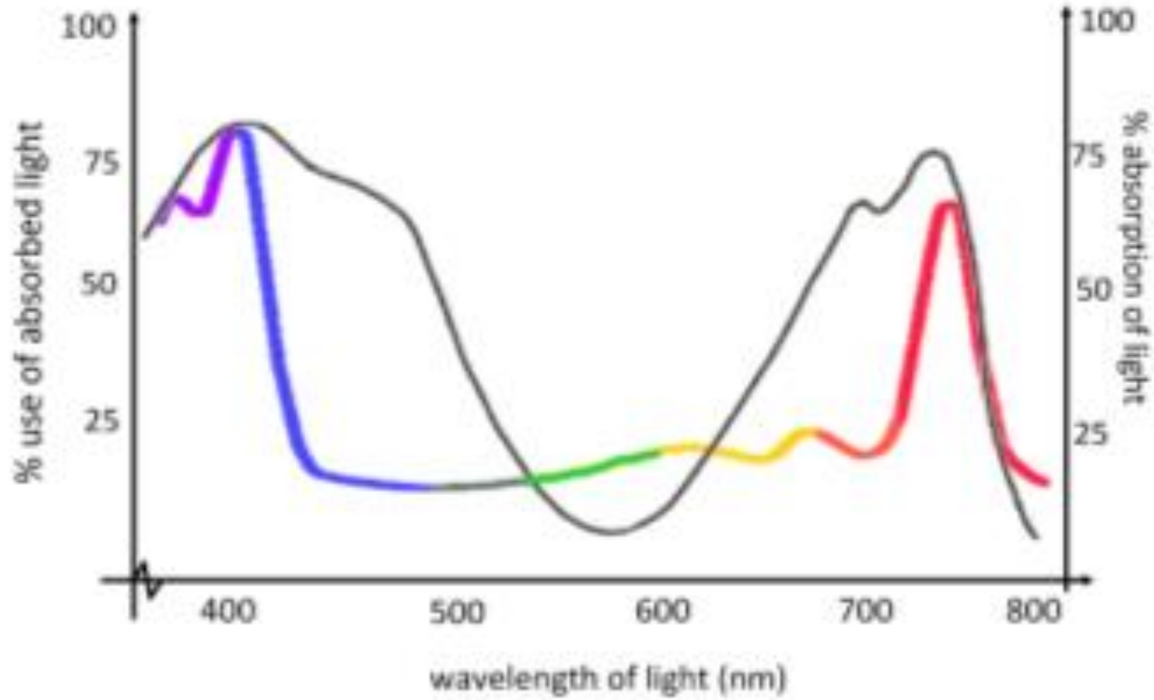


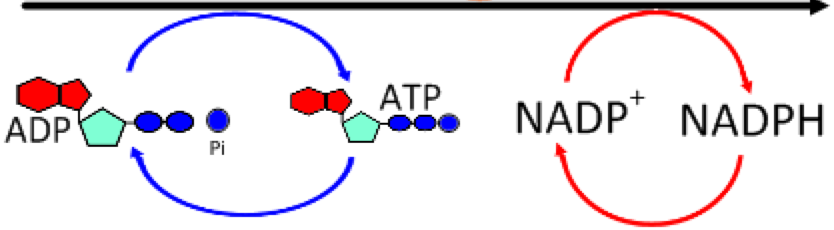
Photosynthesis

Photosynthesis

Photo: using light — synthesis: production

Photosynthesis is a metabolic pathway consisting of light-dependent and light-independent reactions. Overall, water and carbon dioxide are used to produce carbohydrates, with oxygen as a waste product

$$6\,CO_2 + 6H_2O \xrightarrow{\text{sunlight}} C_6H_{12}O_6 + 6O$$



$C_6H_{12}O_6$: used in respiration, stored as starch or used to build cell walls as cellulose

H_2O: Split through photolysis in *light-dependent reactions*. H^+ ions used to generate ATP and NADPH.

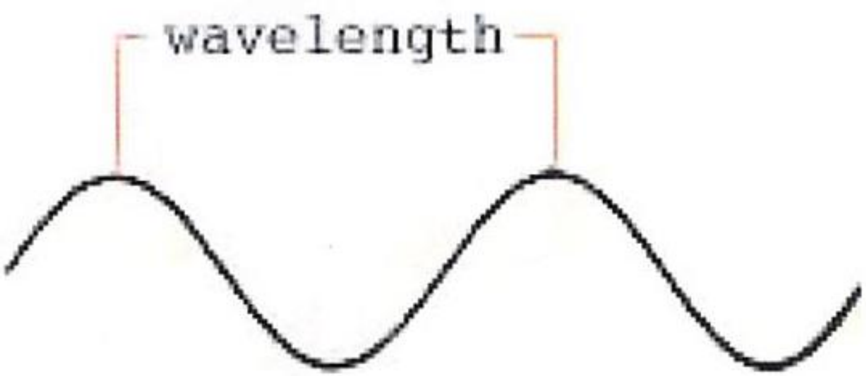
CO_2: Carbon is fixed in *light-independent reactions,* using ATP and NADPH.

Why do we see colors?

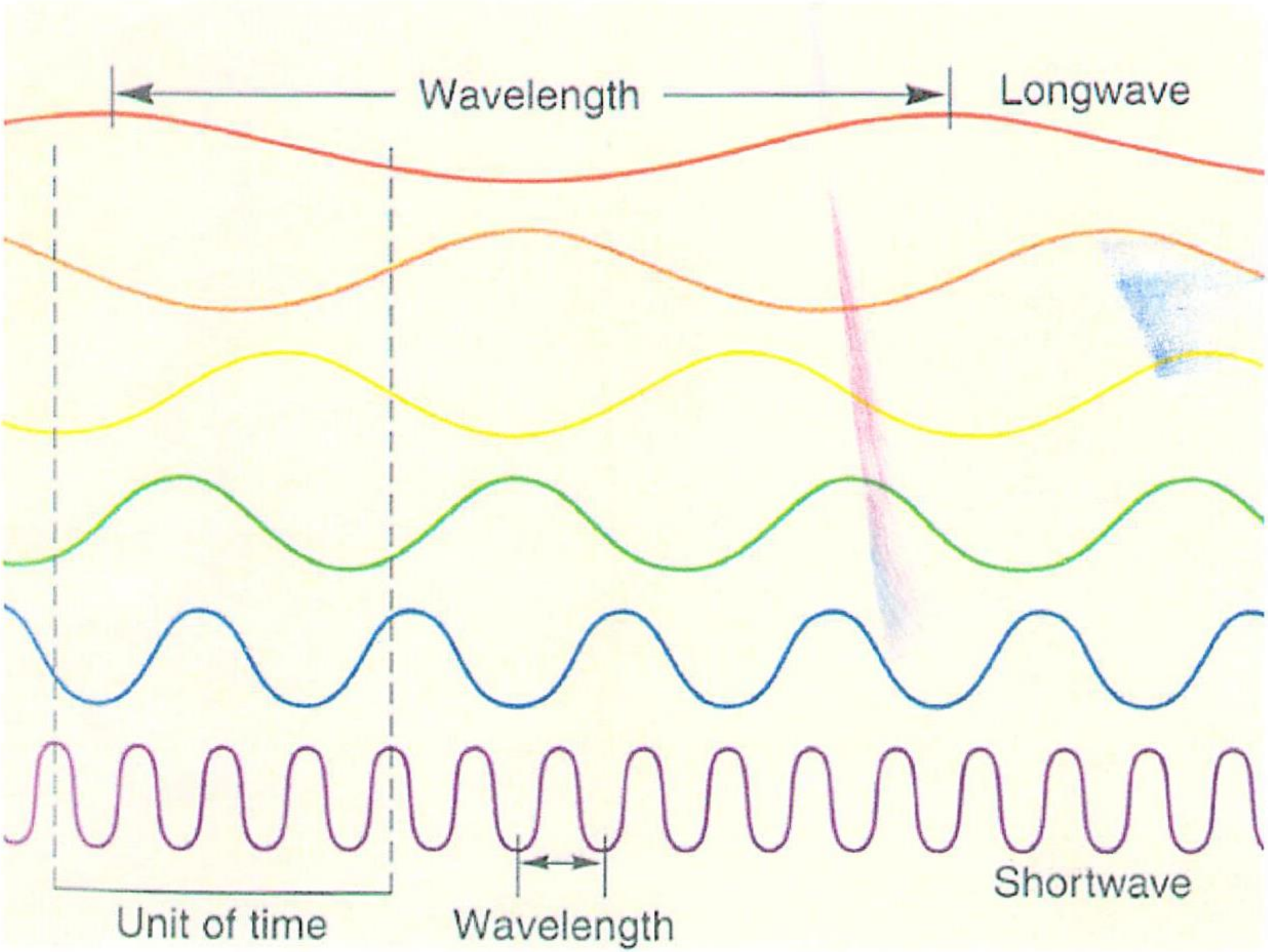
- Light is a form of energy that is transmitted in waves.
- Sunlight is also called visible (white) light.
- Visible (white) light is composed of many colors in a range of wavelengths.

- Visible (white) light is composed of many colors in a range of wavelengths.

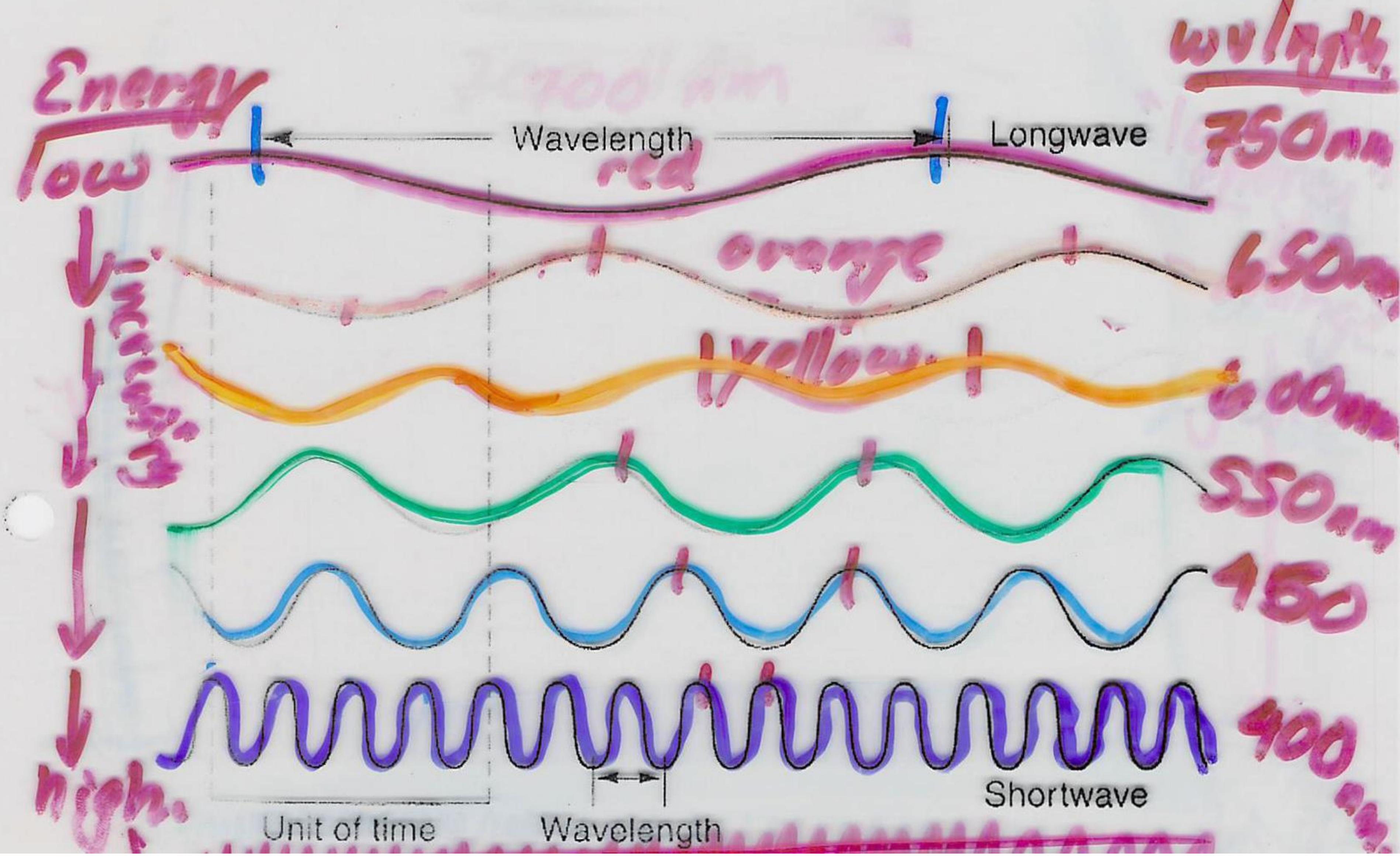
- Wavelength:



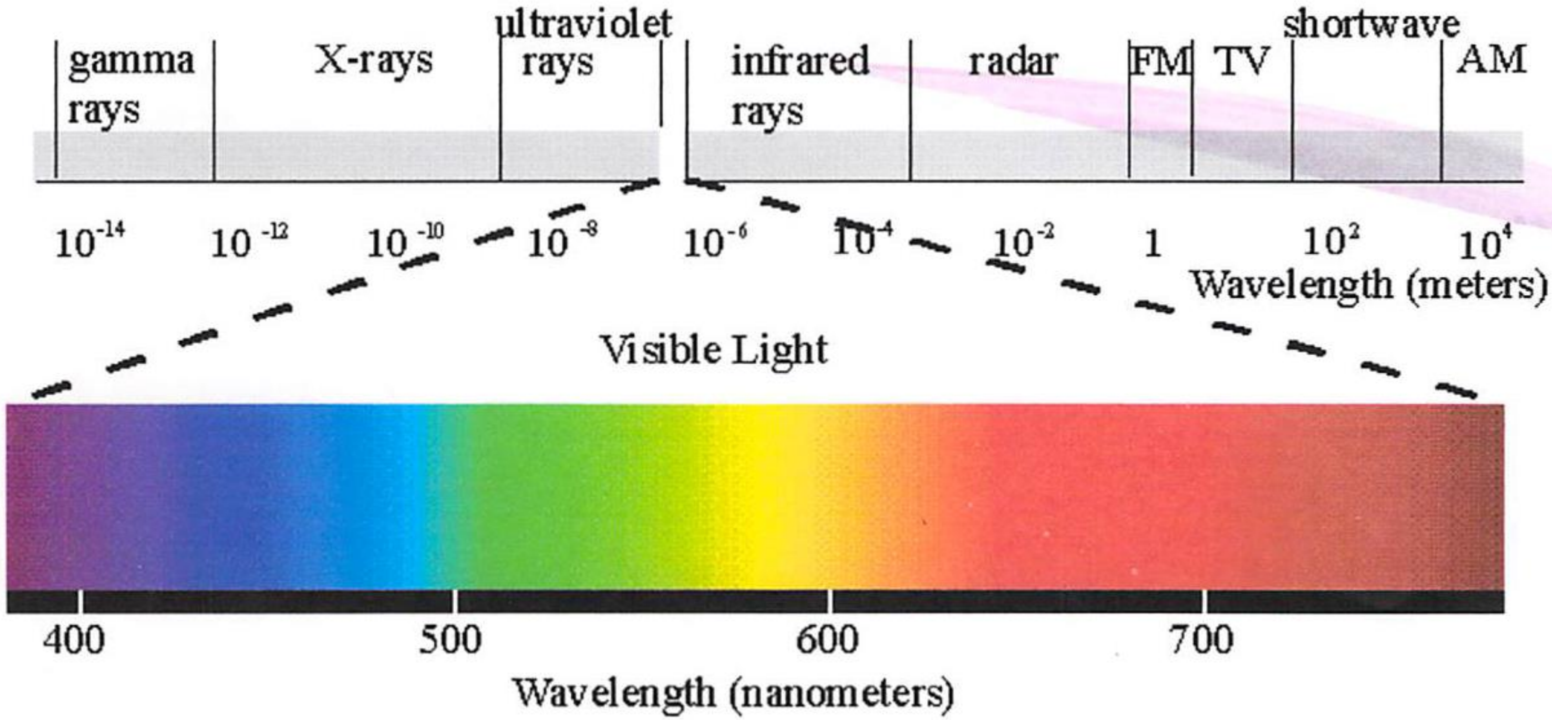
- Different colors of light have different wavelengths.



- Different colors of light have different wavelengths.



- Together this range of colors (wavelengths) is called a spectrum.



- Wavelengths are measured in nanometers.

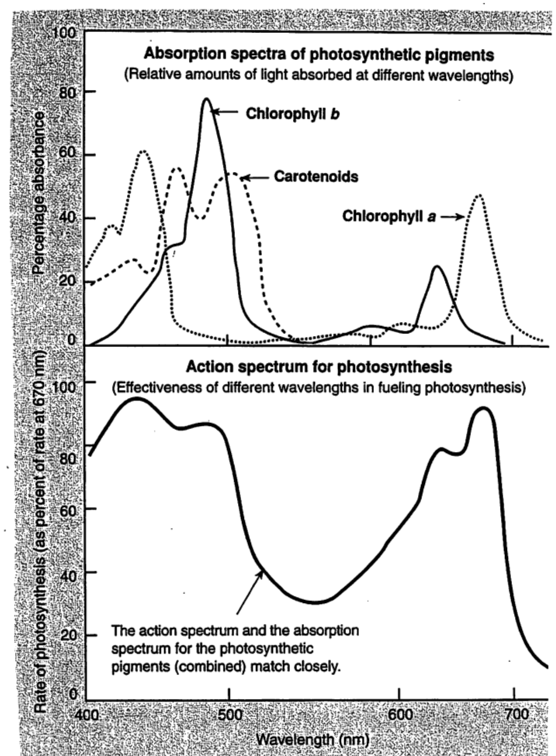
How do pigments work?

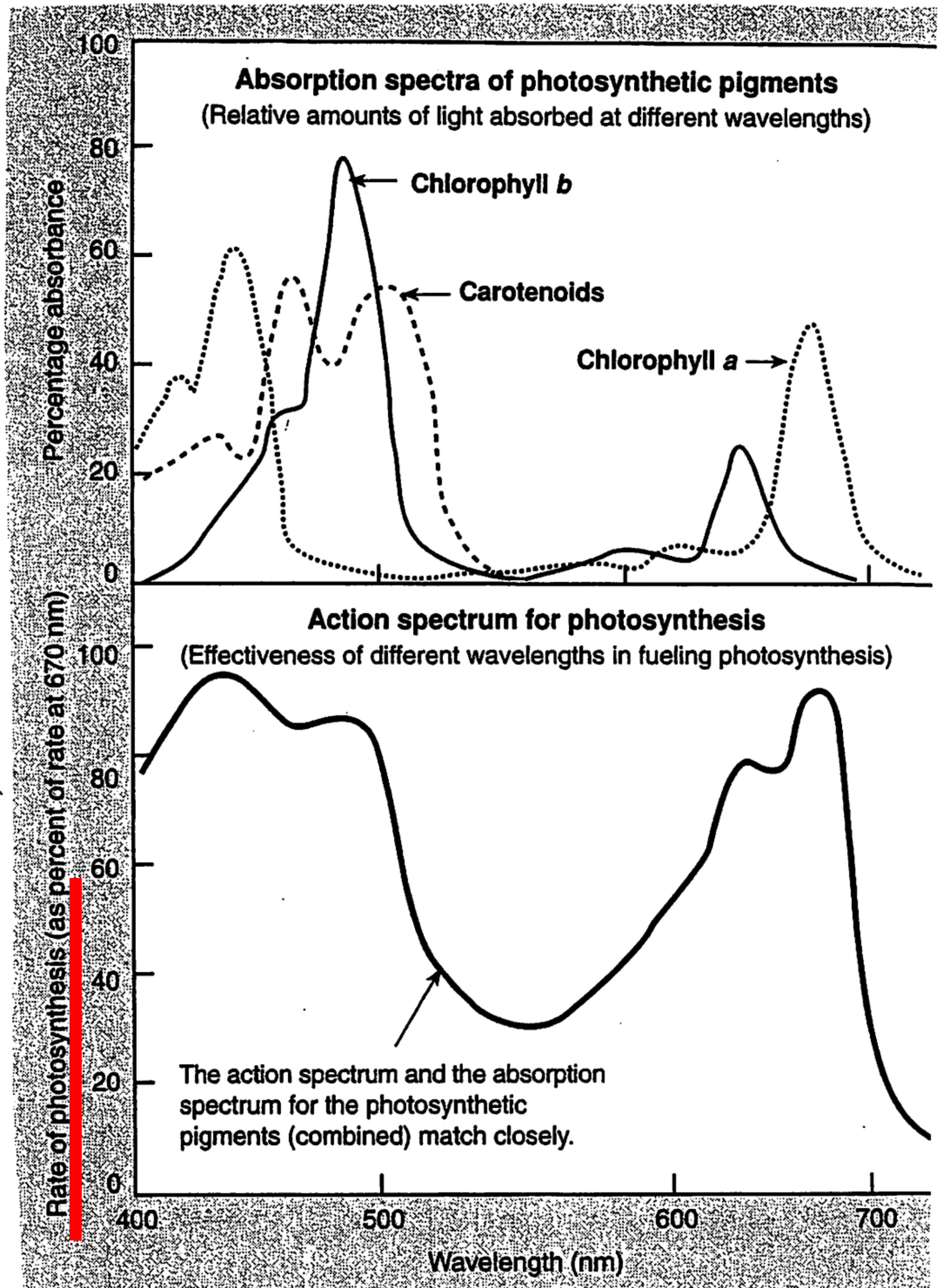
- Light can be absorbed or reflected.
- Pigments absorb all colors except the color they appear to be. This color is reflected.
- For example: Chlorophyll a appears green so it absorbs blue, red, and purple light, but reflects green light. Therefore it appears GREEN!

Absorption Spectrum

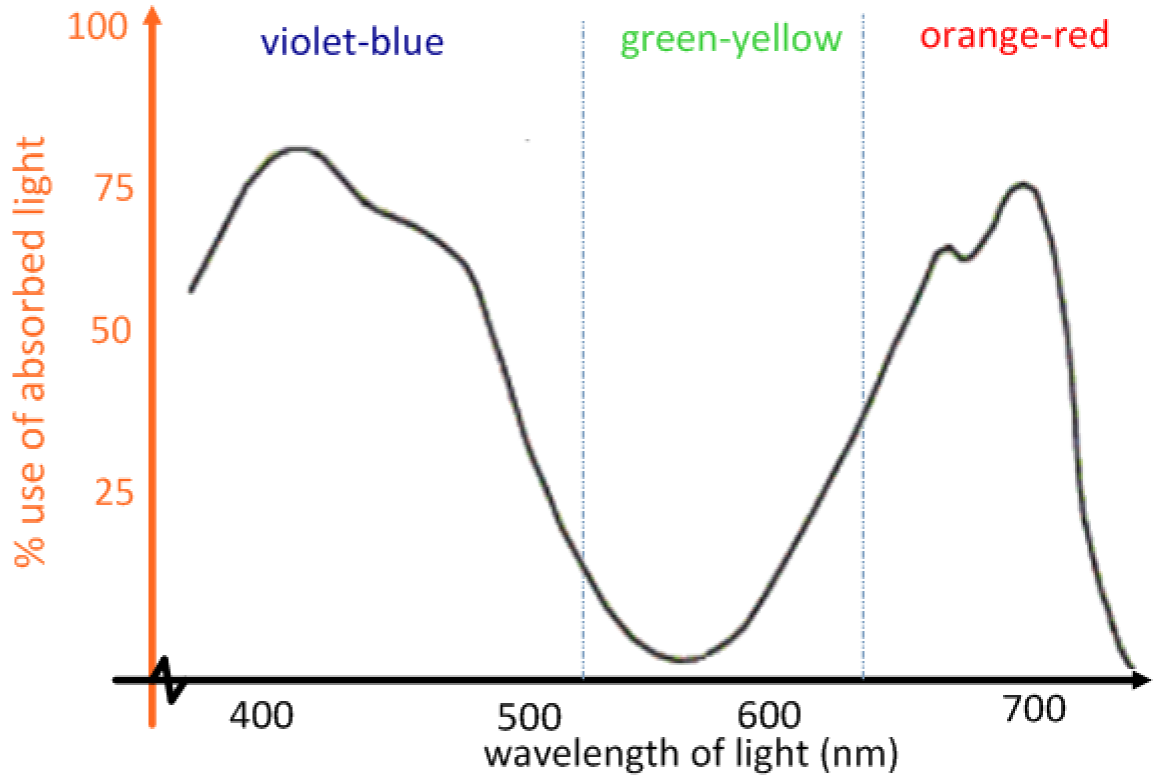
- An absorption spectrum is a graph depicting which wavelengths different pigments absorb.

- On your worksheet, please color in the colors of light near their corresponding wavelength.

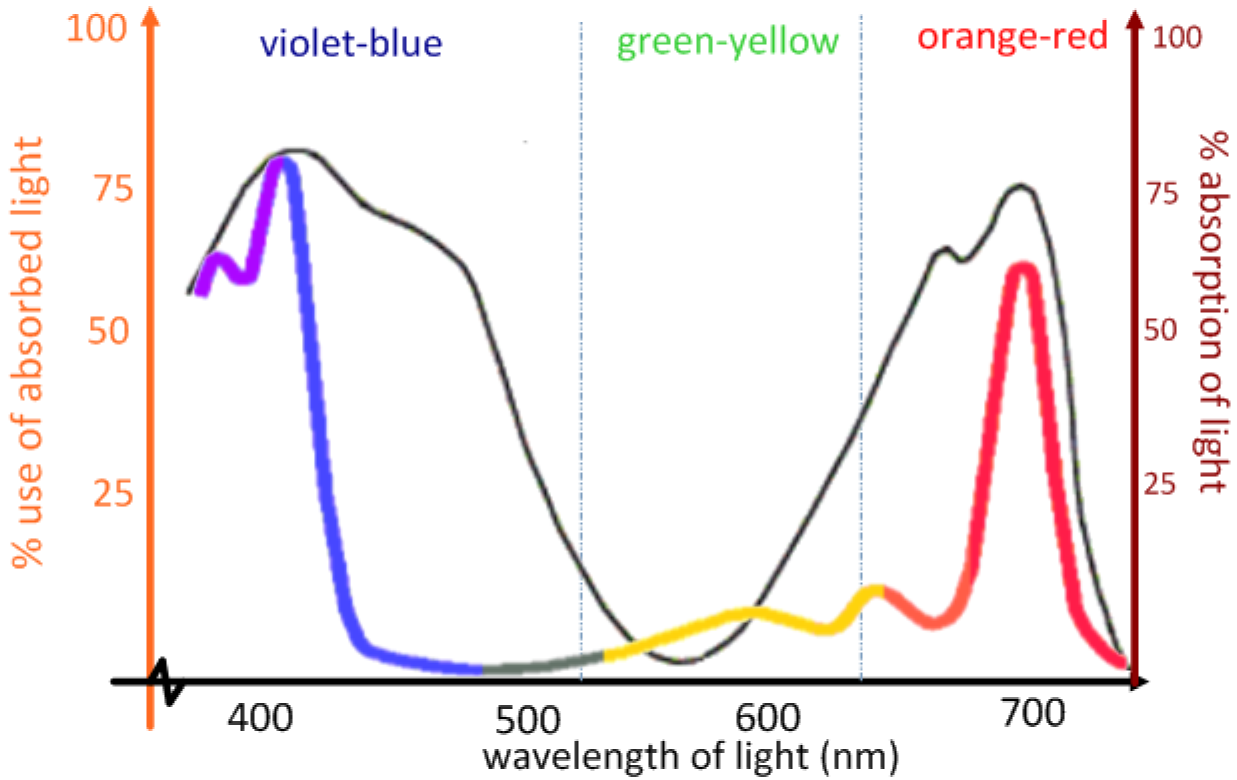



Absorption spectra of photosynthetic pigments
(Relative amounts of light absorbed at different wavelengths)
Chlorophyll *b*
Carotenoids
Chlorophyll *a*
Percentage absorbance
100
80
60
40
20
0
Action spectrum for photosynthesis
(Effectiveness of different wavelengths in fueling photosynthesis)
Rate of photosynthesis (as percent of rate at 670 nm)
100
80
60
40
20
0
The action spectrum and the absorption spectrum for the photosynthetic pigments (combined) match closely.
400
500
600
700
Wavelength (nm)

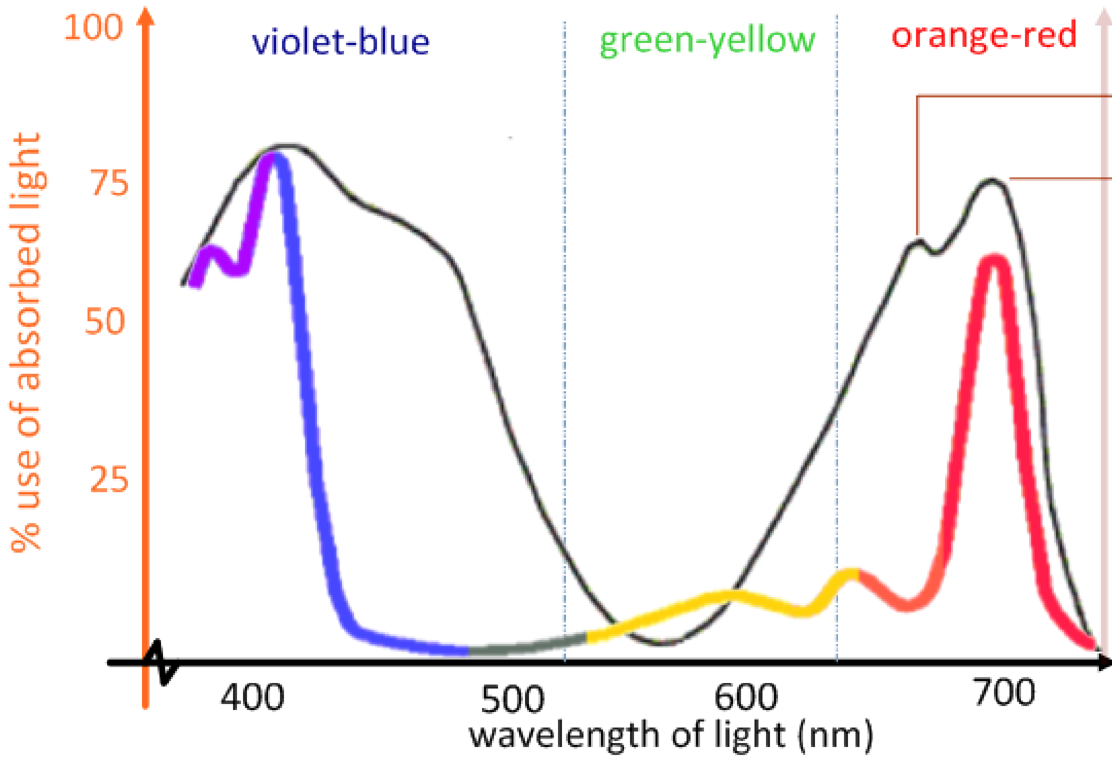
The action spectrum of photosynthesis is the range of wavelengths of light over which photosynthesis is most active.



The action spectrum of photosynthesis is the range of wavelengths of light over which photosynthesis is most active. The absorption spectrum of chlorophyll corresponds with the action spectrum of photosynthesis.



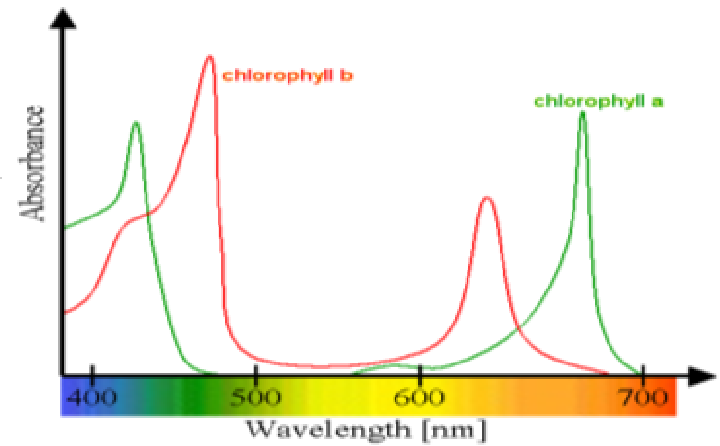
The action spectrum of photosynthesis is the range of wavelengths of light over which photosynthesis is most active. The absorption spectrum of chlorophyll corresponds with the action spectrum of photosynthesis.



Peak of activity at 680nm represents PSII

Peak of activity at 700nm represents PSI

PSI and PSII are consist of different proportions of chorophyll a and b, which have slightly different absorption spectra:



http://en.wikipedia.org/wiki/Chlorophyll

High-energy blue light is also active in photosynthesis

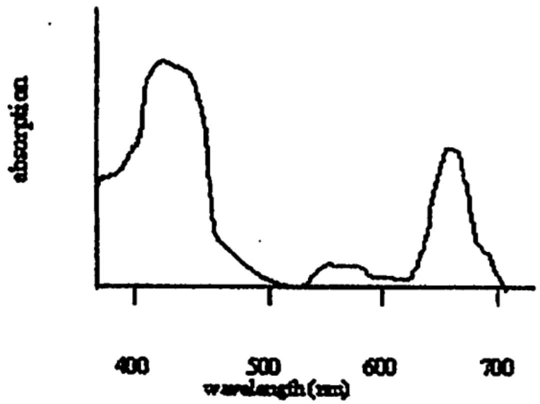
Green light is not used - so not absorbed by chlorophyll and therefore reflected

Name That Color!

Name:________________________

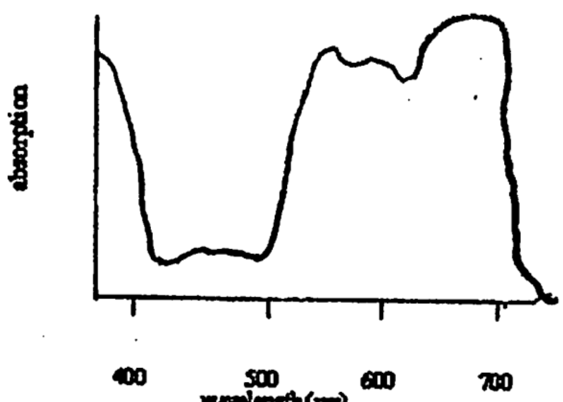
For the following absorption spectra, list the color the object appears.

1.)



This object appears...______________________________

2.)

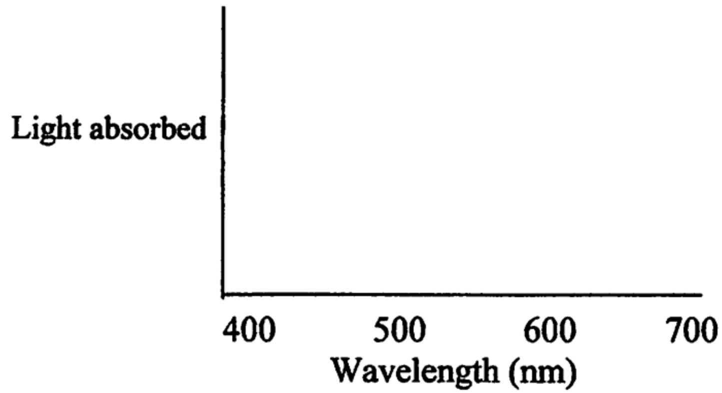


This object appears...______________________________

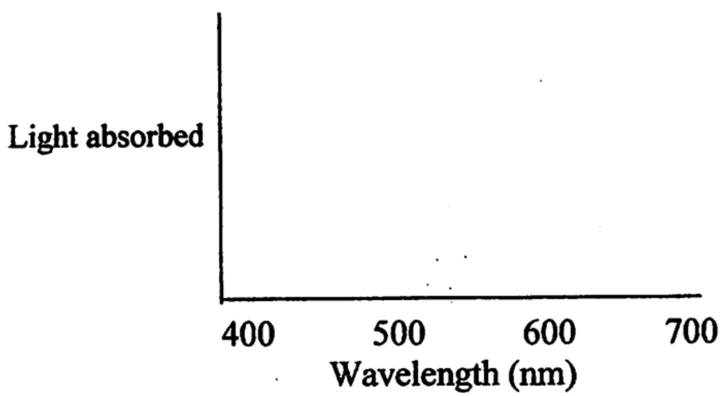
Absorption Spectra

An absorption spectrum is a graph that plots the relative absorption of light against the different wavelengths (colors) of the spectrum for any item or pigment. For the following items draw an absorption spectrum as you estimate it would look.

Item: A bright red shirt.



Item: A yellow duckling.



Item: A white piece of paper.

Chromatography

- A technique used by scientists to separate substances from mixtures.
- In this experiment, acetone is used as a solvent to dissolve the spinach juice (and the pigments in it)- the solutes
- As the acetone wicks up the filter paper, different molecules travel different distances based on their molecular mass, their charge, and their solubility in acetone.
- Closest to the spinach juice line you will see Chlorphyll b (yellow green color), then chlorophyll a (blue green color), Carotenoids are usually along the solvent front (Yellow orange). A fourth pigment, Xanthophylls will be visible between Chl a and the Carotenoids .

- **Each pigment has a characteristic Rf value. The Rf value is the relative distance traveled by the pigment:**

- **Rf= (distance traveled by the pigment) / (distance to solvent front)**

$$Rf = \frac{\text{(distance traveled by the pigment)}}{\text{(distance to solvent front)}}$$

- **Your goal is to calculate the Rf values for Chlorophyll a, Chlorophyll b, Xanthophylls and Carotenoids.**

Mark the solvent line, measure all distances (or ave dist), Make a chart displaying these results, showing your calculations, and giving Rf values

1.) Complete the following chart for the three common plant pigments.

Pigment Name	Color the pigment appears	Colors the pigment absorbs	Color(s) the pigment reflects

Photosynthesis!

- Photosynthesis is another chemical process like cellular respiration!

- Whereas Cellular Respiration is the breakdown of glucose to make ATP, Photosynthesis involves the conversion of light energy into chemical energy (glucose).

- Photosynthesis happens in mainly in plant cells, but also in algae and certain prokaryotes.

- Photosynthesis happens in mainly in plant cells, but also in algae and certain prokaryotes.

- The photosynthetic organelle is the Chloroplast.

- Chlorophyll is the main photosynthetic pigment and is found in the Chloroplast.

Pigments

- Pigments are responsible for light absorption (capturing energy) in plants.

- There are two main categories of pigments in plants
    - Chlorophylls
    - Carotenoids
    - xanthophylls

- Both are located in the membrane of the thylakoid disks.

What did you observe in your chromatographic extraction?

- Chlorophylls appear green. There are two types…
    - Chlorophyll a → green
    - Chlorophyll b → lt. green

- Carotenoids appear orange, yellow, or red

  chlor. covers up. → caratenoids show up!

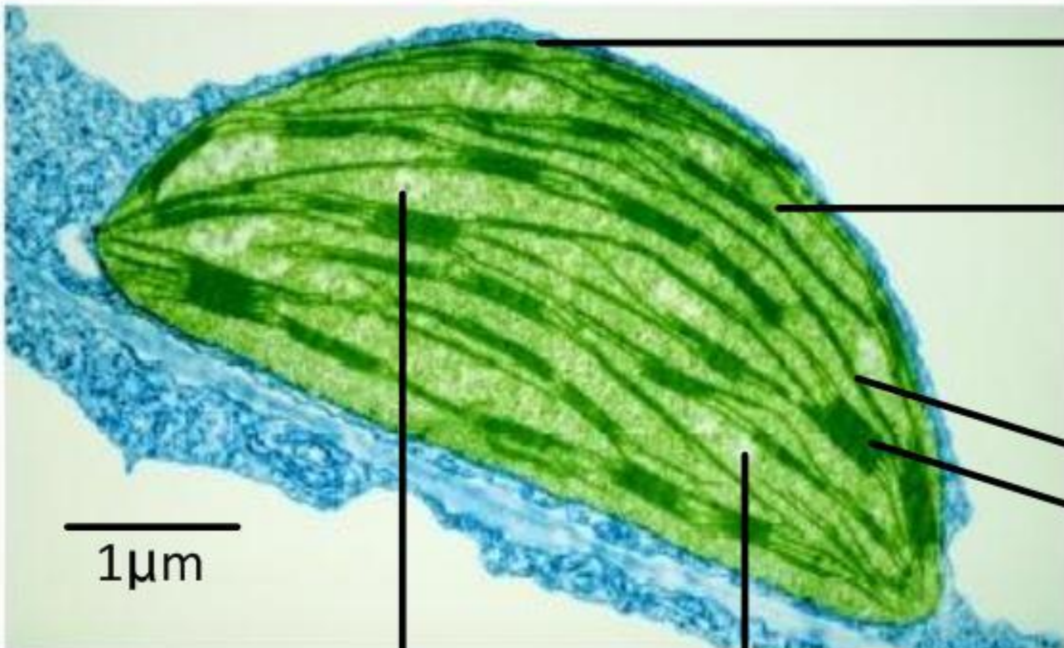
- Why do leaves change color in the fall?

  Green → lt. grn. yellow orange red brown

  warm → colder.

Chloroplast: the centre for photosynthesis

TEM Image



chloroplast envelope
(inner & outer membranes)

stroma
(70S ribosomes and naked DNA)
light independent reactions

thylakoid membranes &
thylakoid stack (granum)
light dependent reactions

starch grain

oil droplet

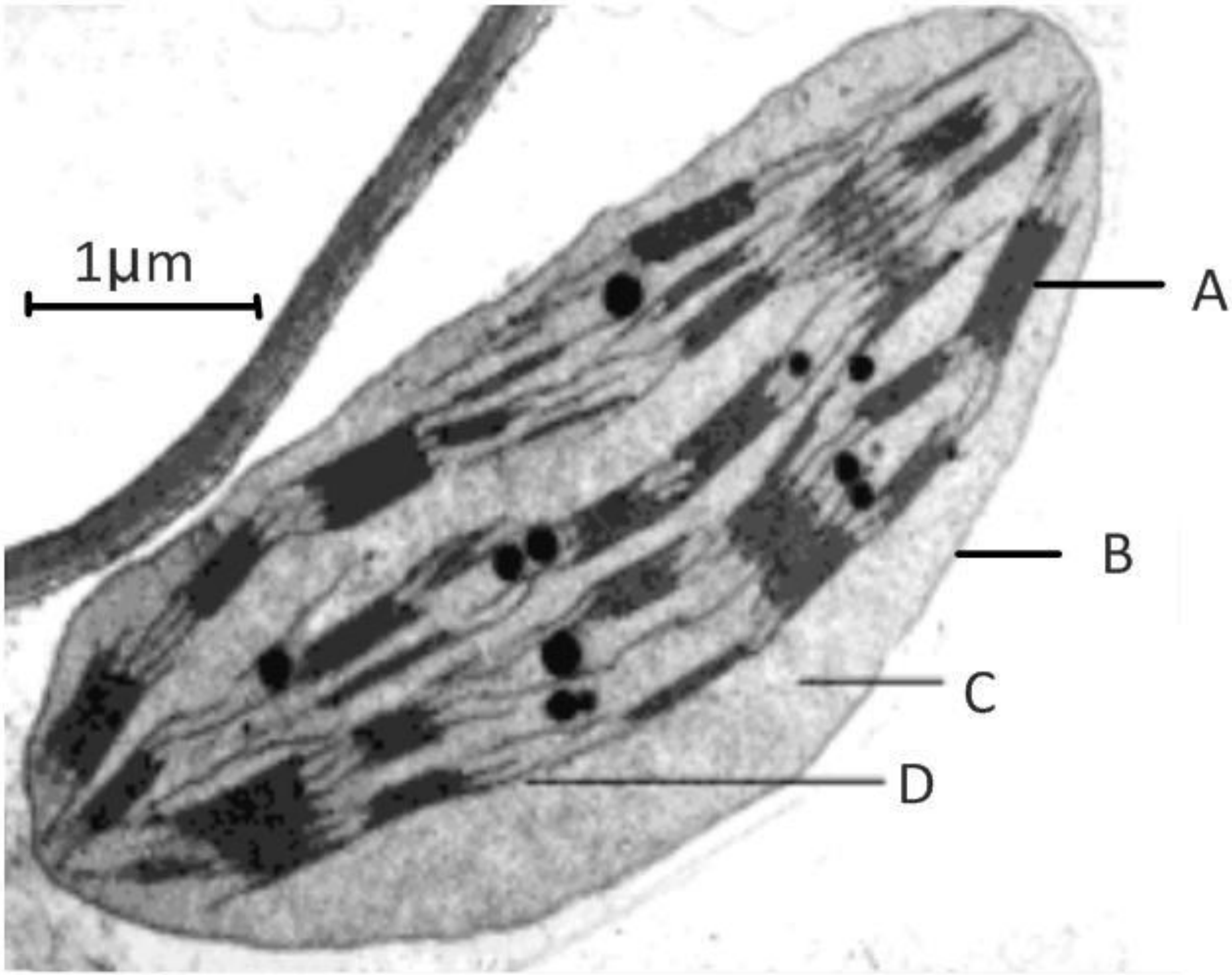
chemical energy store
(products of photosynthesis)

http://www.biologyreference.com/images/biol_01_img0077.jpg

How does the structure of the chloroplast assist its function?

Compare:
chloroplasts vs mitochondria

Label these structures of a chloroplast



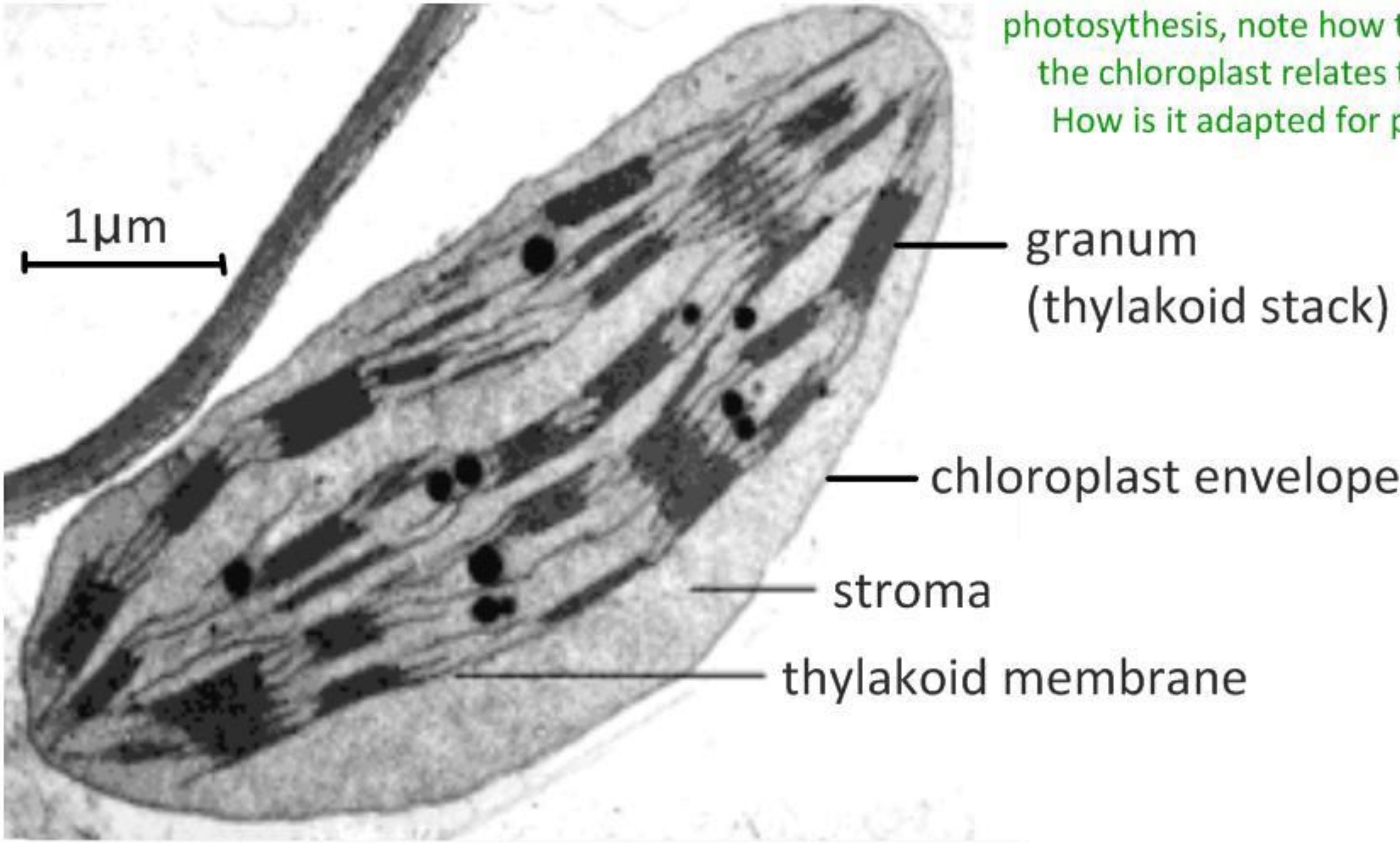
http://www.uic.edu/classes/bios/bios100/lectures/em-chloroplast1.gif

Print this page and practice the following calculations:

1. Calculate the magnification of the image
2. Calculate the maximum length of this chloroplast

Label these structures of a chloroplast

As you work through the stages of photosythesis, note how the structure of the chloroplast relates to the function. How is it adapted for photosynthesis



http://www.uic.edu/classes/bios/bios100/lectures/em-chloroplast1.gif

Print this page and practice the following calculations:

1. Calculate the magnification of the image
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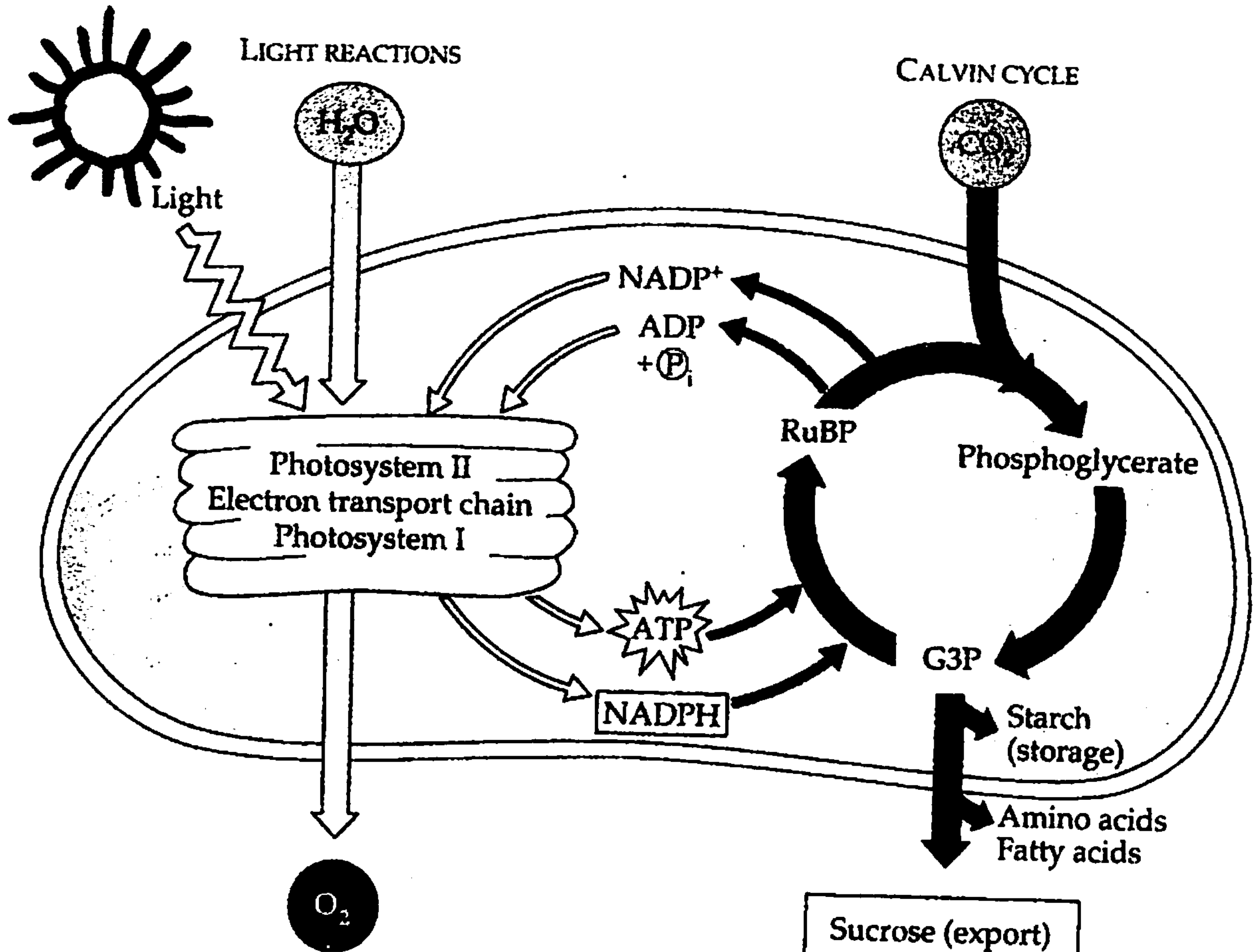
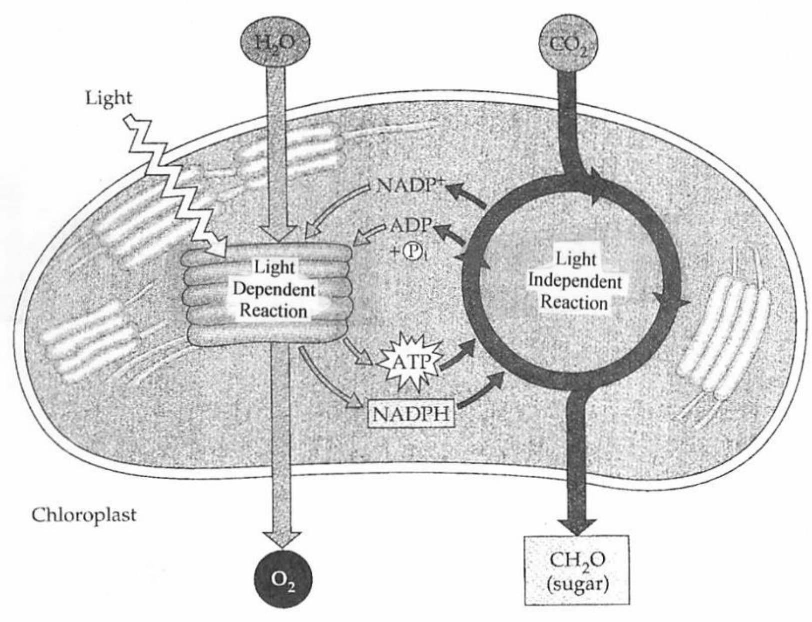

LIGHT REACTIONS
CALVIN CYCLE
H_2O
CO_2
Light
NADP+
ADP
+ Ⓟi
RuBP
Phosphoglycerate
Photosystem II
Electron transport chain
Photosystem I
ATP
NADPH
G3P
Starch
(storage)
Amino acids
Fatty acids
O_2
Sucrose (export)

Photosynthesis Continued…

Photosynthesis is a series of two complex processes each with several steps!

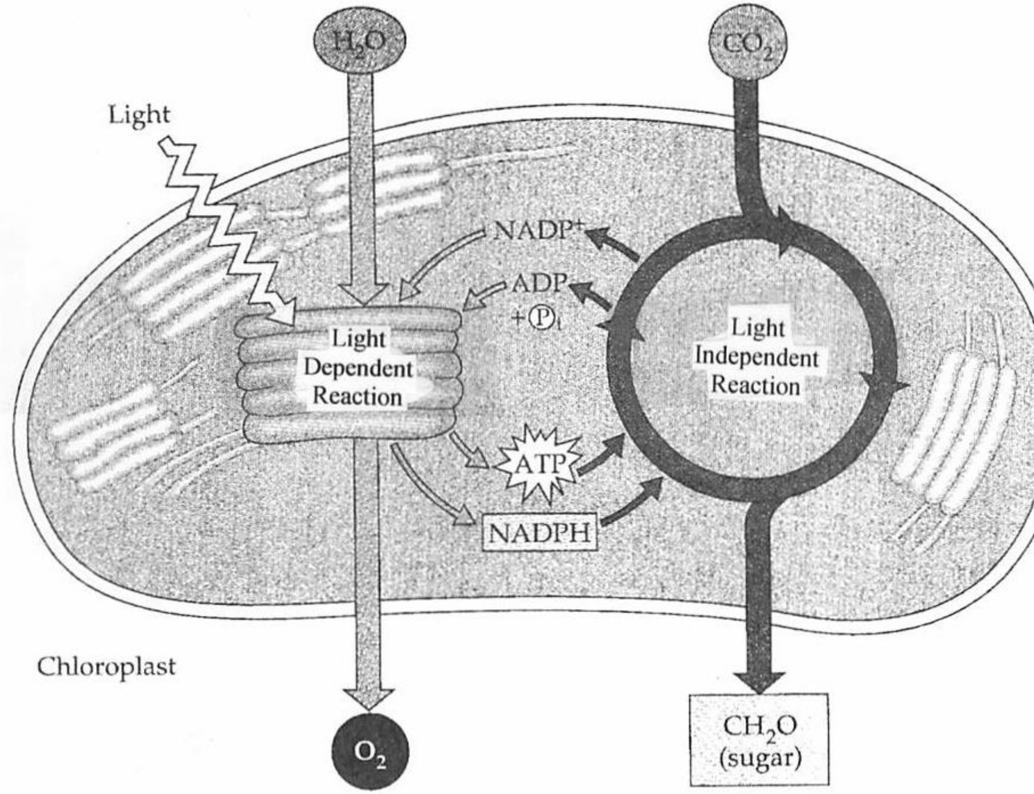
- An overview:
  1. The first major process is called the Light-Dependent Reaction.
     - Happens in the thylakoid membrane
     - Requires light to occur!



- The light dependent reaction takes in:
    - H_2O (from the environment)
    - Light (from the environment)
    - NADP (from the Calvin Cycle)

      {NADP is a cousin to NAD and FAD}
    - ADP (from the Calvin Cycle)
- The light dependent reaction puts out:
    - O_2 (to the environment)
    - ATP (to the Calvin Cycle)
    - NAPDH (to the Calvin Cycle)

2. The second major process is called the Light-Independent Reaction (also known as the Calvin Cycle)
   - Happens in the stroma of the chloroplast
   - Can happen in the light OR dark (Independent of light).



- The light independent reaction takes in:
  - CO_2 (from the environment)
  - NADPH (from the Light Reaction)
    {NADP is a cousin to NAD and FAD}
  - ATP (from the Light Reaction)
- The light independent reaction puts out:
  - CH_2O{Glucose}(to the environment)
  - ADP (to the Light Reaction)
  - NADP (to the Light Reaction)

Using what you have just learned about the products and reactants of the Light Dependent Reaction and the Light Independent Reaction, write a general (unbalanced) equation for…

A.) The Light Dependent Reaction

B.) The Light Independent Reaction

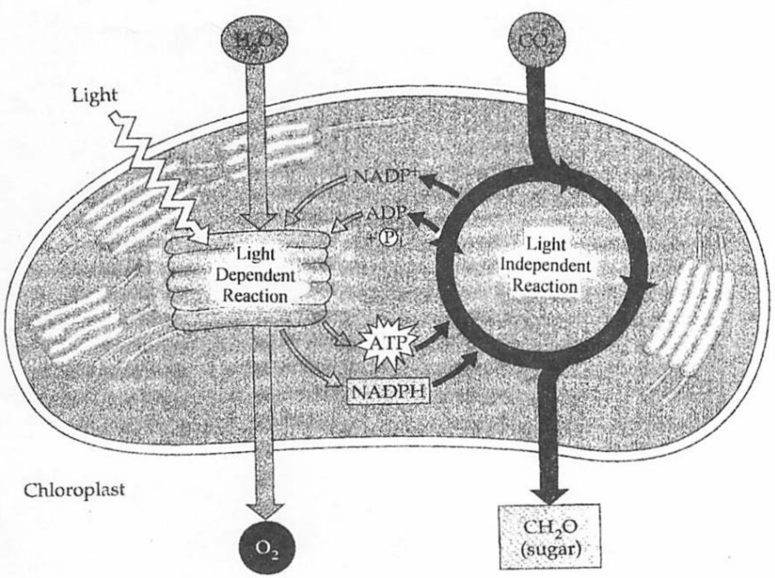


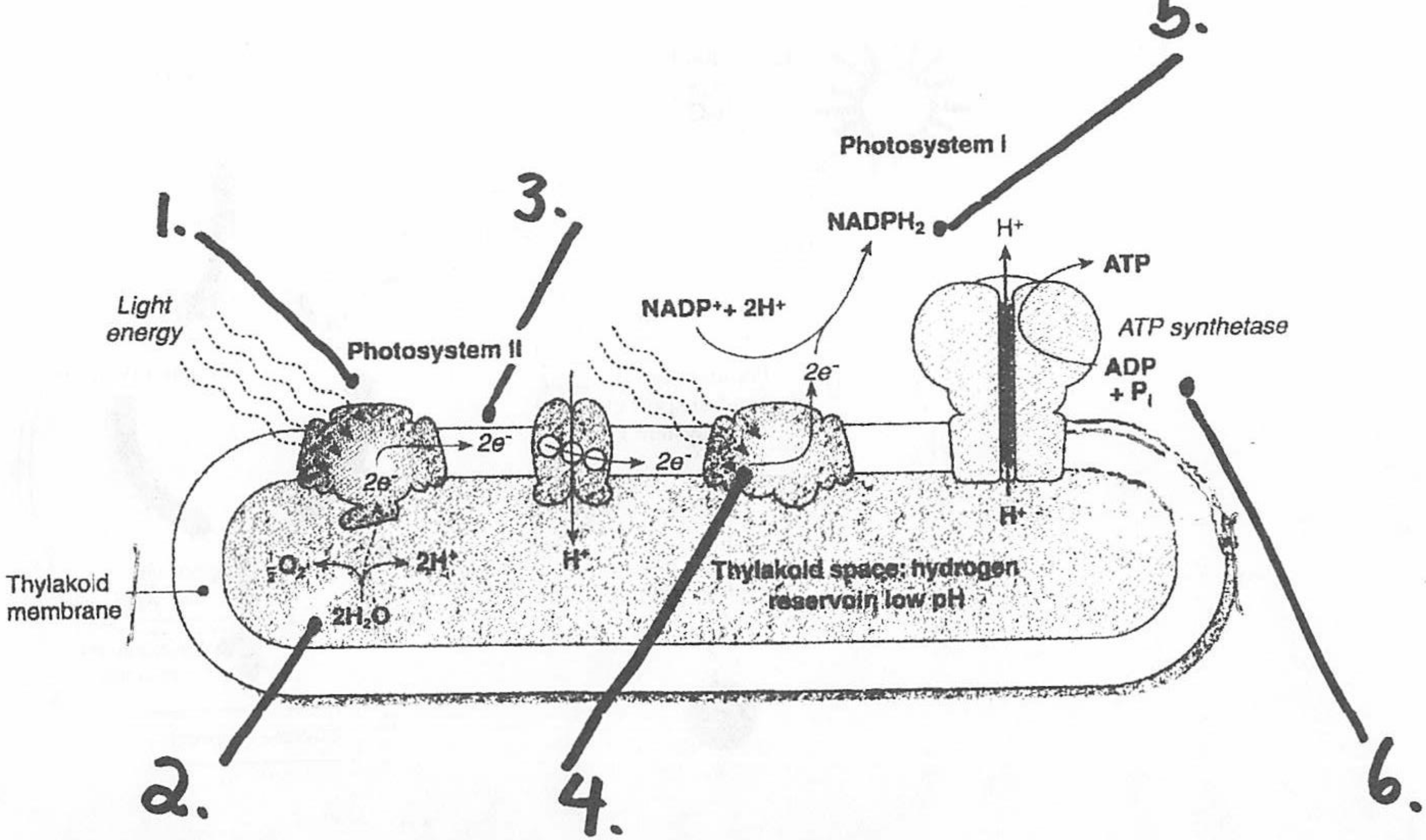
FIGURE 10.4 · An overview of photosynthesis: cooperation of the light reactions and the Calvin cycle. The light reactions use solar energy to make ATP and NADPH, which function as chemical energy and reducing power, respectively, in the Calvin cycle. In contrast to ATP generated by cellular respiration, ATP produced in the light reactions of photosynthesis is usually dedicated to a single kind of cellular work, driving the Calvin cycle. The Calvin cycle incorporates CO_2 into organic molecules, which are converted to sugar. (Recall from Chapter 5 that most simple sugars have formulas that are some multiple of CH_2O.) Thylakoid membranes, especially those of the grana, are the sites of the light reactions, whereas the Calvin cycle occurs in the stroma.

A smaller version of this diagram will reappear in several subsequent figures as a reminder of whether the events being described occur in the light reactions or in the Calvin cycle.

Name of the Stage	AKA (Also Known As)	Where in the chloroplast does the stage happen?	Input (What are they and where do they come from?)	Output (What are they and where do they go to?)
Light-Dependent Reaction	N/A			

Light Dependent Phase

(Energy capture)



Photosynthesis in Depth!

I. Light Dependent Reaction

1.)

- Light hits photosystem II (pigment arranged on the surface of the thylakoid) and causes high-energy electrons to be released.
- Thus photosystem II is being oxidized.

2.)

- Photosystem II wants its electrons back and takes them through a process called "The photolysis of water" (Light splitting of water)
- Through this process, water is split into O_2 and H+ ions, the electrons released during this process are taken up by photosystem II

3.)

- The electrons released from photosystem II are transported by electron transport chain to photosystem I.
- As this is done, Hydrogen ions are pumped across the thylakoid membrane into the thylakoid space.

4.)

- Photosystem I (pigment arranged on the surface of the thylakoid) is struck by light which causes photosystem I to release its high energy electrons into the stroma.

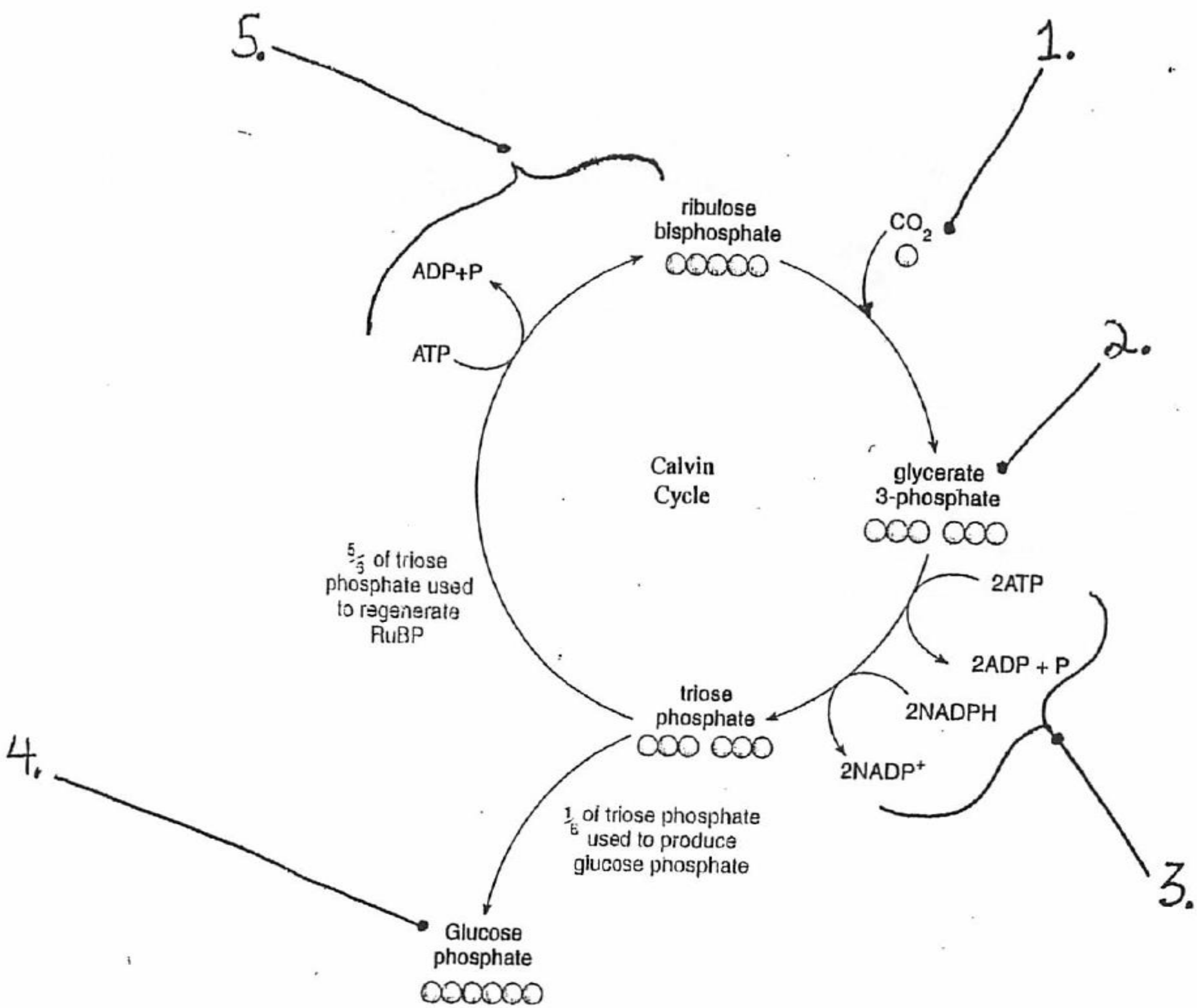
5.)

- These high energy electrons are then used to bond together NADP and 2 H+ ions to become $NADPH_2$ (electron carrier)

6.)

- The H+ ions become crowded in the thylakoid space and begin to flow down their concentration gradient through ATP Synthase!
- ATP synthase uses the released energy to turn ADP and P_i into ATP!!

Light Independent Phase



II. Light Independent Reaction

1.) CO_2 enters the Calvin cycle and bonds with Ribulose bisphosphate to make a 6 carbon compound. This is called Carbon Fixation.

2.) The six-carbon compound (not represented here) immediately splits into two 3-carbon compounds called Glycerate 3-Phosphate.

3.)
   - The 2 molecules of Glycerate 3-Phosphate are reduced to two molecules of Triose Phosphate.
   - During this process 2 ATP are converted to 2ADP and $NADPH_2$ are converted NADP.

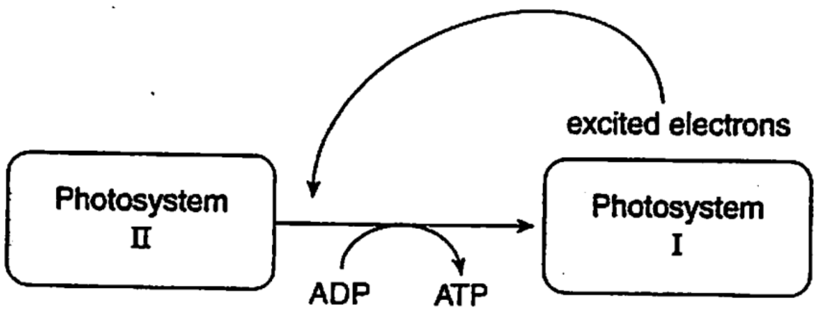
4.)

- 1 Carbon from two molecules of Triose Phosphate is used to make Glucose phosphate.
- The Calvin cycle must "turn" 6 times to make one molecule of Glucose phosphate (Sugar / Carbohydrate).

5.)

- The other 5 carbons are used to regenerate Ribulose bisphosphate so the cycle can continue.
- During this process one ATP is used.

Summary of cyclic photophosphorylation



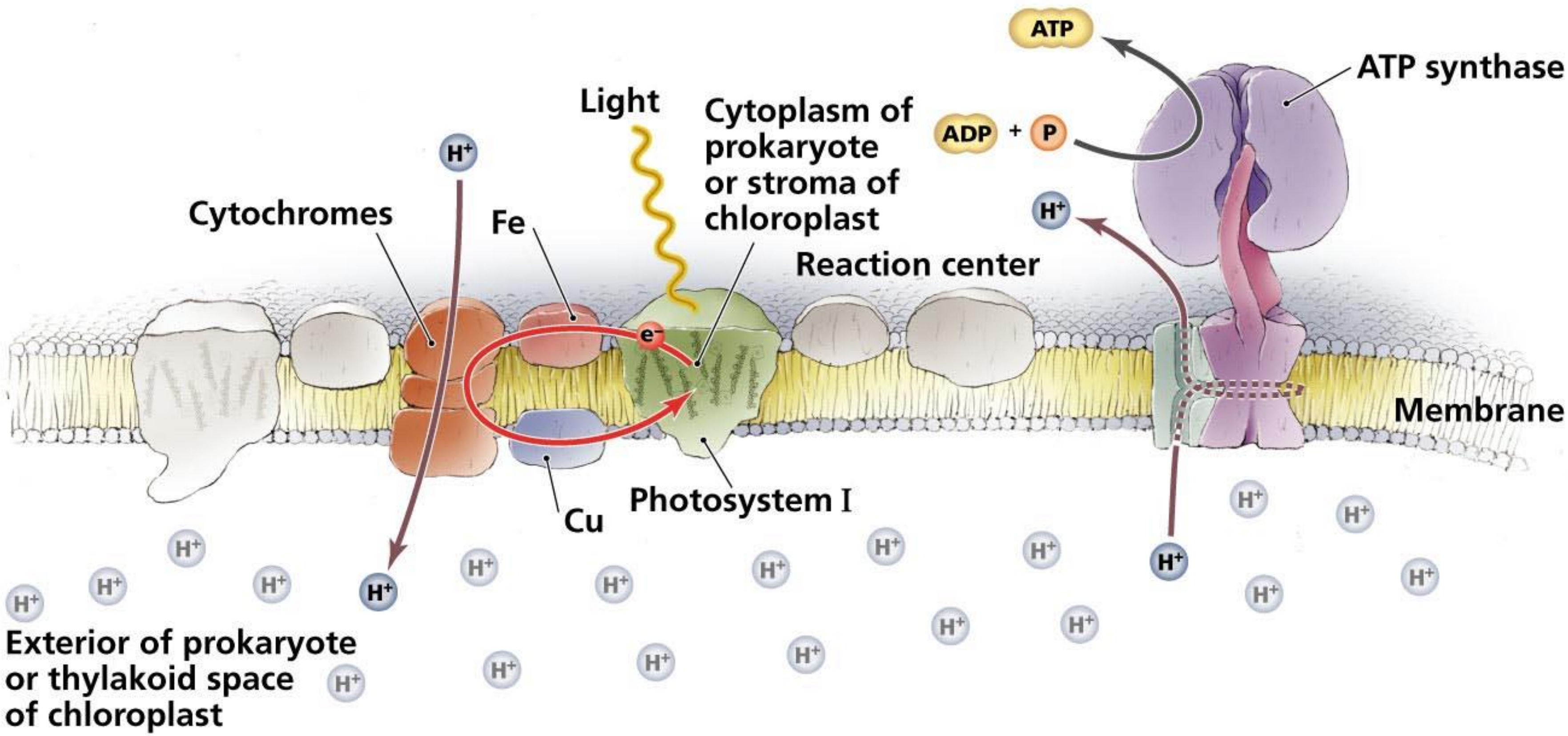
CYCLIC PHOTOPHOSPHORYLATION

When light is not the limiting factor, NADPH tends to accumulate in the stroma and there is a shortage of $NADP^+$. The normal flow of electrons in the thylakoid membranes is inhibited because $NADP^+$ is needed as a final acceptor of electrons. An alternative route can be used that allows ATP production when $NADP^+$ is not available.

This pathway is called **cyclic photophosphorylation**.

- Photosystem I absorbs light and is photoactivated.
- Excited electrons are passed from photosystem I to a carrier in the chain between photosystem II and photosystem I.
- The electrons pass along the chain of carriers back to photosystem I.
- As the electrons flow along the chain of carriers they cause pumping of protons across the thylakoid membrane.
- A proton gradient is formed and this allows production of ATP by ATP synthase.

The figure (left) shows the pathway used in cyclic photophosphorylation.

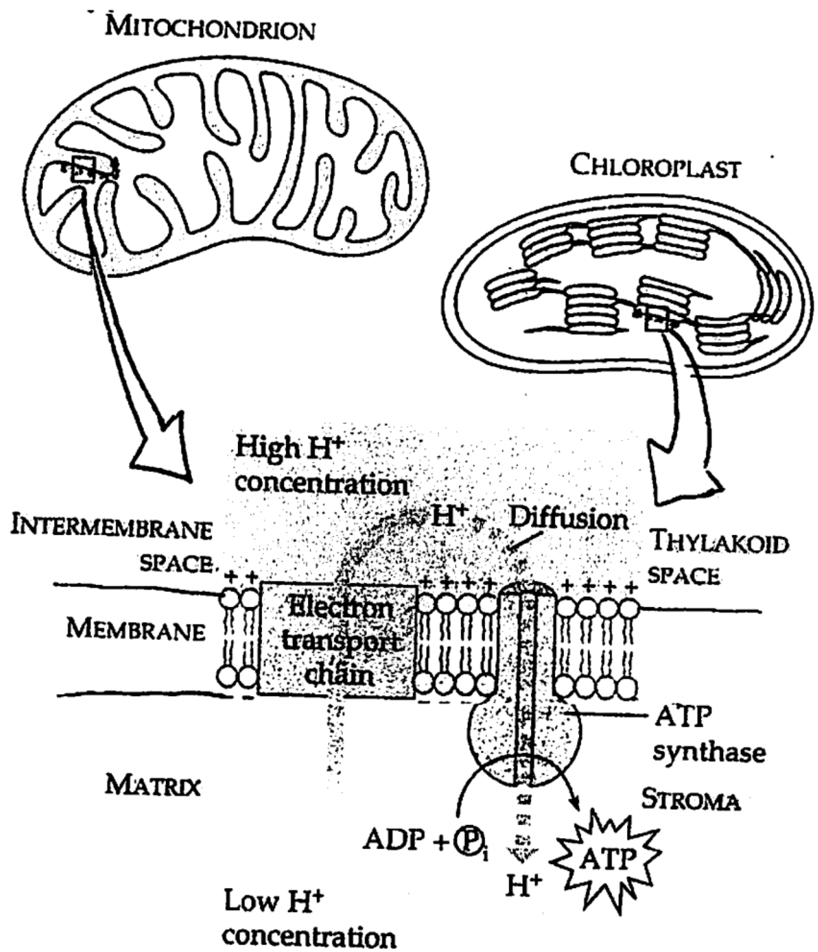


(a) Cyclic photophosphorylation

Photophosphorylation in Photosynthesis

Vs.

Oxidative Phosphorylation in Cellular respiration



Measuring Photosynthetic Rates

- Photosynthesis can be measured in three ways…
- 1.) Production of Oxygen
  - ex: bubbles are produced from aquatic plants
- 2.) Uptake of Carbon Dioxide
  - ex: leaves take in CO_2 from the air and water
  - ex: hard to measure directly, but can be measured by a change in pH (If CO_2 is absorbed from the water, the pH rises.)

What must you consider?

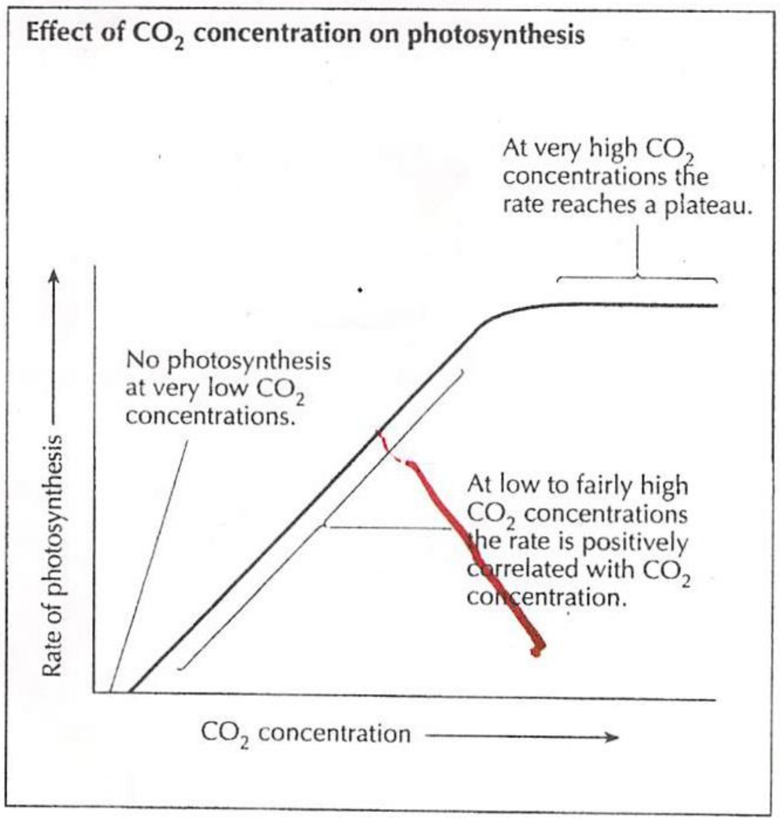
- 3.) Increase in biomass
  - ex: the mass increase of a plant is an indirect measure of the amount of photosynthesis that has taken place

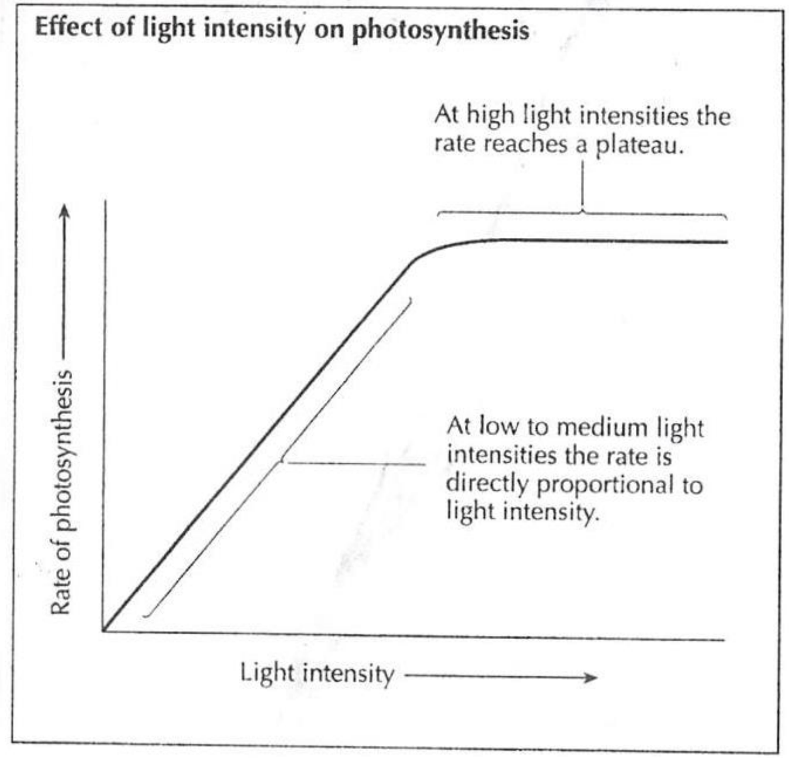
Limiting Factors in Photosynthesis

- Factors that effect the rate of photosynthesis are called "limiting factors"
- Three limiting factors in photosynthesis are:
  - Light Intensity
  - CO_2 concentration
  - Temperature
  - water

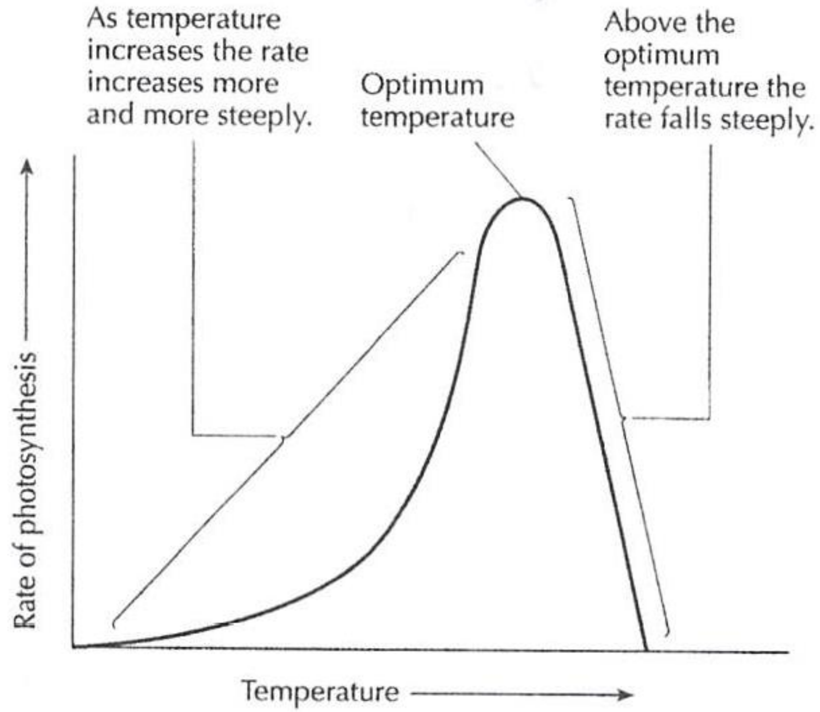
- Limiting factors are usually insufficient reactants
  - Ex: at low light intensities, there is a shortage of the products of the light dependent reaction
  - Ex: At low CO_2 concentrations, there is not enough CO_2 available to fix CO_2 to make glycerate 3 – phosphate
  - Ex: At low (and high) temperatures the enzymes that catalyze the reactions of the Calvin cycle work slowly

Limiting Factors in Photosynthesis

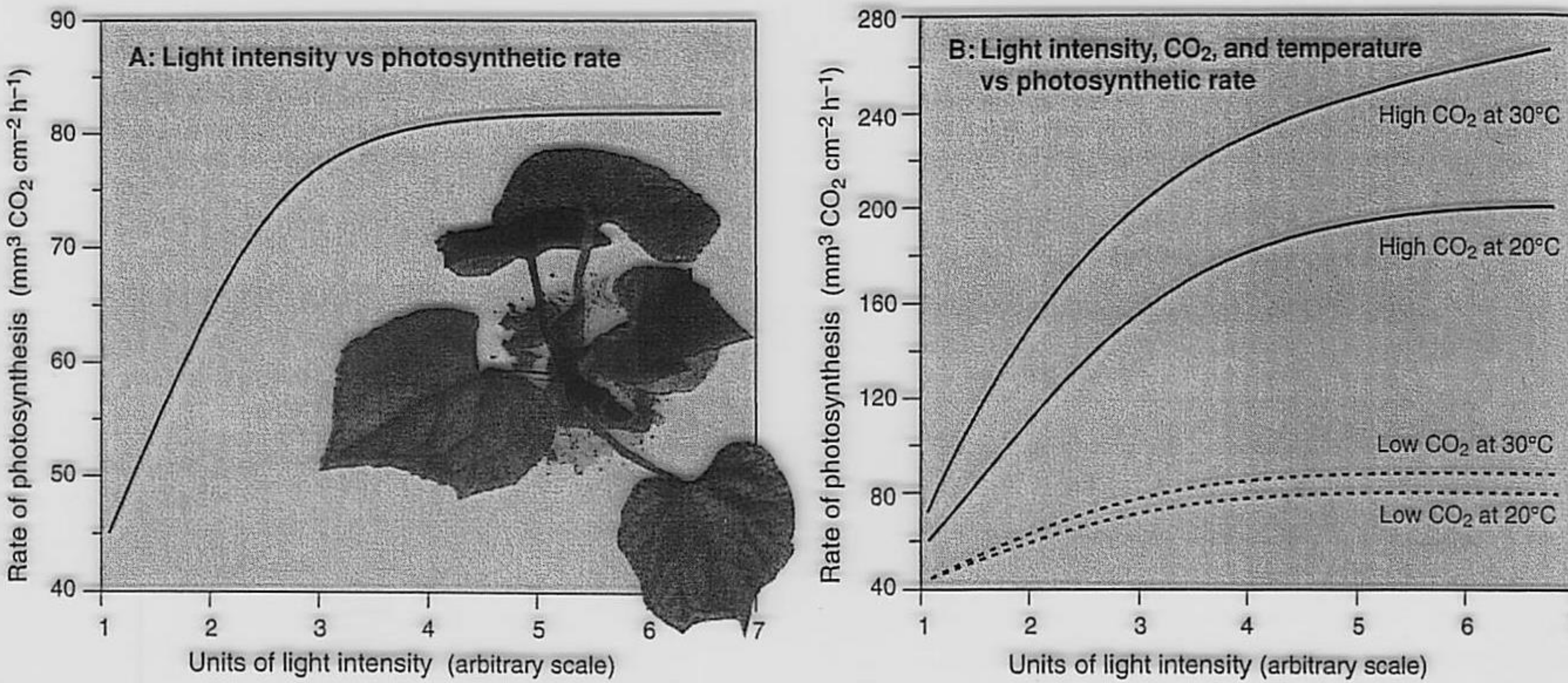




Effect of temperature on photosynthesis



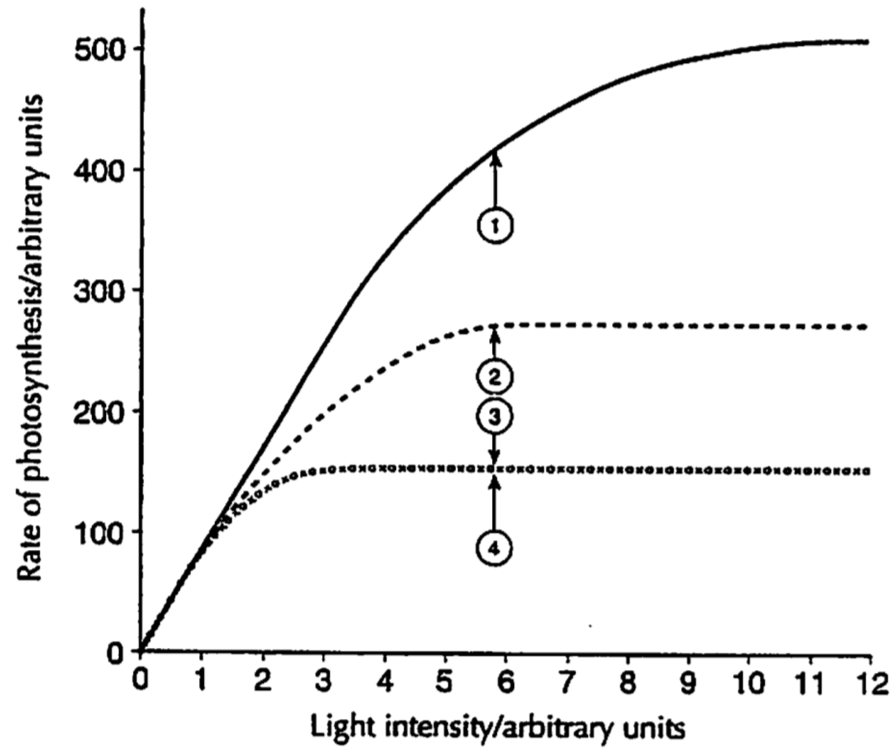
Factors Affecting Photosynthetic Rate -



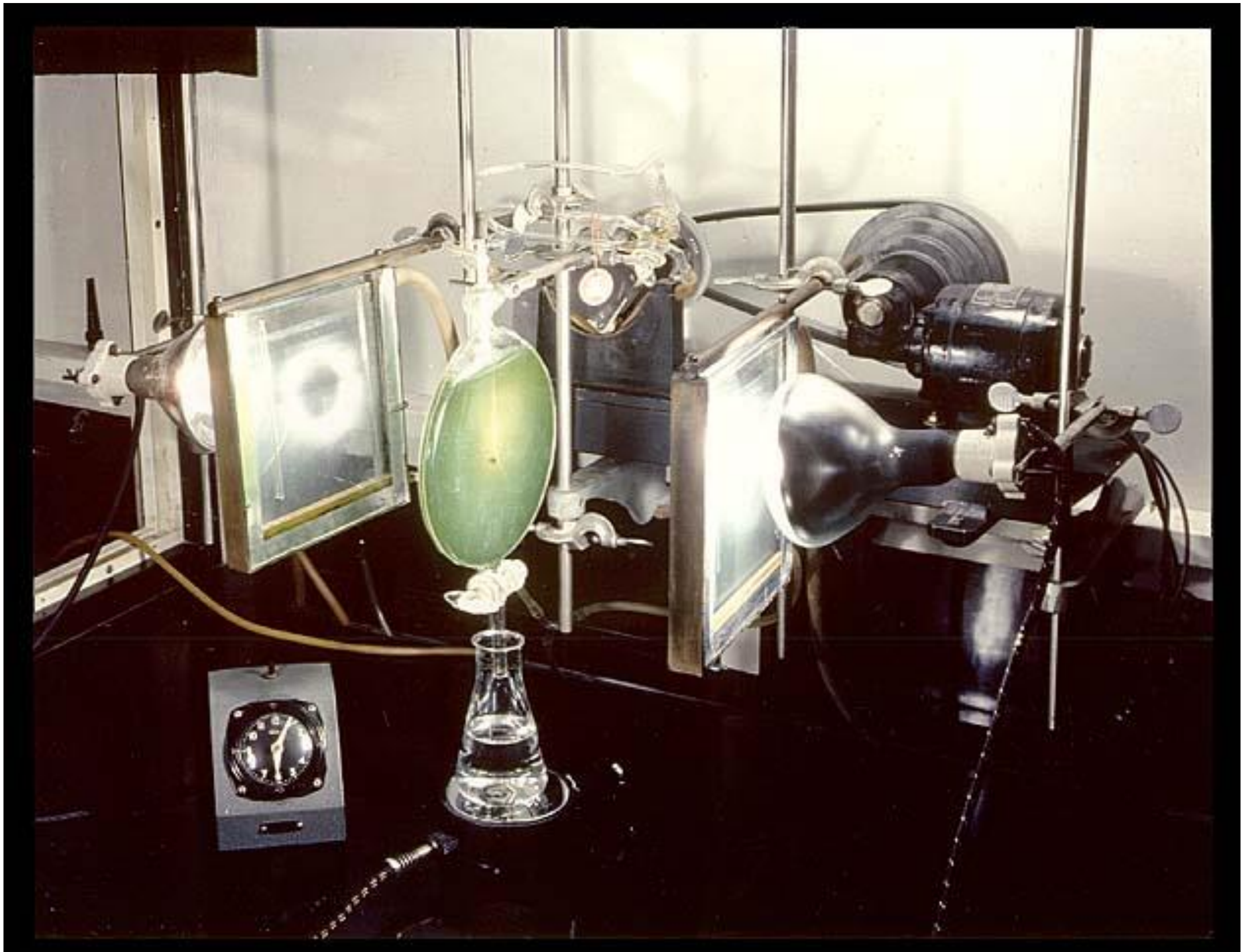
Results of an investigation into limiting factors

The figure (right) shows the effects of light intensity on the rate of photosynthesis at two different temperatures and two carbon dioxide concentrations. It is possible to deduce which is the limiting factor at the point marked with an arrow (① – ④) on each curve.

KEY
- —— 30 °C and 0.15% CO_2
- - - - - - 20 °C and 0.15% CO_2
- × × × × × 30 °C and 0.035% CO_2
- ∘ ∘ ∘ ∘ ∘ 20 °C and 0.035% CO_2



Melvin Calvin &
The Lollipop Apparatus



Now you try it…

- http://www.snabonline.com/Content/TopicResources/Topic5/Activities/Interactives/5_6/5--6.swf

- I need a little light: https://www.youtube.com/watch?feature=player_embedded&v=_IV-E68rh18