 90 times the chemical energy of a molecule of ATP, therefore it is more efficient for cells to keep a small amount of ATP which can be regenerated from ADP

Question and Answer

What is ATP and why is it useful in cells?

What happens during the process of photosynthesis?

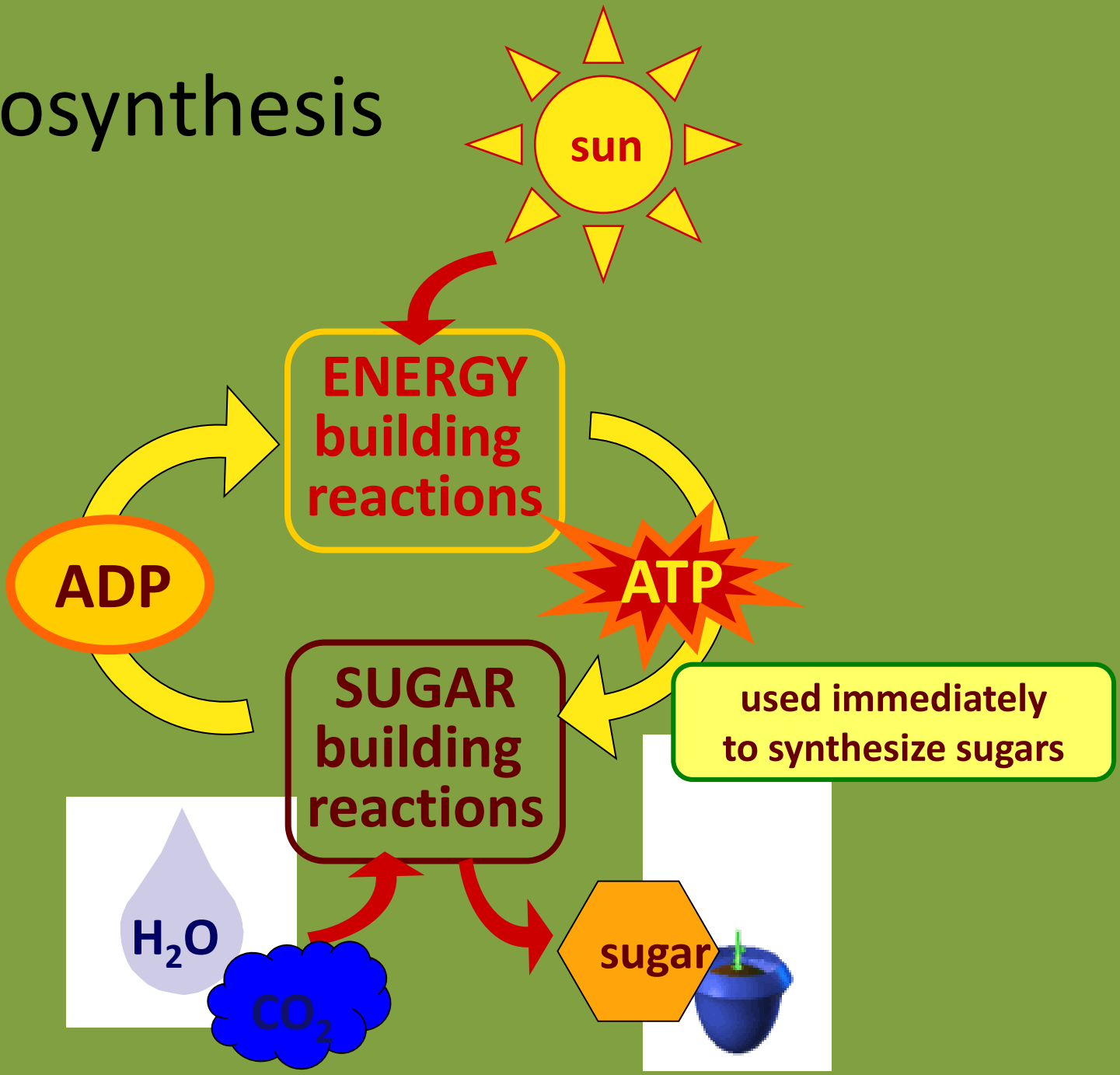
Photosynthesis Overview

- **PHOTOSYNTHESIS:** A process in which plants and Cyanobacteria use the energy from sunlight to convert water and carbon dioxide into oxygen and high energy carbohydrates- such as sugar (monosaccharide) and starches (polysaccharide)
  - *Reactants*: carbon dioxide and water
  - *Products*: oxygen and sugar (monosaccharide- glucose).

$$6CO_2 + 6H_20 \Rightarrow C_6H_{12}0_6 + 6\ O_2$$

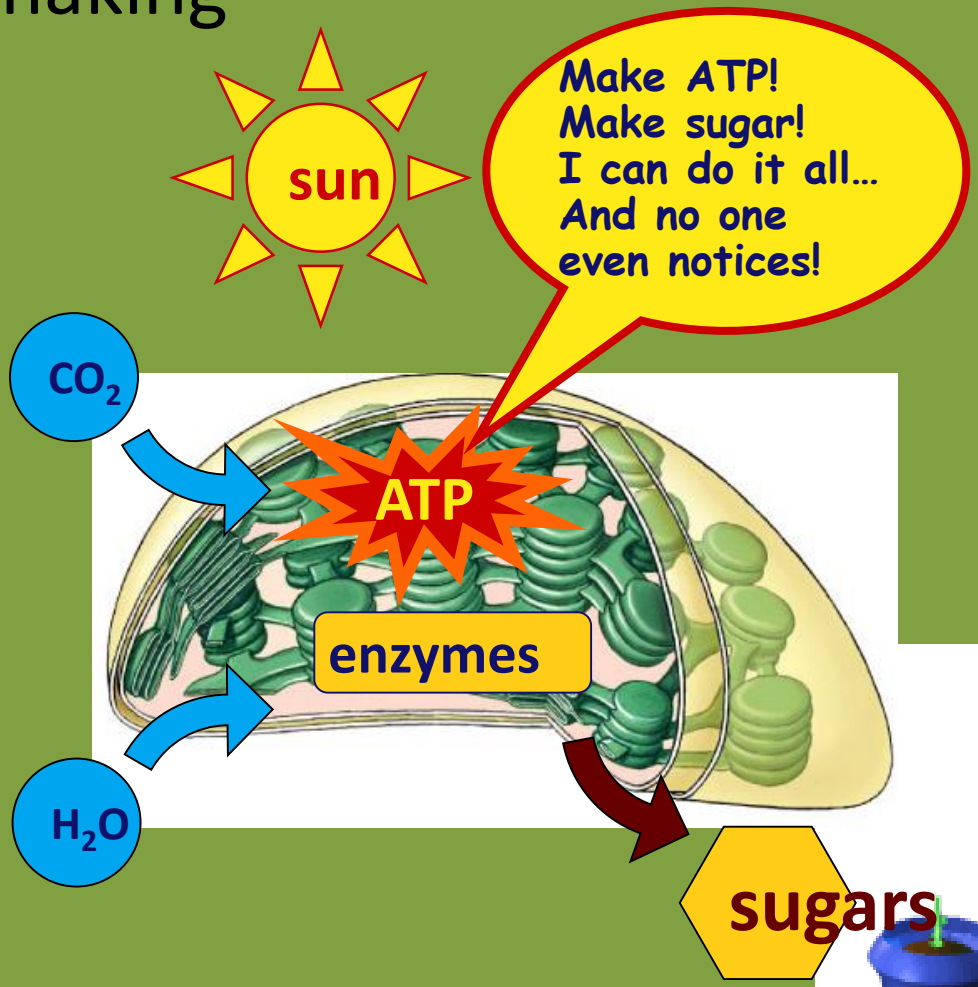
Carbon dioxide + water $\xrightarrow{\text{OR}}$ **sugars + oxygen**

Photosynthesis



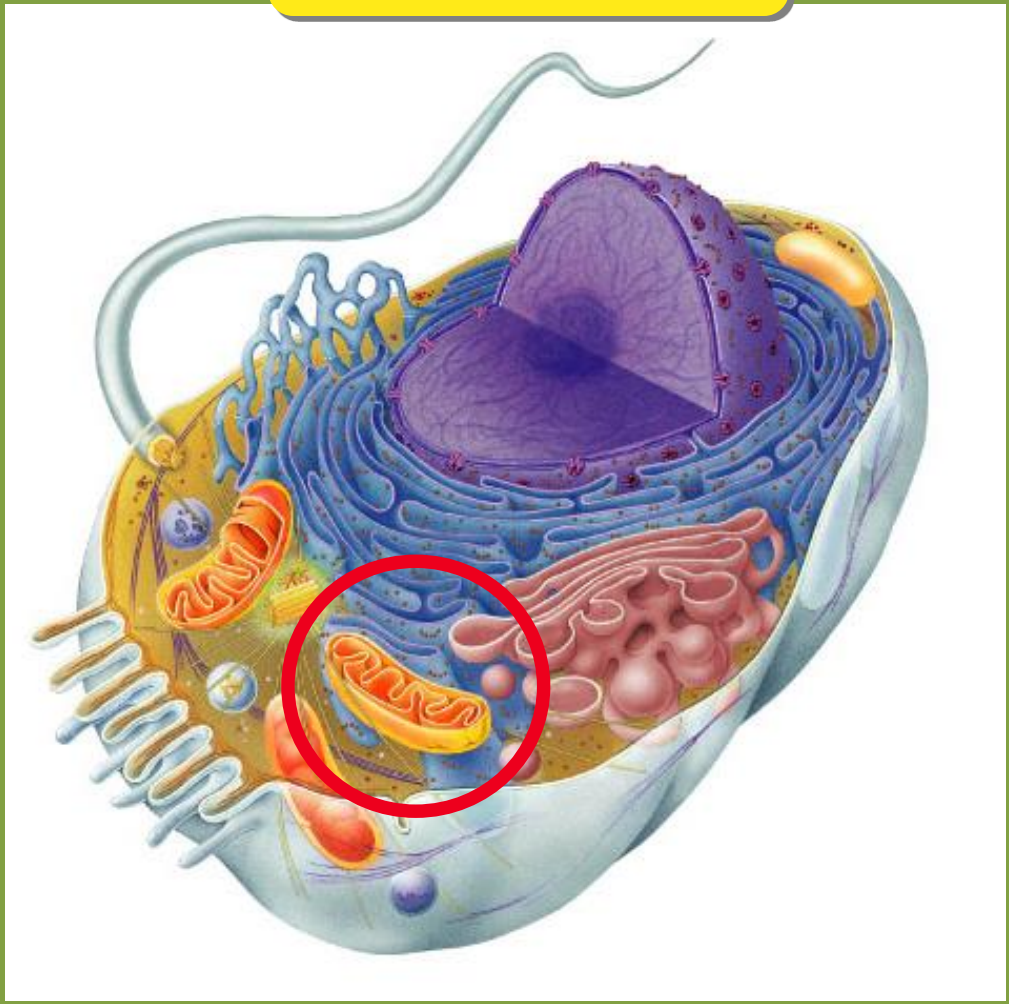
What do plants need to grow?

- The “factory” for making energy & sugars
  - chloroplast
- Fuels
  - sunlight
  - carbon dioxide
  - water
- The Helpers
  - enzymes

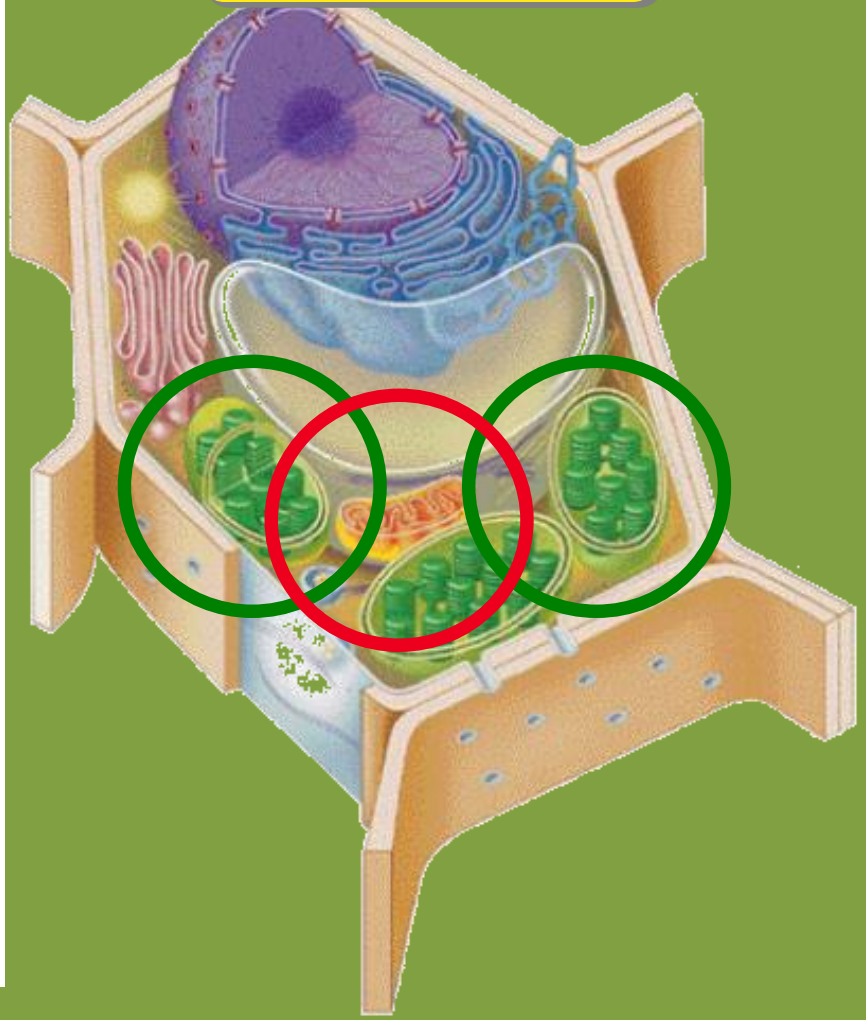


Chloroplasts are only in plants

animal cells



plant cells



Question and Answer

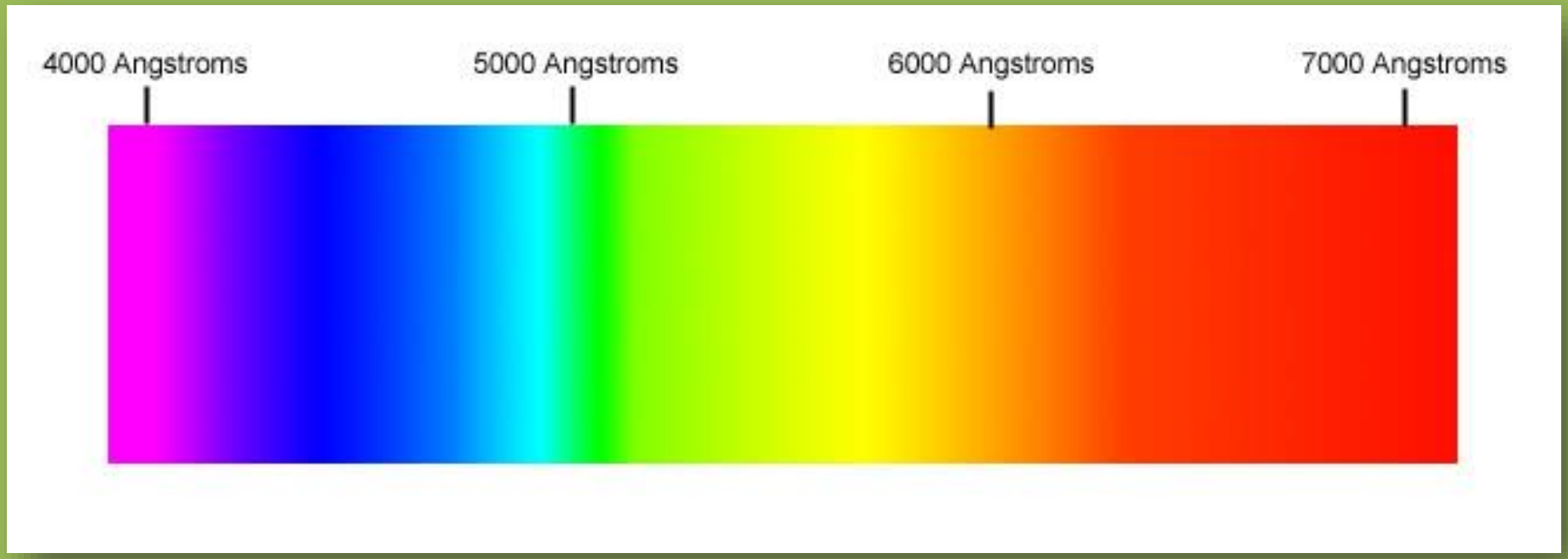
What happens during the process of photosynthesis?

What role do pigments play in the process of photosynthesis?

Light and Pigments

- Photosynthesis requires light and ***chlorophyll***, a molecule found in chloroplasts. Other pigments include carotenoids and anthocyanins.
- Energy from the sun travels to Earth in the form of light which appears "white"
  - Since light is a form of energy, any compound that absorbs light also absorbs the energy from that light
  - This light is actually made up of a mixture of different wavelengths of light- many of which are visible to your eyes

The wavelengths of light

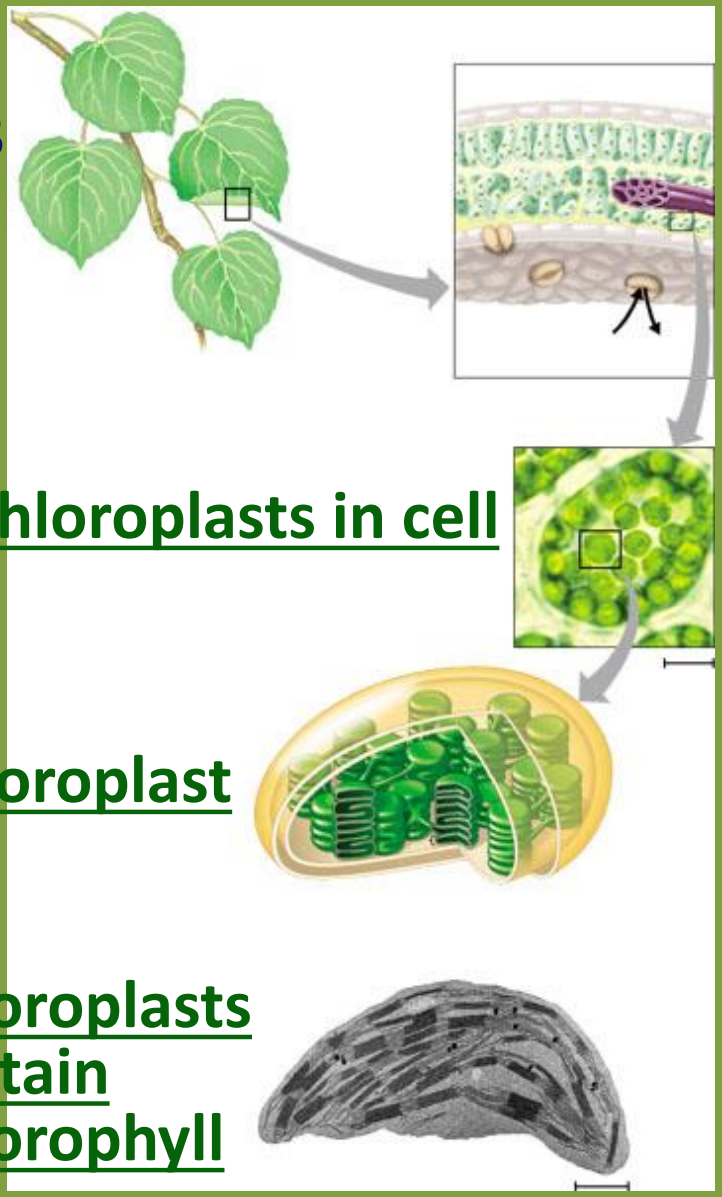


- **Pigments** are used to gather the sun's energy with light absorbing molecules, ex. Carotene and chlorophyll
- Most of the time, the green color of the chlorophyll overwhelms the other pigments, but as temperatures drop and chlorophyll molecules break down, the red and orange pigments may be seen.
  - The principal pigment is ***chlorophyll***
    - Chlorophyll absorbs light very well in blue-violet and red regions but NOT the green regions. Green light is reflected (that's why plants look green)

- There are **2** main types of chlorophyll
  1. chlorophyll a (absorbs mainly blue-violet and red regions)
  2. chlorophyll b (absorbs mainly in blue and red regions)

Chloroplasts

Leaves



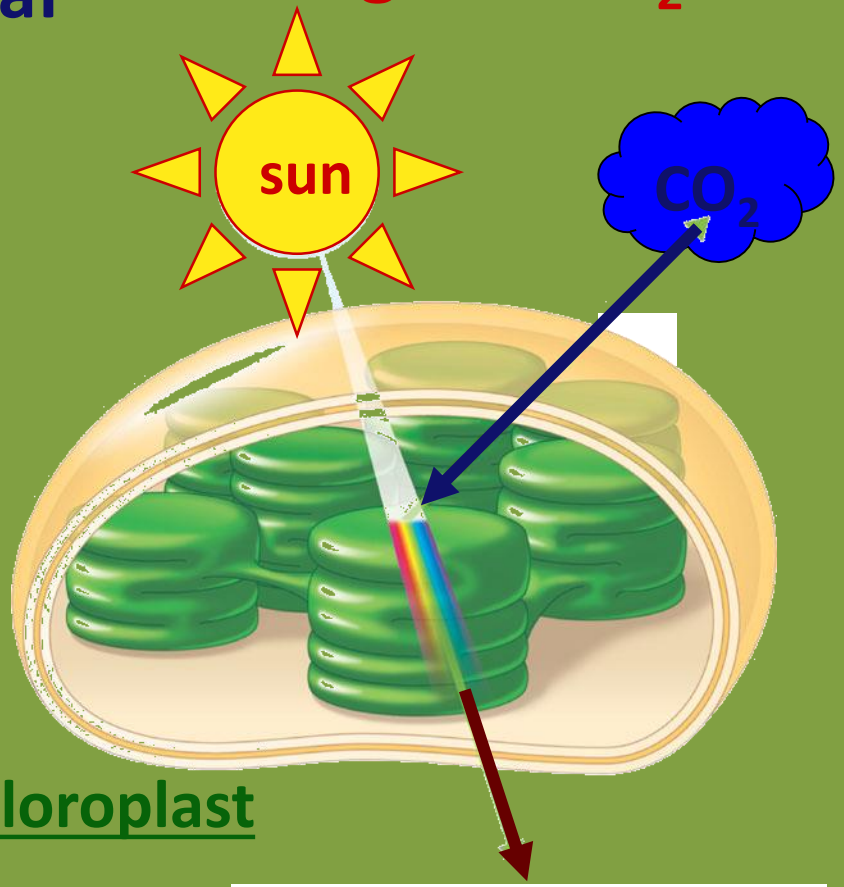
Chloroplasts in cell

Chloroplast

Chloroplasts contain Chlorophyll

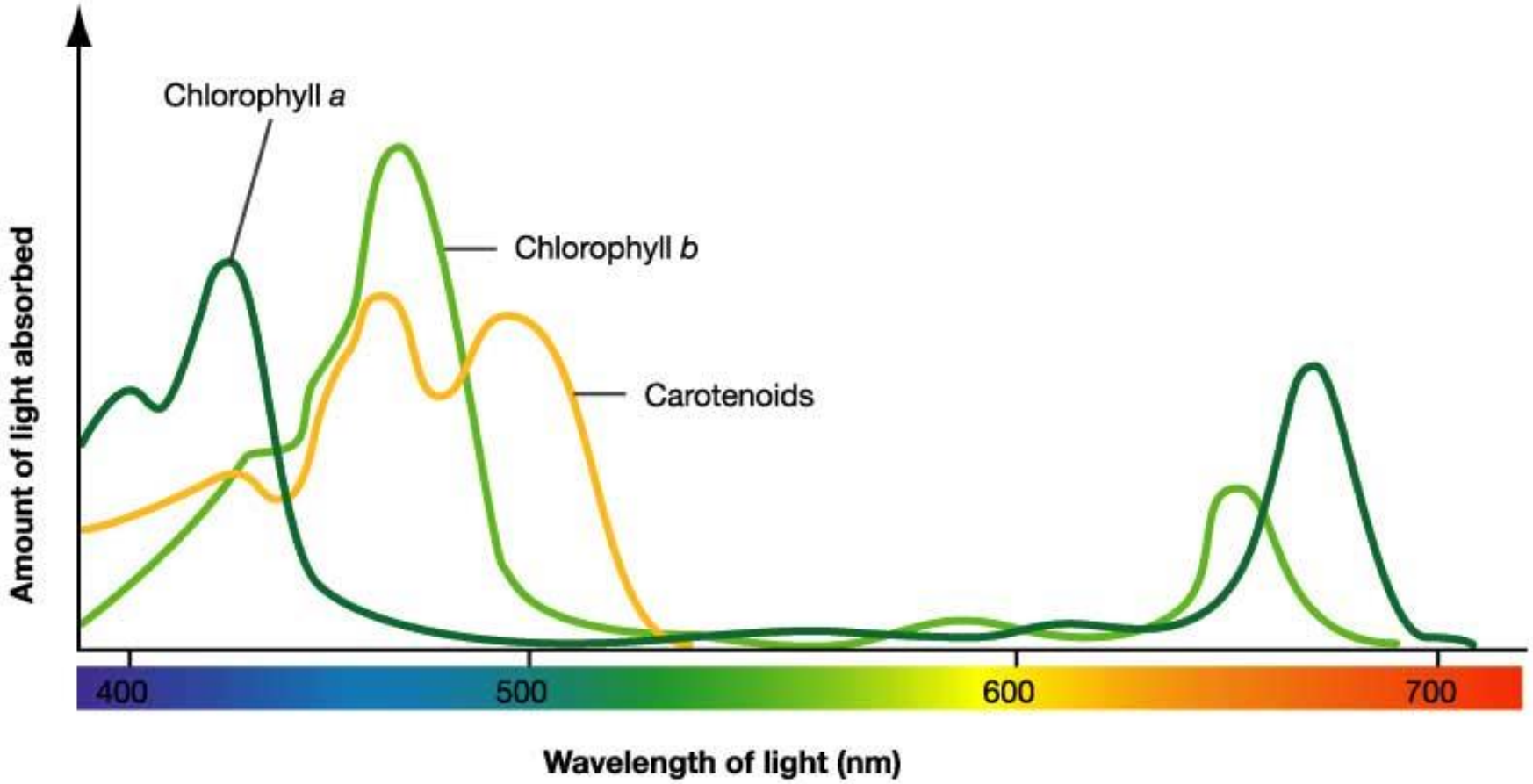
Leaf

absorb sunlight & CO_2

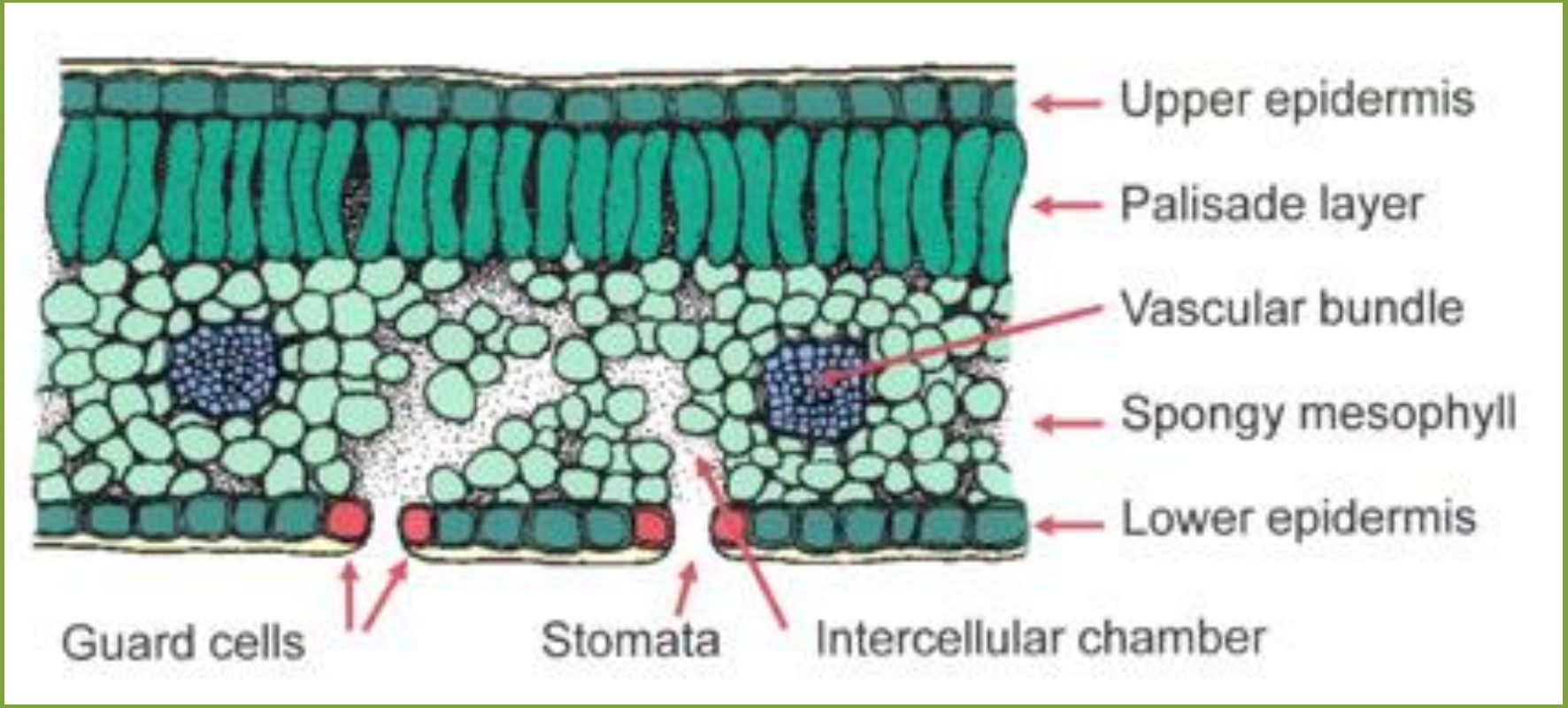


Chloroplast

make ENERGY & SUGAR

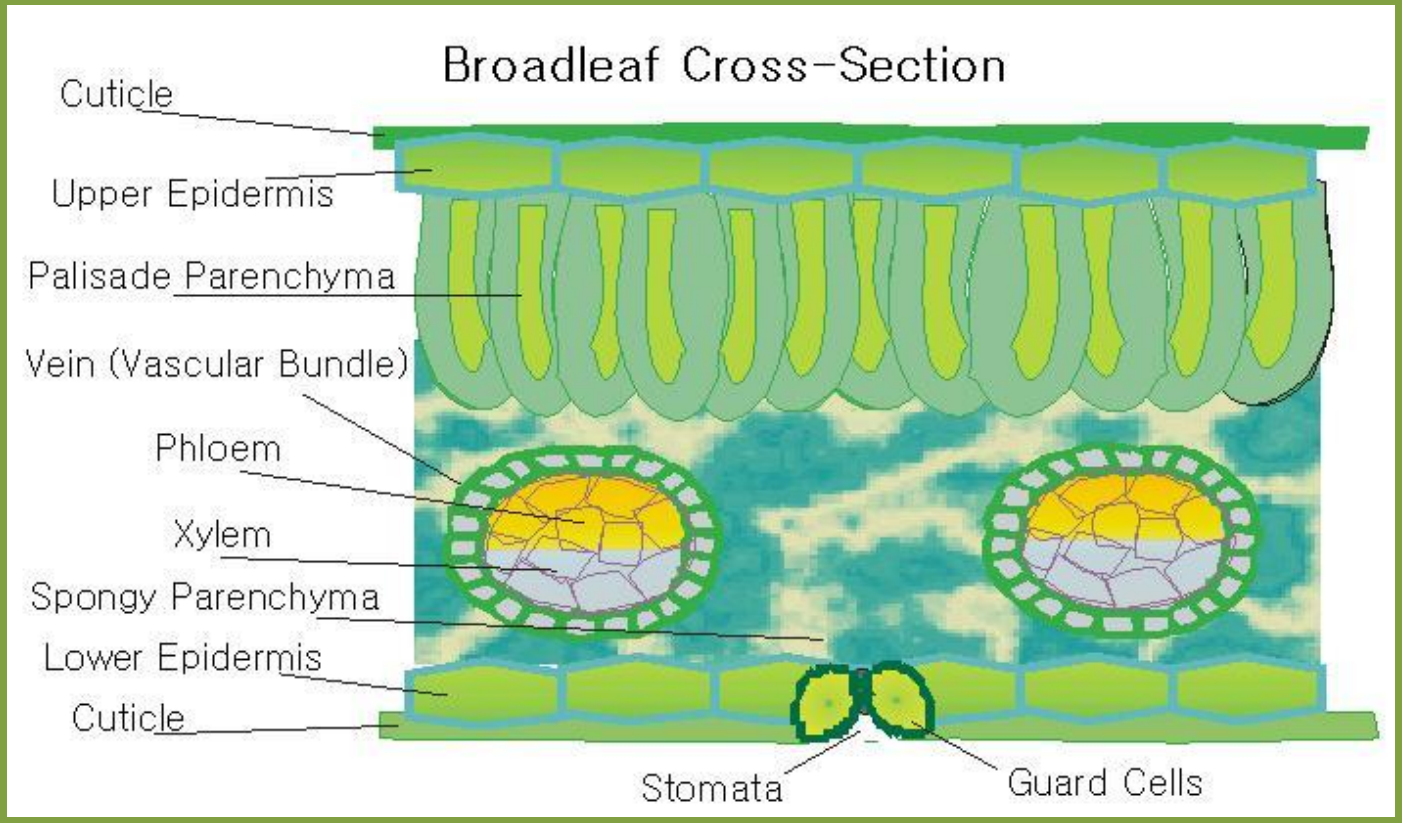

Chlorophyll *a*
Chlorophyll *b*
Carotenoids
Amount of light absorbed
400
500
600
700
Wavelength of light (nm)

Cross- section of a leaf



- ***Guard cells-*** are cells surrounding each stoma. They help to regulate the rate of transpiration by opening and closing the stomata, therefore helping to maintain homeostasis
- ***Stomata***- Pores in the epidermis in which the exchange of oxygen and carbon dioxide in the leaf (as well as the loss of water vapor in transpiration) occurs.

Cross- section of a leaf



- The ***cuticle*** is a water-impervious protective layer covering the epidermal cells of leaves and other parts and limits water loss.
- The **mesophyll** make up the bulk of internal leaf tissue and are the major site of photosynthesis in a plant by virtue of containing large populations of chloroplast organelles

Question and Answer

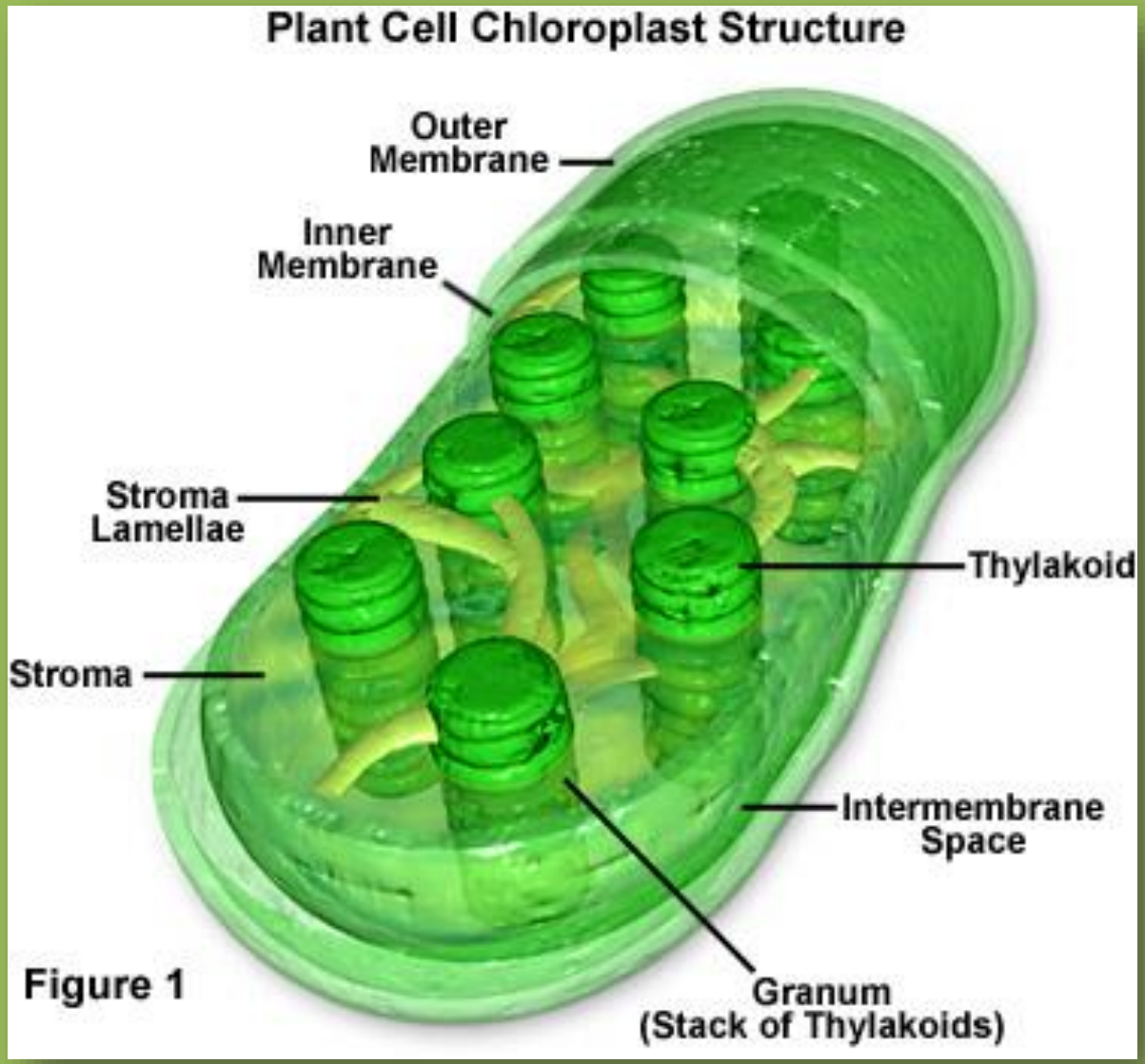
What role do pigments play in the process of photosynthesis?

What processes occur during photosynthesis?

Reactions of Photosynthesis

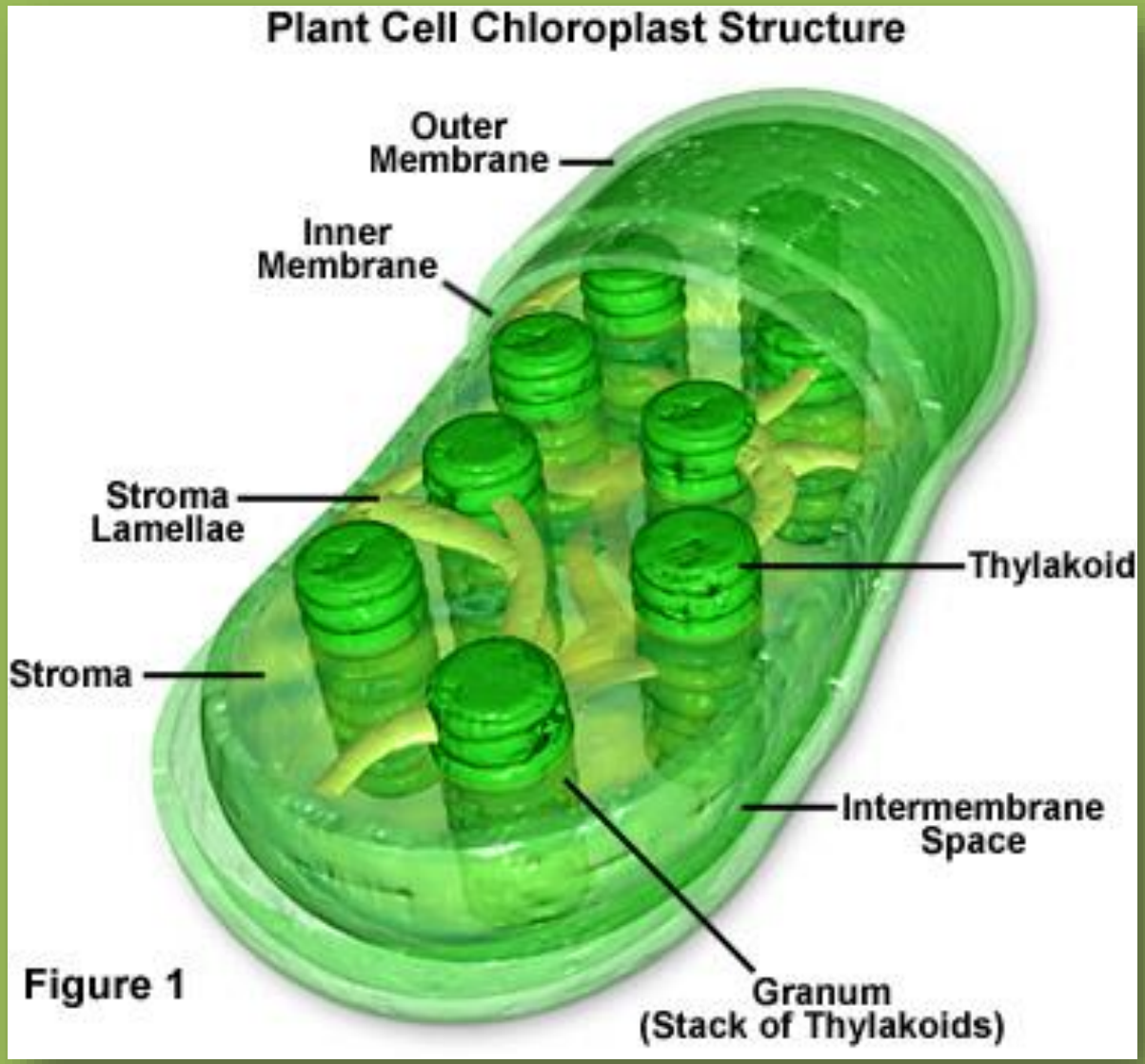
- Photosynthesis takes place in the chloroplast
- Chloroplasts contain a sack-like photosynthetic membrane called a ***thylakoid*** which are arranged in stacks called ***grana***
- Proteins in the thylakoid membrane organize chlorophyll and other pigments into clusters known as ***photosystems*** (found in the light-collecting units of the chloroplast)

A chloroplast



- The reactions of photosynthesis can be categorized into **2** main parts:
  - *1.**Light-dependent reaction***
    - Takes place within the thylakoid membranes
    - Photosynthetic phosphorylation or photophosphorylation is the process of phosphate group transfer into ADP to synthesize energy rich ATP molecule making use of light as external energy source.
  - 2. ***Light-independent reaction or Calvin cycle***
    - Takes place in the ***stroma:*** the space outside the thylakoid membrane

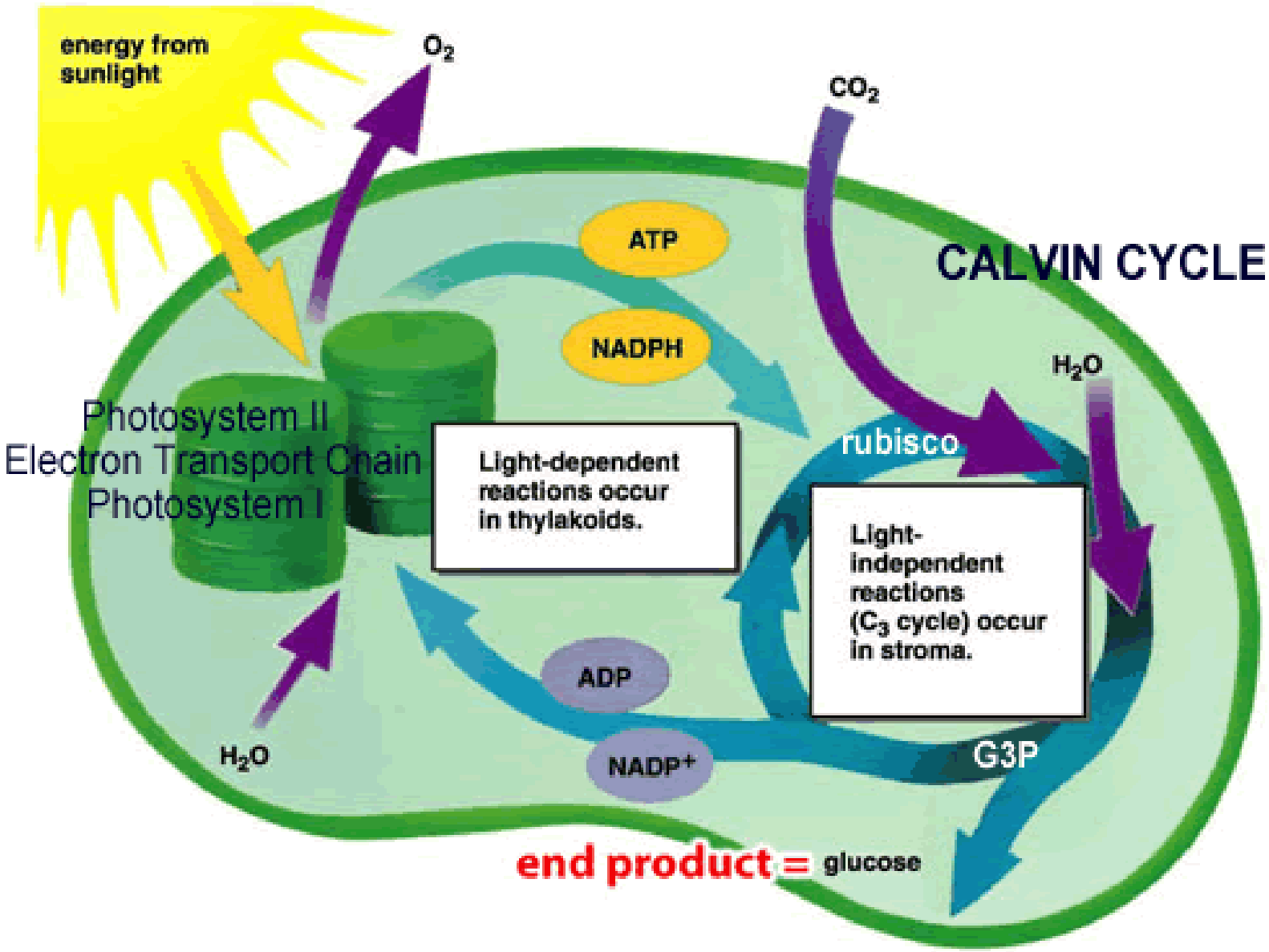
A chloroplast



Electron carriers

- A ***carrier molecule*** is a compound that can accept a pair of high-energy electrons and transfer them along with most of their energy to another molecule
- This process is called ***electron transport*** and the electron carriers themselves are known as the ***electron transport chain***

- ***NADP+*** is a carrier molecule that accepts and holds 2 high energy electrons along with a hydrogen ion (H^+) form NADPH
  - $NADP^+$ + 2 electrons (2 e^-) + H^+ = NADPH
- NADPH carries these high energy electrons to chemical reactions elsewhere in the cell


energy from sunlight
O_2
CO_2
ATP
NADPH
CALVIN CYCLE
H_2O
Photosystem II
Electron Transport Chain
Photosystem I
Light-dependent reactions occur in thylakoids.
rubisco
Light-independent reactions (C_3 cycle) occur in stroma.
ADP
H_2O
$NADP^+$
G3P
end product = glucose

Light-dependent reactions

- Requires light
- Uses energy from light to produce ATP, oxygen, and NADPH
- Water provides the electrons that are used to pump hydrogen ions (H^+) from the stroma to the thylakoid space. The electrons are then added to the NADP+ molecules to produce NADPH.
- The gradient produced from hydrogen ions (H+) pumped into the stroma provides the energy to make ATP.
- Photosynthetic phosphorylation or photophosphorylation is the process of phosphate group transfer into ADP to synthesize energy rich ATP molecule making use of light as external energy source.

- http://www.science.smith.edu/departments/Biology/Bio231/ltrxn.html
- http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter10/animations.html#

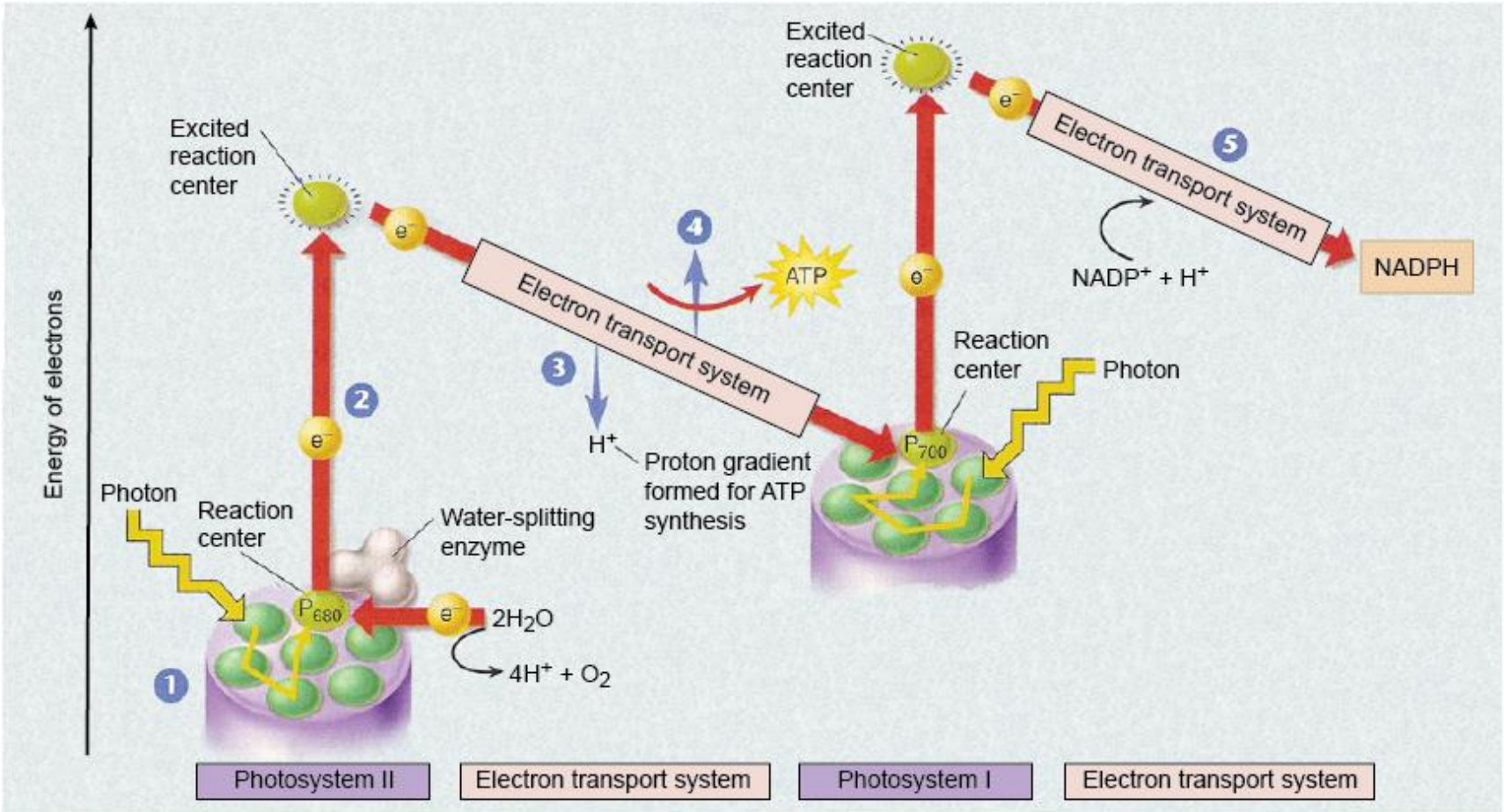
Light-dependent reactions- Part 1

- Light reactions take place in structures within the chloroplast called the *grana*. Grana are simply stacks of membrane-bound sacs called thylakoids. The thylakoid membrane is where light is harvested and its energy captured. The structures embedded within the thylakoid that harvest light are called photosystems; a chloroplast contains thousands of photosystems.
- Photosystems are made up of pigment molecules. In plants, chlorophyll is the main pigment, but accessory pigments such as the carotenoids are also present. These allow the plant to absorb a broader spectrum than just the wavelengths of light absorbed by chlorophyll.

Light-dependent reactions- Part 2

- The light-dependent reaction of plants uses two photosystems. In the first photosystem (called *Photosystem II* because it was discovered second), the captured energy that reaches the reaction center chlorophyll boosts an electron to a higher orbital. That high-energy electron is picked up by an electron acceptor in the thylakoid membrane and transported through a series of proteins that make up an electron transport system. As the electron moves through these proteins, it loses energy.
- It then reaches a second photosystem (called *Photosystem I* because it was discovered first). The energy from the sun is absorbed by the pigments in this photosystem and again used to raise the energy level of the electron. Once again the electron is passed through an electron transport system giving up energy. Ultimately, this energy is converted to ATP and NADPH which will be used in the light-independent reactions.

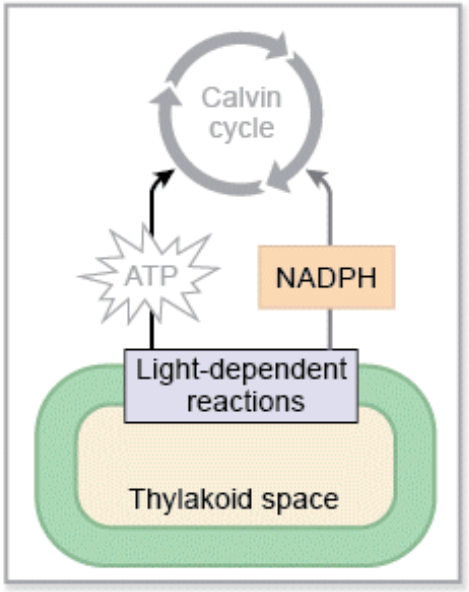
Light-dependent reactions

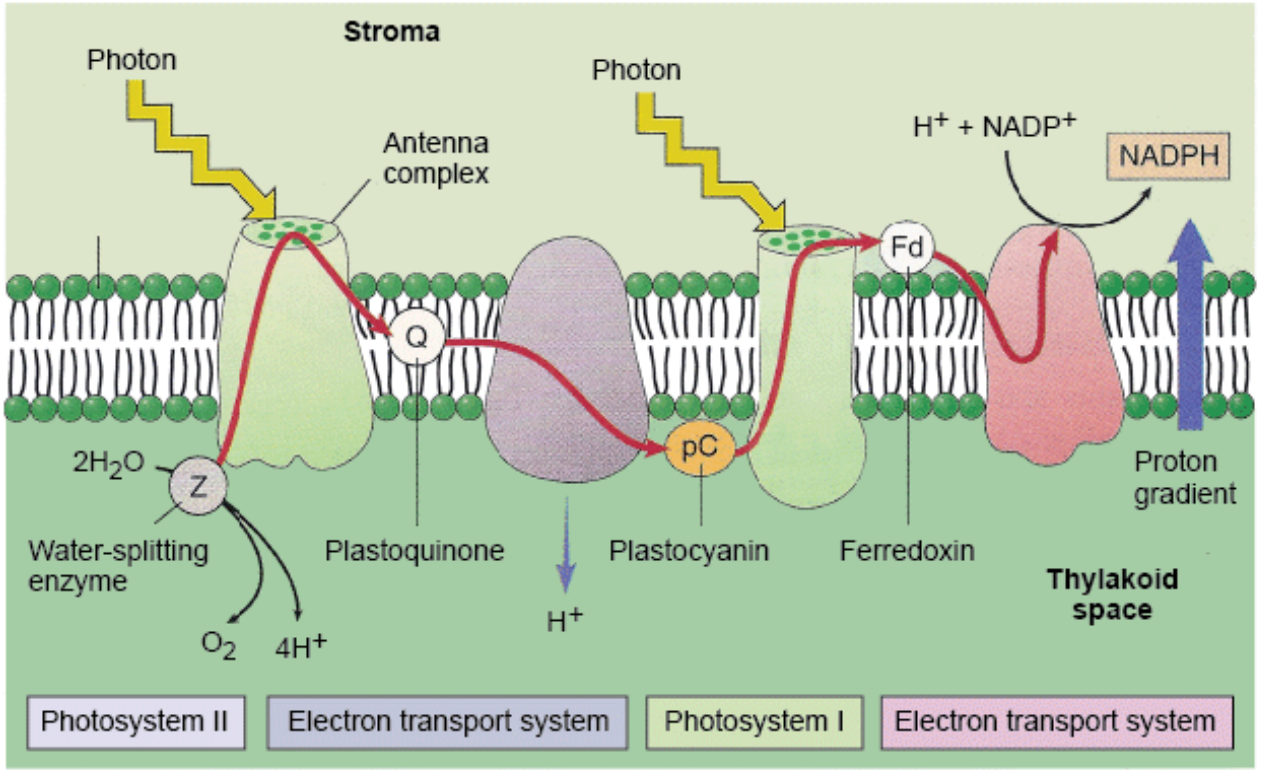


Light-dependent reactions- Part 3

You may wonder what happens after the electron leaves the reaction center chlorophyll--does the photosystem stop working because the pigment molecule is missing an electron? Actually, a process called *photolysis* replaces these electrons in a reaction where a water molecule is split. Enzymes in the thylakoid split a water molecule into hydrogen ions and oxygen gas. Electrons are released and recharge the reaction center chlorophyll. The oxygen generated by photosynthesis is derived from this process, which is dependent on water. A plant that runs out of water runs out of a supply of electrons to keep its chlorophyll molecules "recharged." Thus you can understand the important role of water in photosynthesis.

Light-dependent reactions

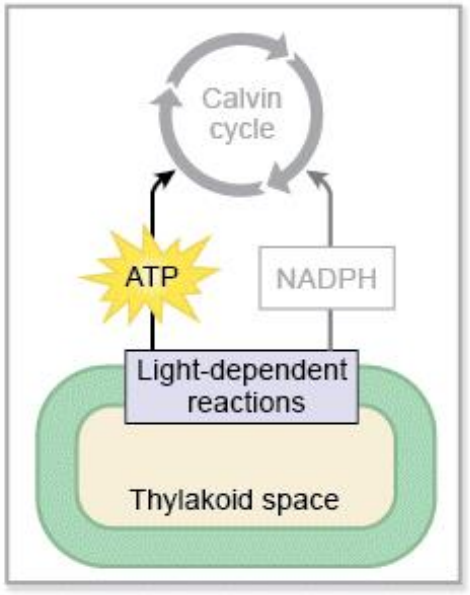


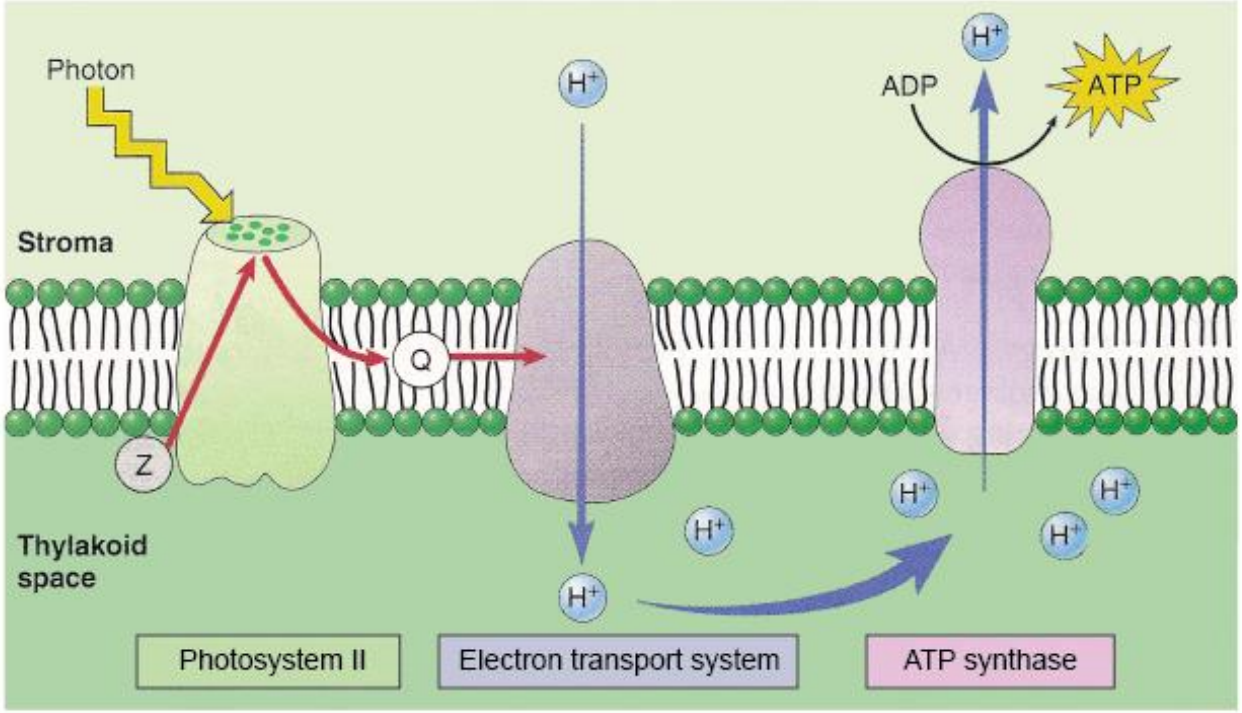


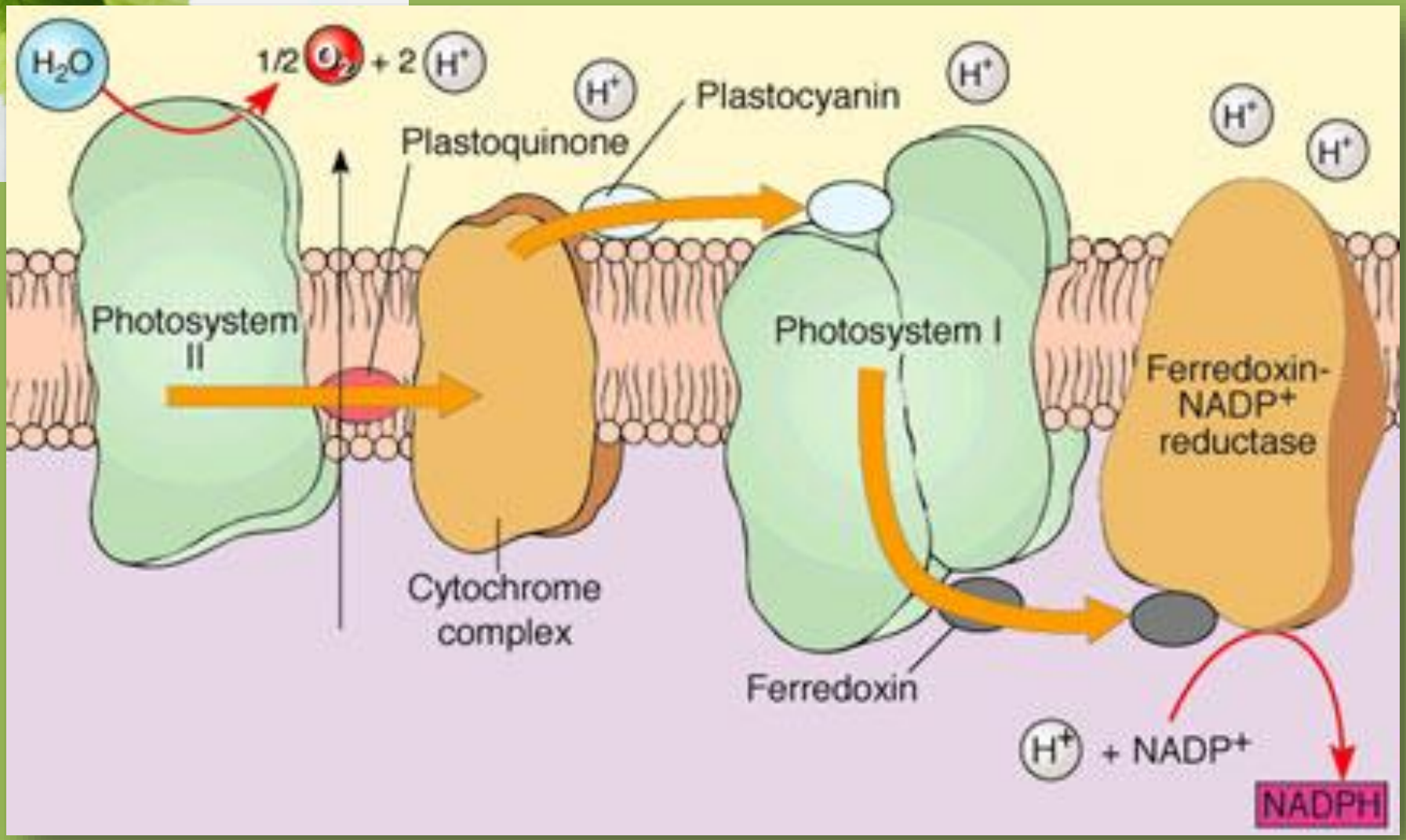
Light-dependent reactions- Part 4

Electrons moving through the electron transport system proteins in the thylakoid membrane lose energy. Where does that energy go? It is used indirectly to make ATP. As the electrons energized in Photosystem II move through the first electron transport system, they power the pumping of hydrogen ions across the thylakoid membrane, against their concentration gradient. (The proton pump is a type of active transport channel). This creates a proton gradient. Remember, a hydrogen ion that has lost its electron is called a proton because it has a single proton in the nucleus of its atom. This process produces a high concentration of protons inside the thylakoid. This gradient is potential energy, just like the water stored behind a dam is potential energy. These electrons want to move back across the membrane (just as water wants to flow downstream) but are blocked because they are charged and cannot pass through the membrane without a carrier molecule. When water is released from a dam and flows across a turbine, the potential energy is converted to kinetic energy. The kinetic energy turns the turbines, generating electricity. Similarly, this high concentration gradient of protons is potential energy. There is a specific channel protein called ATP synthase in the thylakoid membrane, and this is the only molecule through which these hydrogen ions can flow back out of the thylakoid. As these hydrogen ions flow through this ATP synthase channel, their potential energy is converted to kinetic energy, and through this process ATP is generated from ADP. This process is called photophosphorylation because the energy used to add the phosphate to ADP and generate ATP comes from light. At the end of the second electron transport system, after Photosystem I, the low-energy electrons and a proton are eventually picked up by $NADP^+$ making NADPH. An electron starts its journey in a water molecule and ends up in a NADPH molecule. What does this accomplish? Where did all the energy from those electrons go? That energy is stored in ATP and NADPH and will be used to power the light-independent reactions producing the organic molecules that feed the plant.

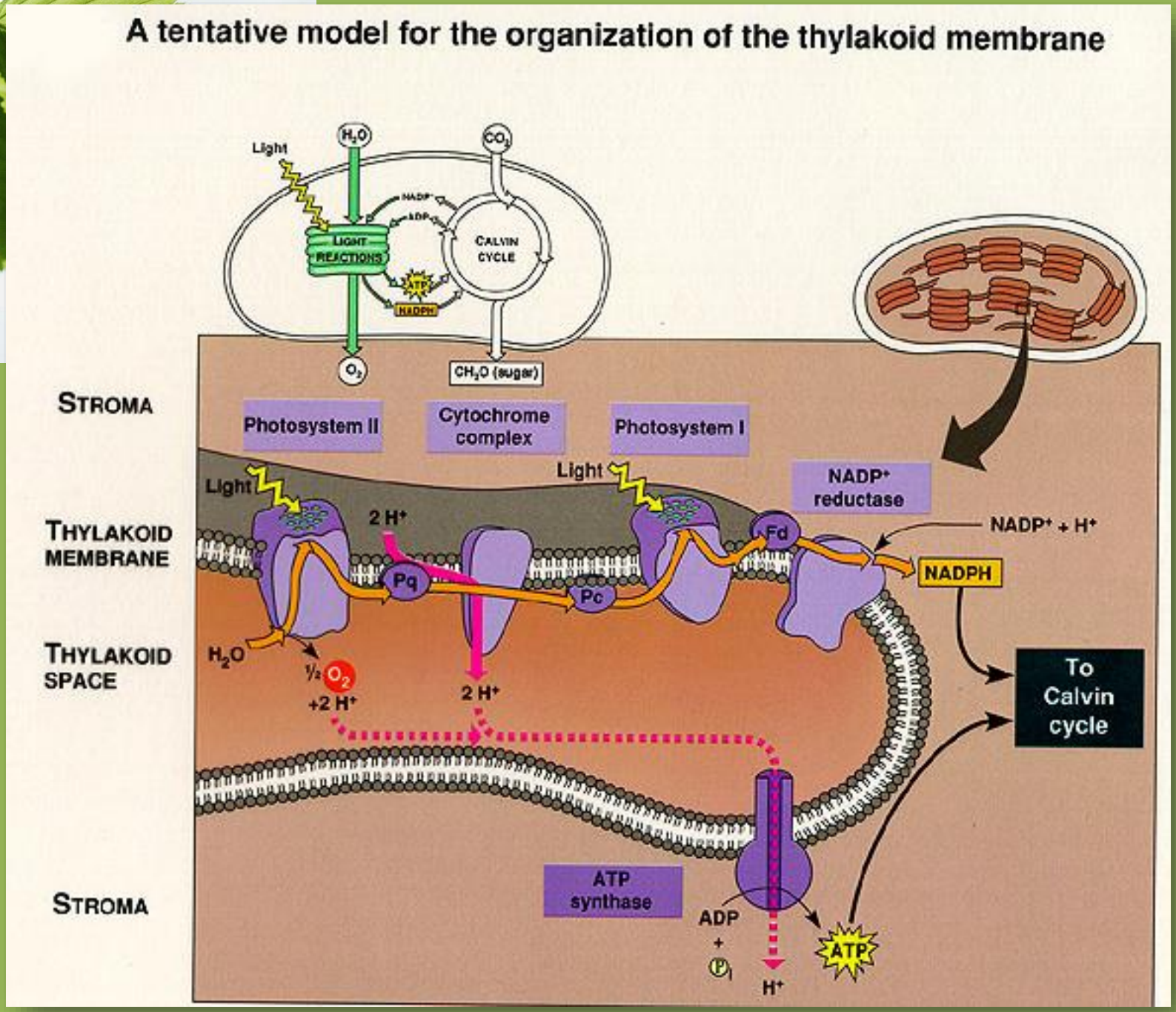
Photophosphorylation





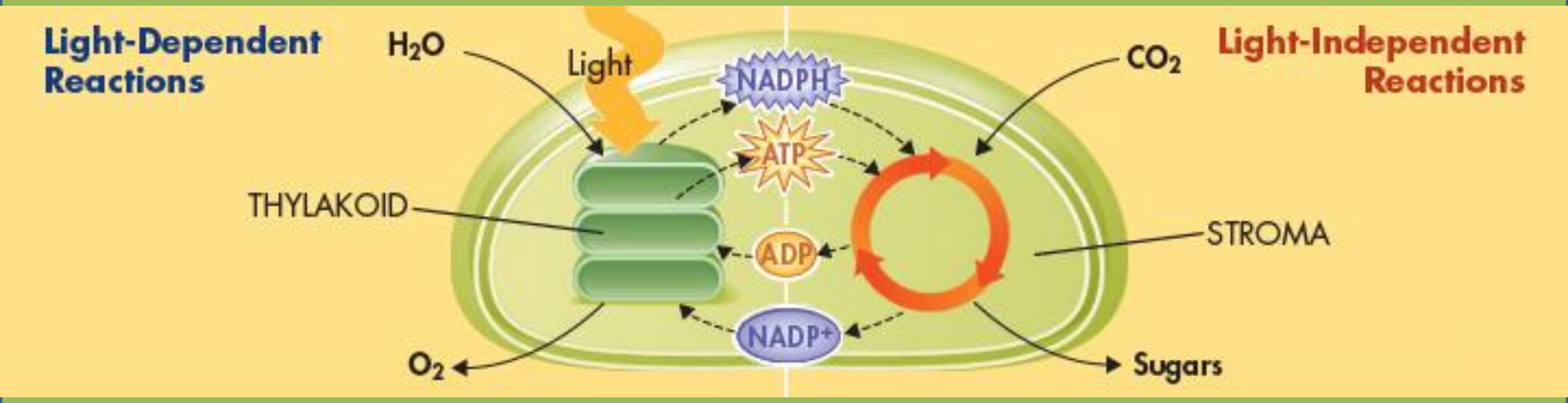

H_2O
1/2 O_2 + 2 H^+
H^+
Plastocyanin
H^+
Plastoquinone
H^+
H^+
Photosystem II
Photosystem I
Ferredoxin-NADP+ reductase
Cytochrome complex
Ferredoxin
H^+ + NADP+
NADPH

A tentative model for the organization of the thylakoid membrane

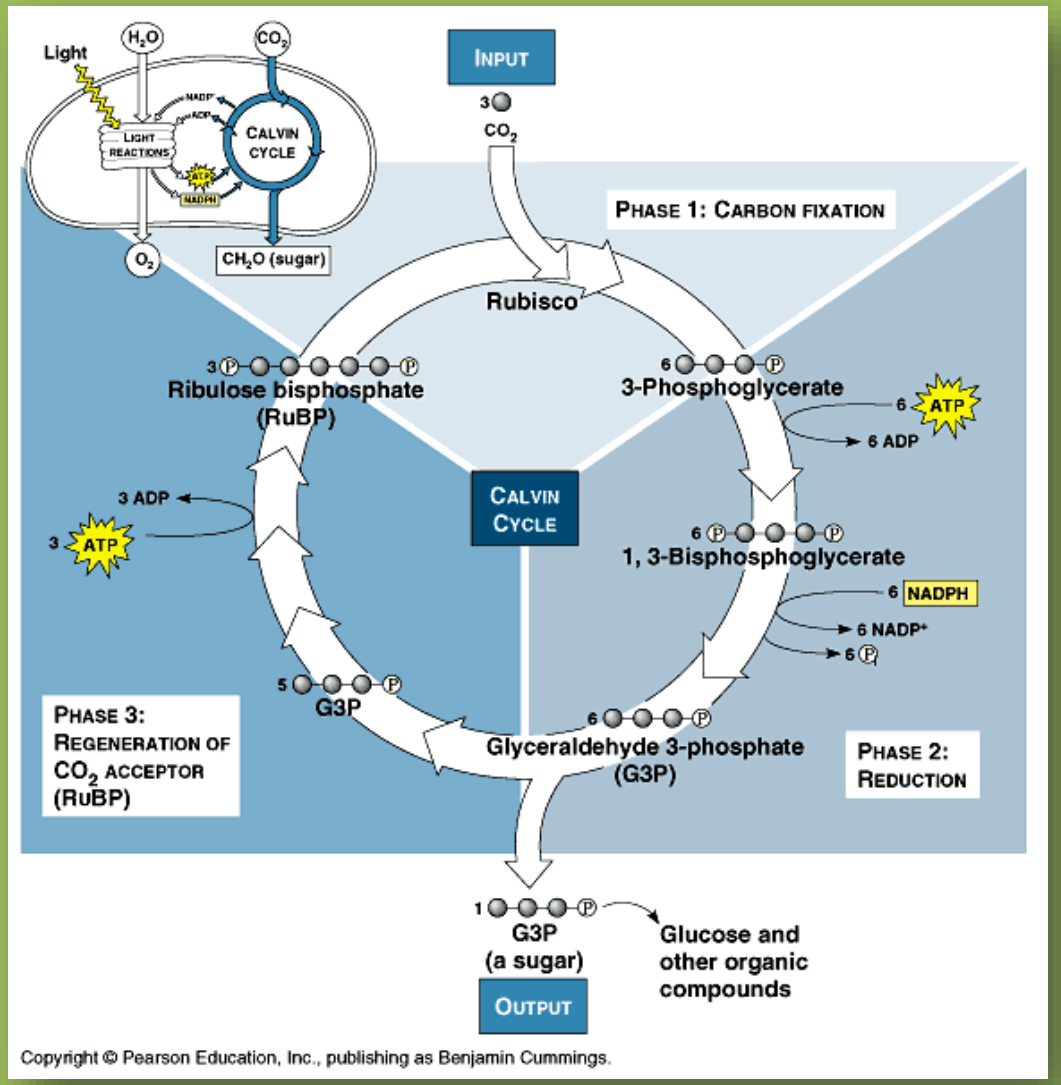


Calvin Cycle or Light independent cycle

- RuBisCo, the enzyme, is used to catalyze the first major step in carbon fixation. It catalyzes RuBp.
- Uses ATP and NADPH to produce sugars due to the action of ATP synthase and the proton pump



Light- independent reaction or Calvin Cycle



Question and Answer

What processes occur during photosynthesis?

What factors affect photosynthesis?

Factors affecting photosynthesis

- Factors below can affect photosynthesis such as
  - 1. ***water availability-*** a shortage of water can slow or even stop photosynthesis
  - 2. ***temperature***- between 0^{o} C and 35^{o}C are ideal due to enzymatic functions.
  - 3. ***Intensity of light-*** increasing can speed up photosynthesis when all other conditions are met

What factors affect photosynthesis?

Energy cycle

Photosynthesis

plants

CO_2 H_2O

glucose
sugars

O_2

animals, plants

Cellular Respiration

ATP

The Great Circle of Life! Mufasa?

How are they connected?

Respiration

glucose + oxygen → carbon dioxide + water + energy

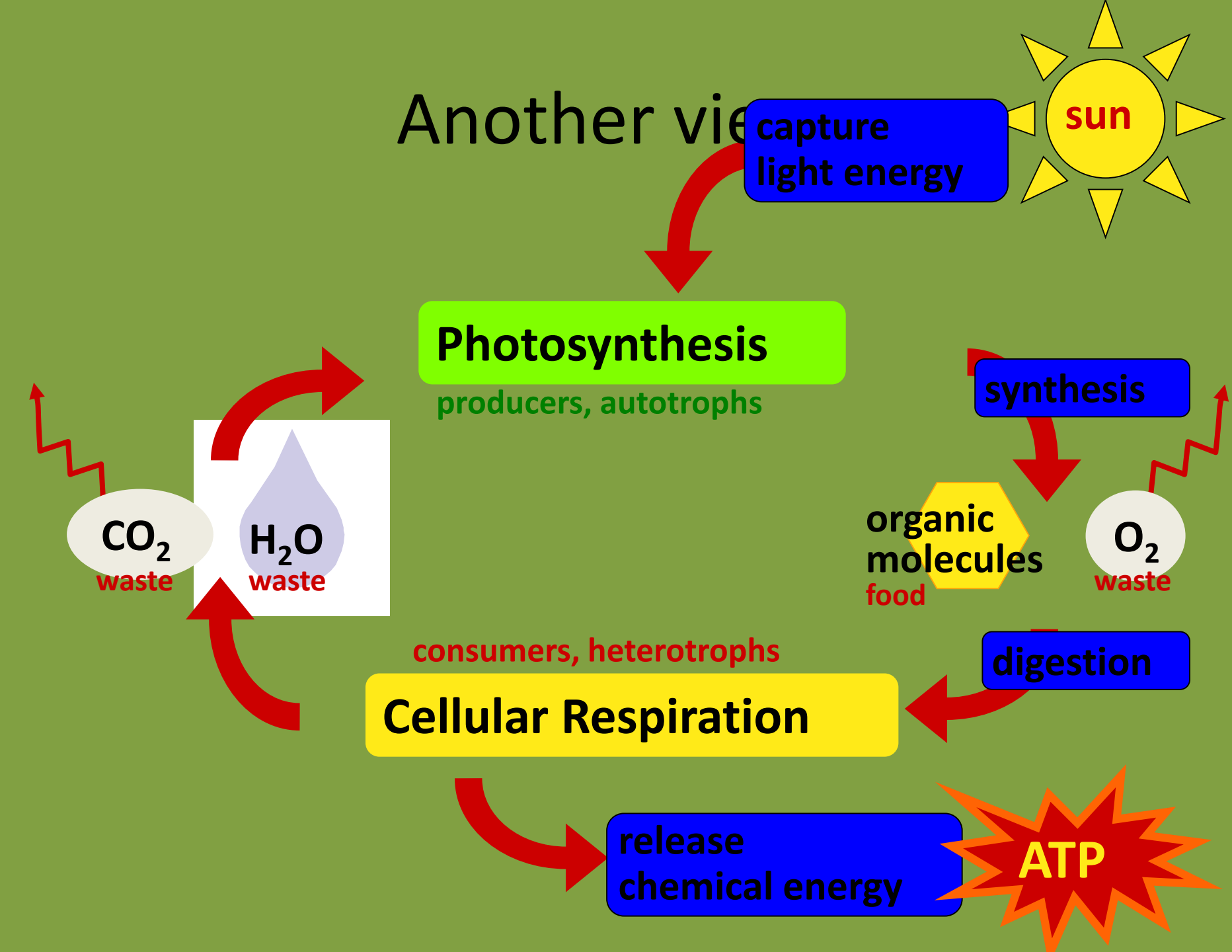
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$

Photosynthesis

carbon dioxide + water + sun energy → glucose + oxygen

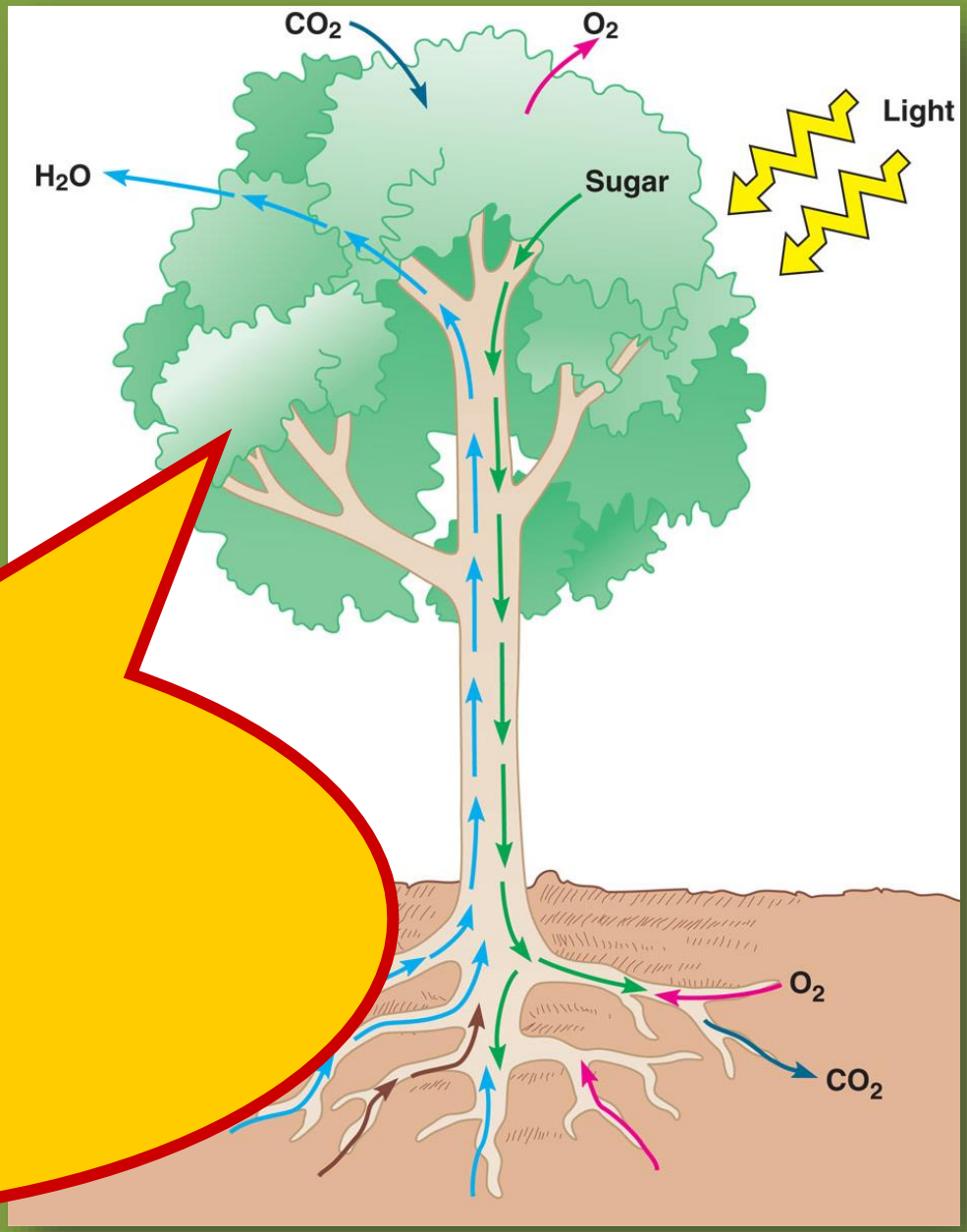
$6CO_2 + 6H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6O_2$

Another vie


capture
light energy
sun
Photosynthesis
producers, autotrophs
synthesis
organic
molecules
food
O_2
waste
CO_2
waste
H_2O
waste
consumers, heterotrophs
digestion
Cellular Respiration
release
chemical energy
ATP

Got the energy…

Ask Questions*!!*



Question and Answer

What factors affect photosynthesis?

Essential Question

- **How do plants and other organisms capture energy from the sun?**