Photoperiodism

Photoperiod and Photoperiodis

Plant Physiology:(lecture):(5)

By: PROF. Dr. Manal Zbari AL-MAYAHI

- **Photoperiod**
  - Word derivation:
    - *Photo*: light
    - *Period*: a specific length of time
  - Definition: the relative length of daylight and night
- **Photoperiodism**
  - Definition: the response of plants to changes in the photoperiod
  - Example: flowering
    - The timing of flowering in plants is determined by the relative length of daylight and night (photoperiod).
    - The seasons are controlled by the length of daylight.
      - Between December and June, in the northern hemisphere, the amount of daylight increases daily.
      - So, increased daylight indicates spring and summer are on the way.
      - Between June and December, the opposite occurs.

The Maryland Mammoth and the Discovery of Short-Day Plants

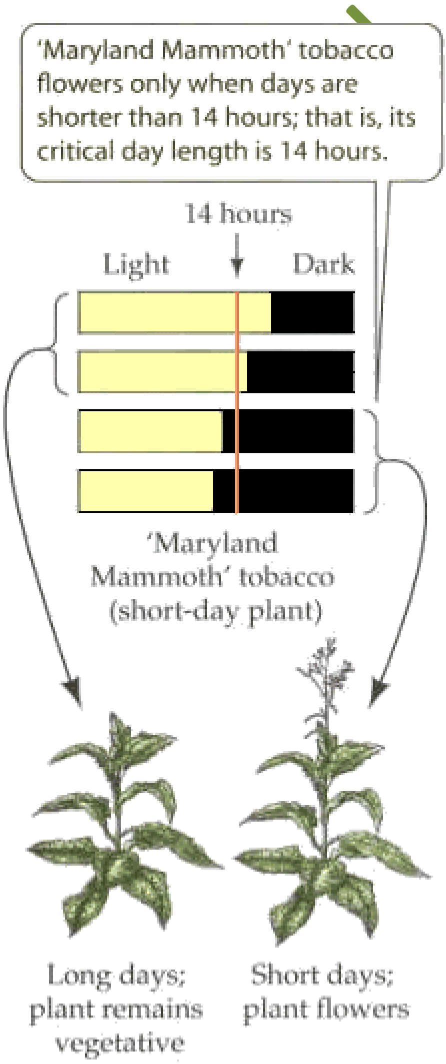
- **Researchers**: Garner and Allard at the USDA in the 1920s
- Worked with the **Maryland Mammoth**, a large tobacco plant that didn't flower in the summer when most tobacco plants bloomed.
- They discovered that the shortening days of winter stimulated flowering in the Maryland Mammoth.
  - Under controlled experiments, in light-tight boxes where they could manipulate the amount of light and dark, they

discovered that flowering only occurred if the day length (amount of light) was 14 hours or less.

- They called the Maryland Mammoth a **short-day plant** because it required a light period *shorter* than a **critical length** to flower.

Short-day Plants

- Short-day plants flower when daylight is less than a critical length.
- They flower in the late summer, fall, or early winter.
- Examples: chrysanthemums ("mums"), poinsettias, some soybeans.



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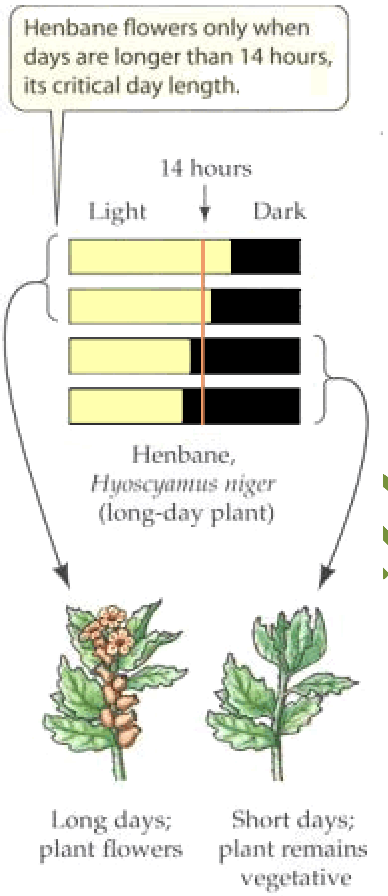
Long-day Plants

- Long-day plants flower when daylight is increasing.
- They flower in the spring and early summer.
- Examples: radishes, lettuces, irises, many cereal varieties.





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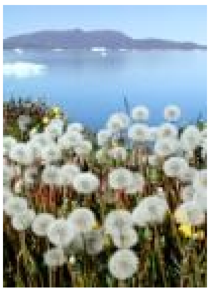
Day-neutral Plants

- Day-neutral plants do not flower in response to daylight changes.
- They flower when they reach a particular stage of maturity or because of some other cue like temperature or water, etc.
- This is the most common kind of flowering pattern.
- Examples: rice, dandelions, tomatoes, etc.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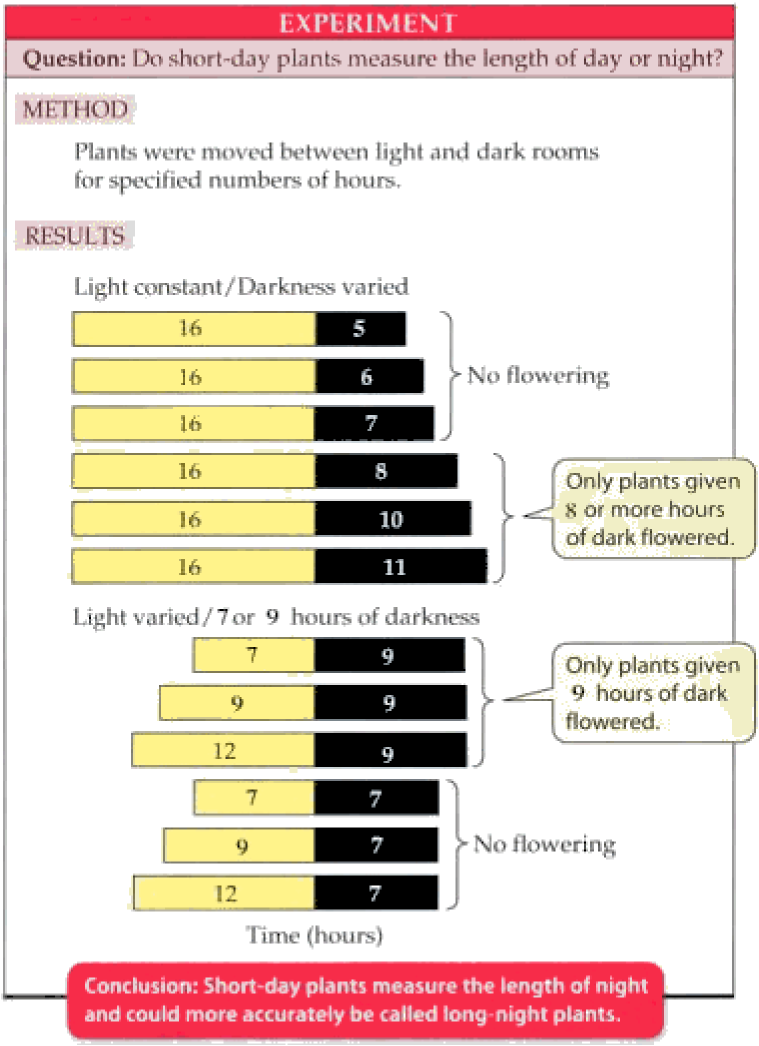
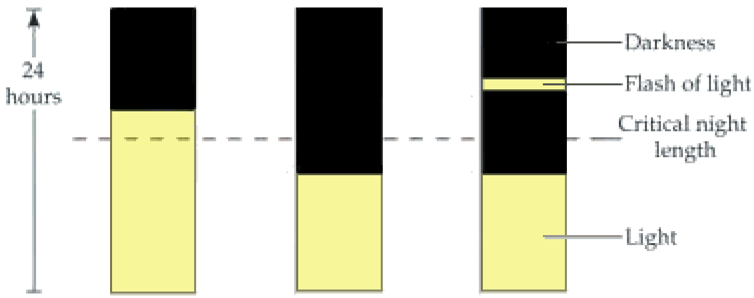
- In the 1920s, when they first did their research on the Maryland Mammoth, they thought it was all about **critical day length**.
    - For twenty years this was the prevailing understanding about how flowering was initiated.
    - All the biology books printed during these years talked about short-day plants and long-day plants.
- But, in the 1940s, researchers discovered it was **night length** rather than day length that determined flowering.

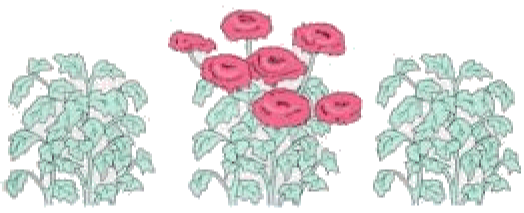
It's All About Night Length, *Not* Day Length!

- Key discovery: **photoperiodism** has nothing to do with day length—it is completely dependent on a **critical night length**.
- Summary of research using the cocklebur plant:
    - The critical night length for the cocklebur is 8 hours: as long as the cocklebur plant has at least 8 hours of **continuous darkness**, it will flower.
    - What was originally called a **short-day** plant is actually a **long-night** plant.
    - If the night is punctuated by light for a few minutes, then it will not flower!

The Experimental Results



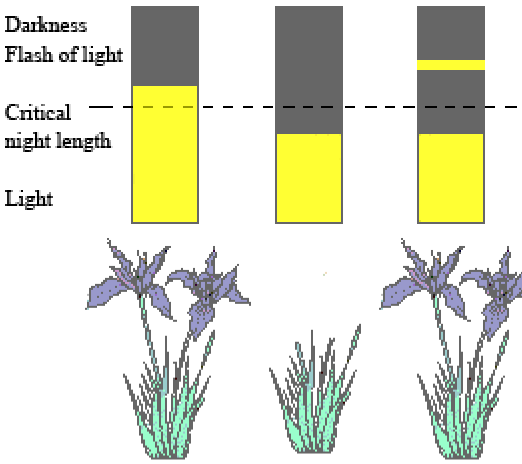




Unknown source; part of figure 39.16, page 766, Campbell's *Biology, 5th Edition*; unknown source

Long-day Plants are Actually Short-night Plants!

- Similarly, what were once thought to be **long-day** plants are actually **short-night** plants: they flower only when the night is shorter than a critical length.
- A few minutes of light during the night will shorten the night length, therefore causing flowering to occur!



Part of figure 39.16, page 766, Campbell's *Biology, 5th Edition*

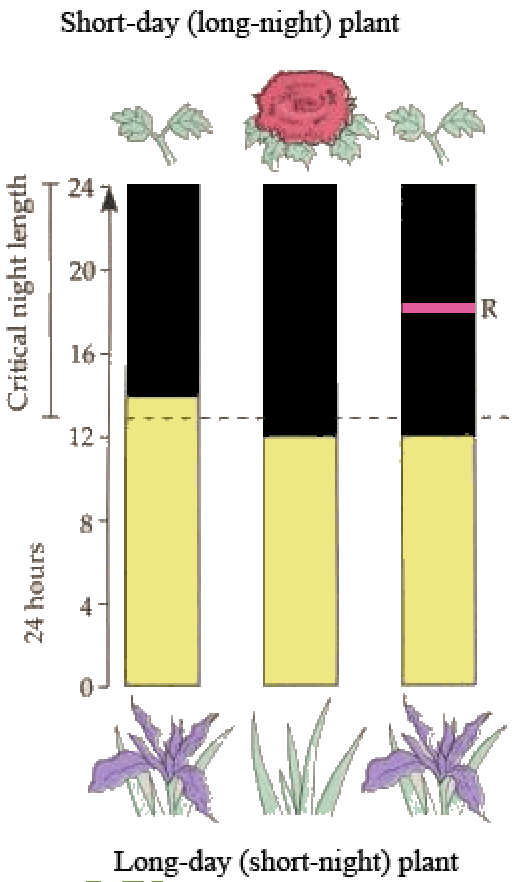
Flower Growers Use Knowledge About Photoperiodism to Make Money!

- As your book mentions, the flower-growing industry uses this knowledge about how photoperiodism works to produce flowers out of season.
- Chrysanthemums are short-day (long-night) plants that normally bloom in the fall.
    - Their blooming can be stalled until Mother's Day in May by exposing the plants to a little light during the long evenings.
    - This effectively shortens the night below the critical night length!

The Details

- Red light, of wavelength 660 nm, is the most effective in interrupting night length.
- Experimental results have confirmed this fact:
    - **Short-day** (long-night) plants experiencing a long night will *not* flower if exposed briefly to 660 nm light sometime during the night.

- **Long-day** (short-night) plants exposed briefly to a 660 nm light *will* flower even if the total night length exceeds the critical number of hours.



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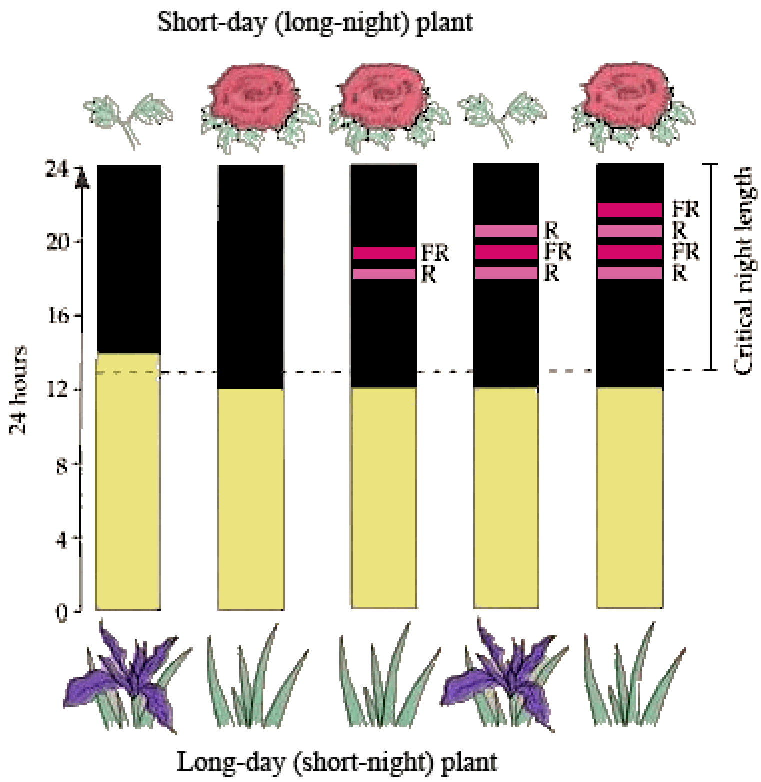
Far-red Light Cancels the Effect of Red Light

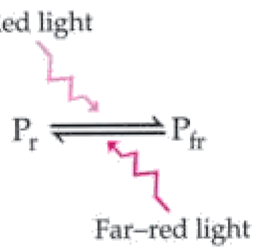
- Shortening of night length by **red light (R)** can be negated by a flash of **far-red light (FR)** of 730 nm.
- When this occurs, the plant perceives no interruption in night length.
- No matter how many times red light is flashed, as long as it is followed by far-red light the effects of red light are canceled.
- This works in both short-day and long-day plants.



Part of figure 39.18, page 768, Campbell's *Biology, 5th Edition*

How Does This Work?

- Light-sensitive proteins called **phytochromes** are partially responsible for the timing of flowering.
- The phytochrome proteins come in two different forms: P_r and P_{fr}.
- These phytochromes act as photodetectors that tell the plant what kind of light is present.
- The absorption of light causes them to convert to the other form:
  - P_r absorbs **red light** to become P_{fr}.
  - P_{fr} absorbs **far-red light** to become P_r.
- The presence of P_{fr} switches on physiological and developmental changes in plants.
  - Not only does it influence flowering, but also triggers other responses to light such as seed germination.



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Circadian Rhythms

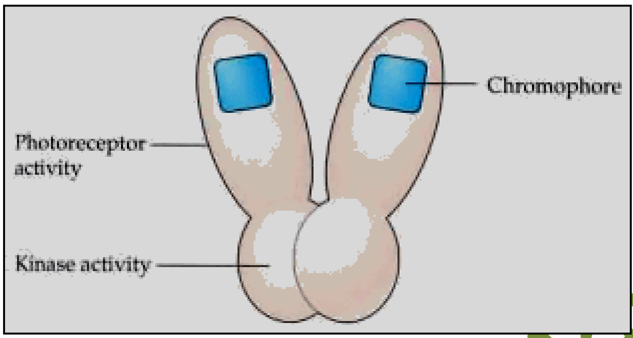
- Most plants and animals exhibit what are called **circadian rhythms**.
    - Word derivation:
        - *Circa*: approximately
        - *Dies*: day
        - "About a day"
    - Circadian rhythms are patterns of physiological change that follow a 24-hour cycle, day after day.
    - These 24-hour cycles can be seen in a variety of physiological responses and are very predictable:
        - Pulse
        - Blood pressure
        - Temperature
        - Rate of cell division
        - Metabolic rate
        - Stomata opening and closing
- The big question in biology is whether these changes are controlled externally (by environmental cues) or whether they are controlled internally (endogenously).
    - The answer seems to be that they are controlled internally.
    - Scientists have put people and plants in darkness for days, and they still exhibit the 24-hour cycle.
    - However, the 24-hour cycle is no longer synchronized with the outside world—it drifts.
- Take-home message: biological clocks exist, but they can drift.

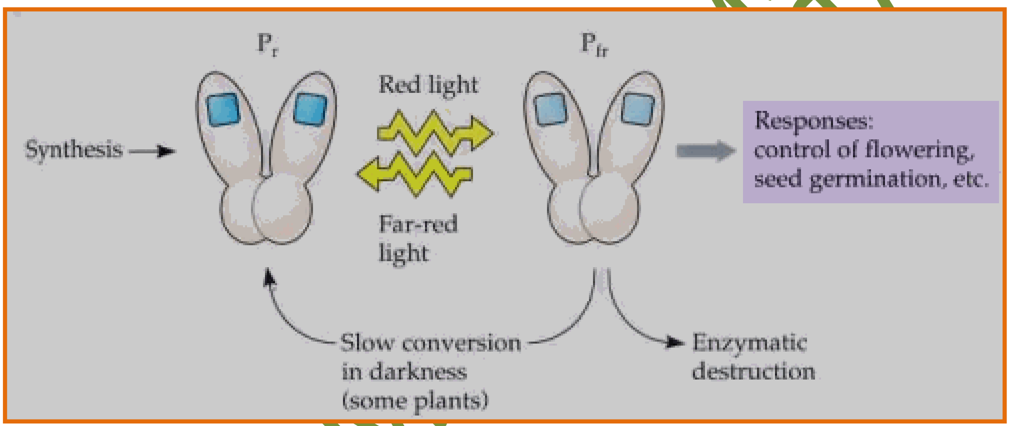
The Phytochrome System Is a Way to Maintain the Circadian Rhythm

- Since ordinary daylight has both red and far-red light, how does this system work?
    - The phytochrome is a **homodimer** (a quaternary protein with two identical halves), bonded to a non-protein light absorbing pigment called a **chromophore**.
    - The P_r form is constantly being synthesized by the plant.
    - When exposed to daylight, some of the P_r is converted to P_{fr}, but some P_{fr} is converted to P_r as well.
        - Eventually, equilibrium is reached and maintained during the day.
    - Degradative enzymes destroy more of P_{fr} than P_r.
- In the dark, P_{fr} is converted to P_r.

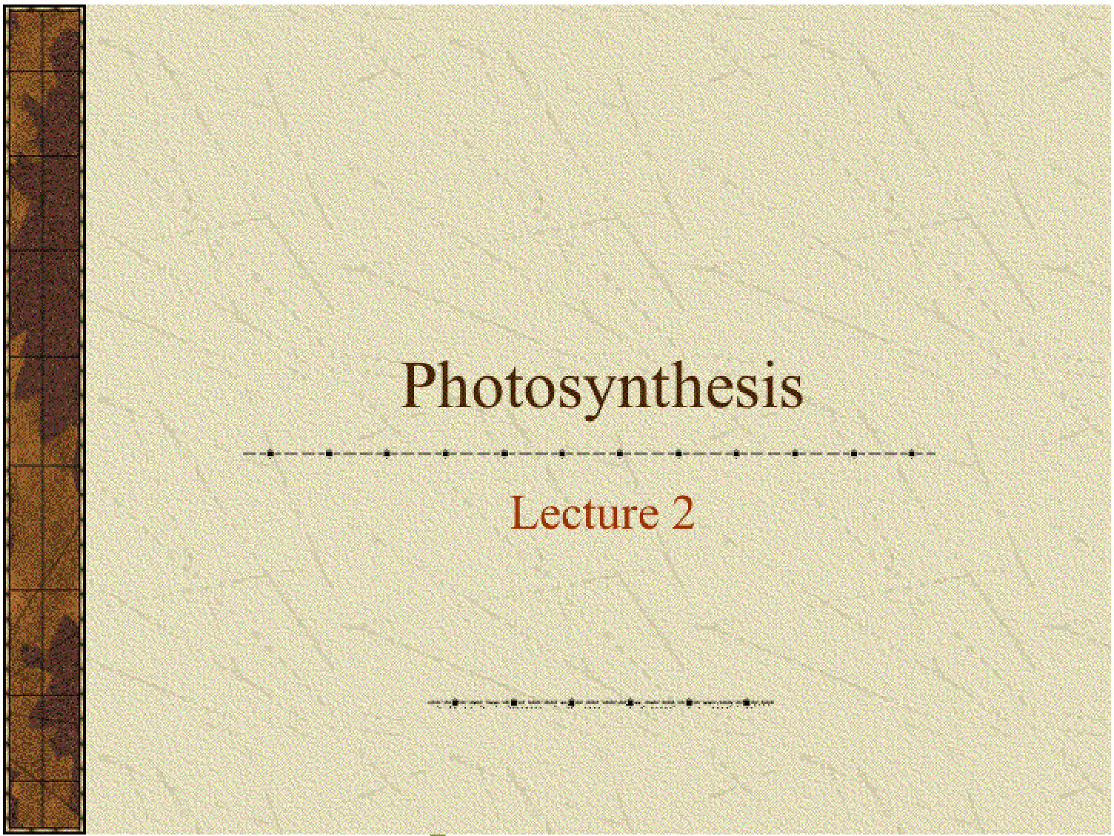
- At sundown, and throughout the night: P_{fr} begins to disappear and P_r accumulates.
- At sunrise: P_{fr} levels suddenly increase, and P_r levels decrease.

- Thus **night length** is responsible for resetting the circadian rhythm clock.



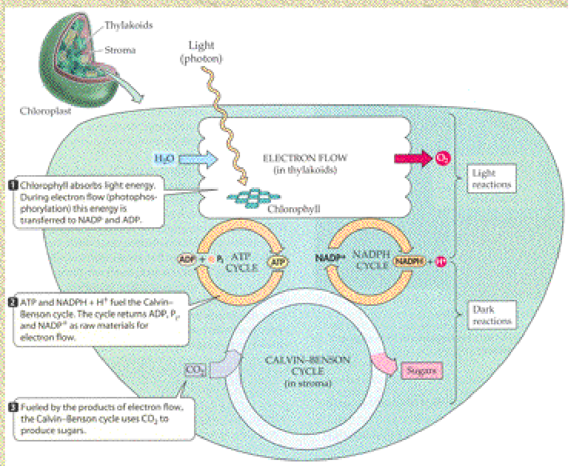


Figures 39.19 and 39.20, page 769, Campbell's *Biology, 5th Edition*


Photosynthesis
Lecture 2

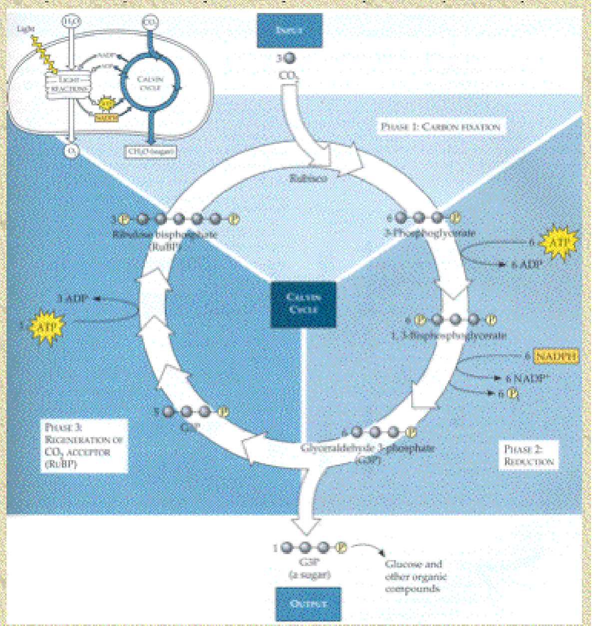
Dark Reaction (Light Independent Reaction) = Calvin Cycle

- Goal: To "fix" CO_2
  - Take a boring uninteresting molecule, **CO_2**, and create an energy rich molecule, **glucose, $C_6H_{12}O_6$**
- It is a **cycle** so it goes around, and around. . .
- Requires **6 turns** to make 1 glucose molecule
- There must be an **energy input** to drive the cycle, so energy rich molecules created in the ***light reaction*** are used
  - **ATP**
  - **NADPH**
- Can occur in dark or light



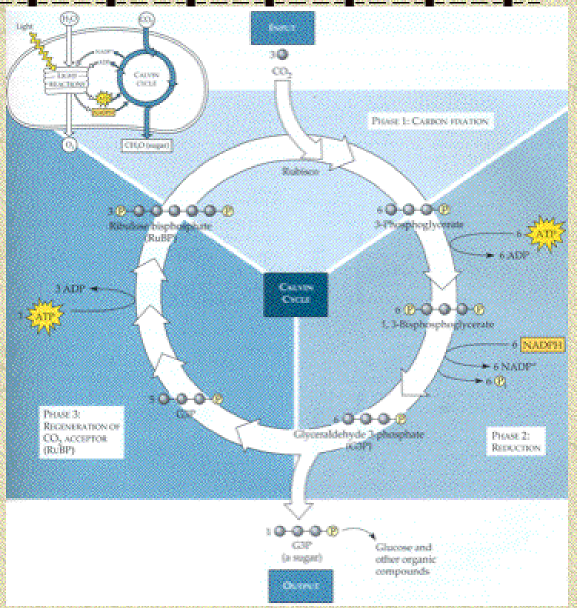
Calvin Cycle Overview

- Three phases of the cycle
  - **Phase 1:** Carbon Fixation
  - **Phase 2:** Reduction
  - **Phase 3:** Regeneration of CO_2 Acceptor (RuBP)
- The product of the **Calvin Cycle** is glyceraldehyde 3-phosphate (G3P) which is a 3 carbon sugar.
  - To make this sugar requires 3 turns of the cycle



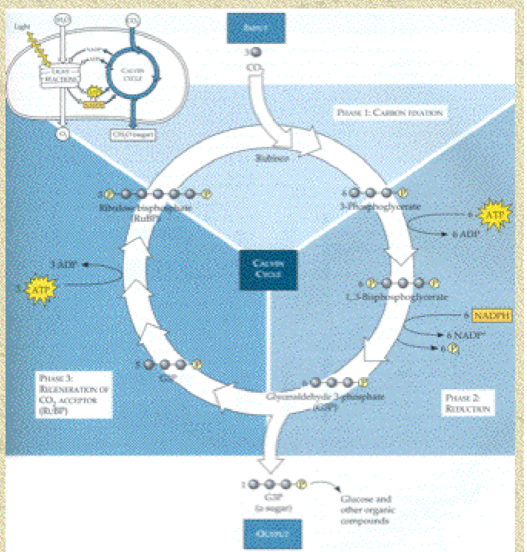
Calvin Cycle
Phase 1: Carbon Fixation

- CO_2 is attached to a five carbon sugar named **ribulose bisphosphate** (RuBP)
- Catalyzed by the enzyme, RuBP carboxylase, **rubisco** (most abundant protein on earth!!).
- **Product**: A 6 carbon intermediate that immediately splits in half to form 2 molecules of **3-phosphoglycerate**.
- **Quick Summary**
  - **Begin**: 1 CO_2 + 1 RuBP (5 C)
  - **End**: 2 3-phosphoglycerate (3 C)



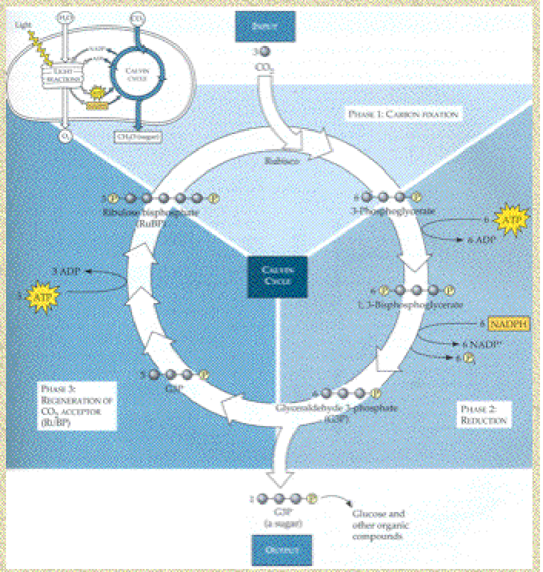
Calvin Cycle
Phase 2: Reduction

- 3-Phosphoglycerate is converted to the energy rich sugar glyceraldehyde 3-phosphate (G3P)
  - Requires 6ATP & 6NADPH
- Two Steps
  - Step One
    - Six 3-Phosphoglycerate becomes six 1,3 bisphosphoglycerate.
    - To do this 6 ATP are required
  - Step Two
    - Six 1,3 bisphosphoglycerate are converted into six glyceraldehyde 3-phosphate.
- Result
  - One glyceraldehyde 3-phosphate leaves the cycle.
  - Five glyceraldehyde 3-phosphate continue around the cycle.



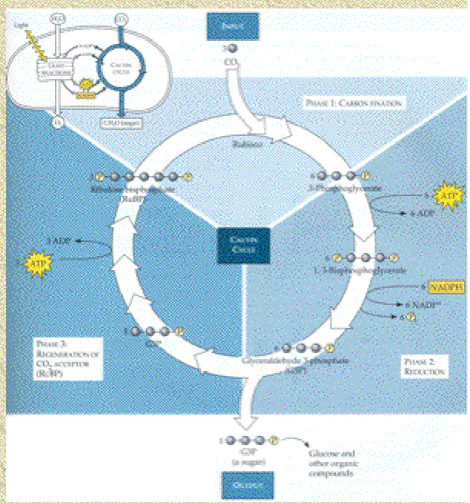
Molecule Count Thus Far. . .

- **Molecule Count**
  - **Phase 1: Fixation**
    - 3 CO_2 + 3 RuBP (5C) produces:
      - 6 3-Phosphoglycerate (3C)
    - Total: 18 carbons
  - **Phase 2 Reduction**
    - 6 3-Phosphoglycerate (3C) converted into:
      - 6 Glyceraldehyde 3-phosphate (G3P) (3C)
    - Total: 18 carbons
  - **Output & Phase 3**
    - 1 G3P (3C) leaves the cycle
    - 5 G3P (3C) continue
    - Total: 18 carbons



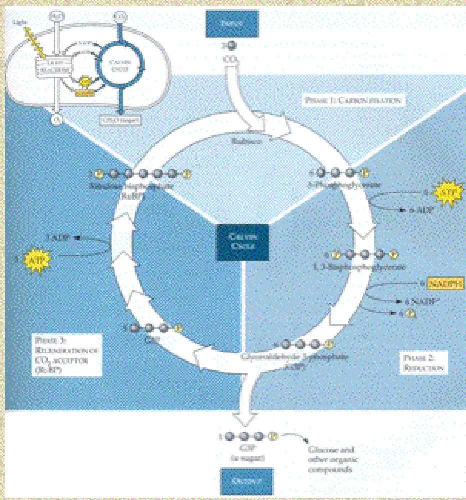
Calvin Cycle Phase 3: Regeneration of CO_2 Acceptor (RuBP)

- 5 glyceraldehyde 3-phosphates (G3P) (3C) are rearranged into 3 ribulose biphosphates (RuBP) (5C).
- 3 ATP are required for this.
- Ribulose biphosphate (RuBP) was the molecule that began the cycle by combining with CO_2 in Phase 1: Carbon Fixation.



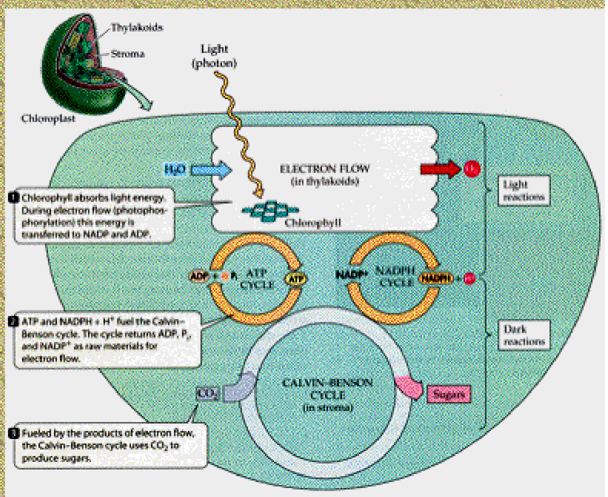
Total Energy Cost

- To make 1 glyceraldehyde 3-phosphate, a 3 carbon sugar
  - 9 ATP
  - 6 NADPH
- To make 1 glucose, a 6 carbon sugar
  - 18 ATP
  - 12 NADPH



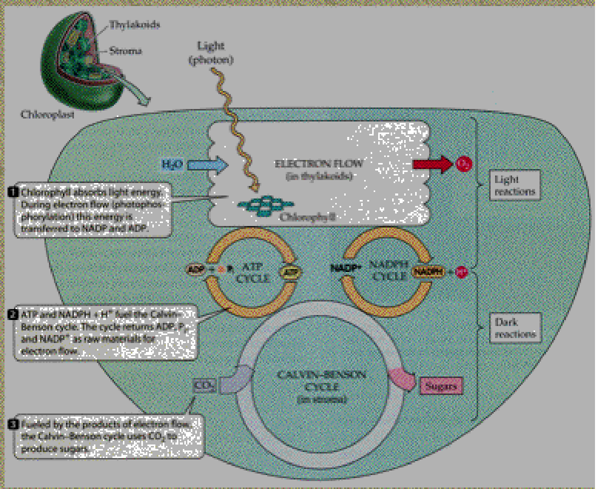
Photosynthesis Overview (1)

- Light Reaction
  - Occurs in the **thylakoids**
  - **Light energy** is transformed into **ATP & NADPH**
    - Non-cyclic electron flow
    - Cyclic electron flow
  - **Water** contributes its **electrons** to the process; **oxygen** is a byproduct



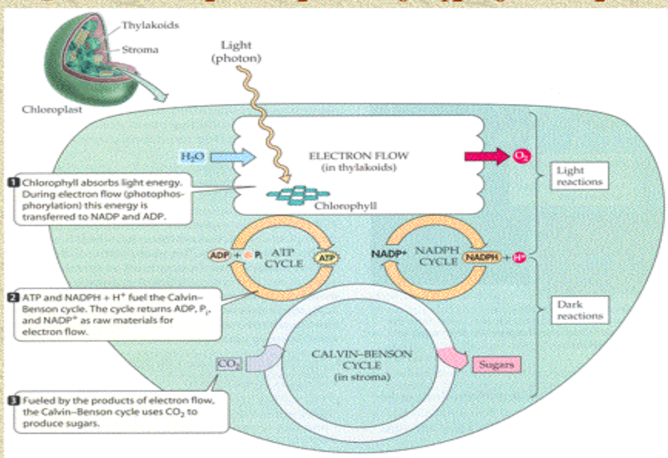
Photosynthesis Overview (2)

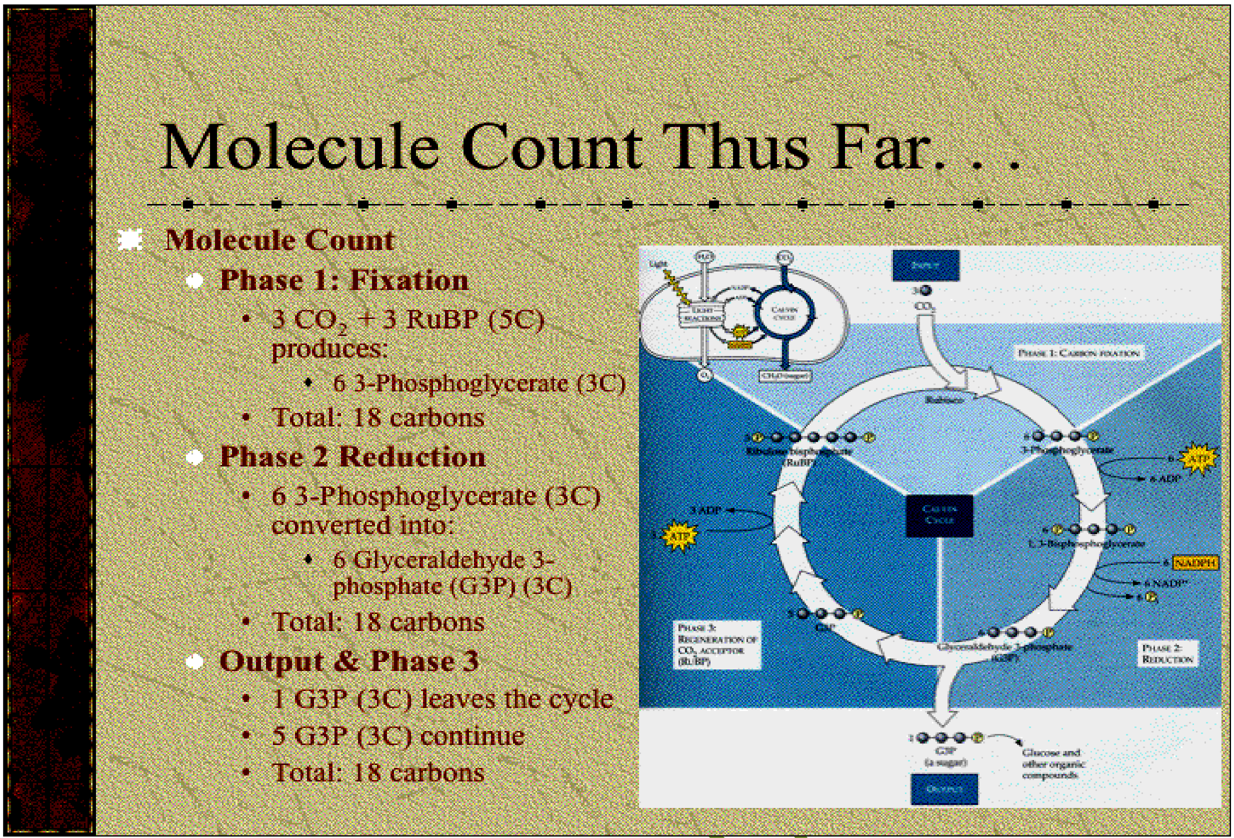
- **Calvin Cycle** (Dark Rxn/ Light Independent Rxn)
  - Occurs in the **stroma**
  - Light is not directly involved.
  - **Glucose** and other sugars are constructed out of CO_2
    - **ATP & NADPH** from the light reaction are the energy source “driving” this process



Photosynthesis Overview (3)

- **Light + $6CO_2$ +$6H_20$ ->$C_6H_{12}O_6$ + $6O_2$**





Plant Physiology - Letuer: (8)

By Dr. Manal Zbari

photosynthesis

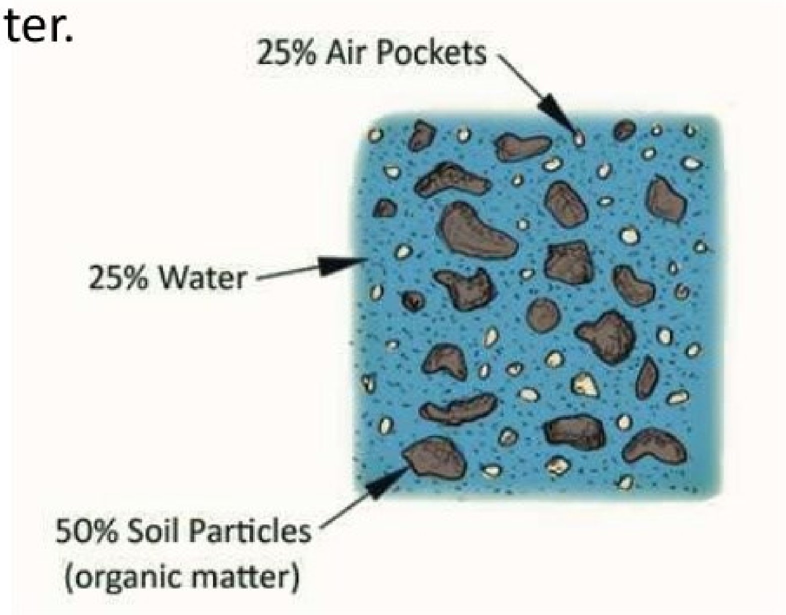
—the process by which the chlorophyll in the leaves of plants capture light energy which they then use to change carbon dioxide and water into food. This plant food is called glucose.

—and in most plants all this takes place in its leaves.

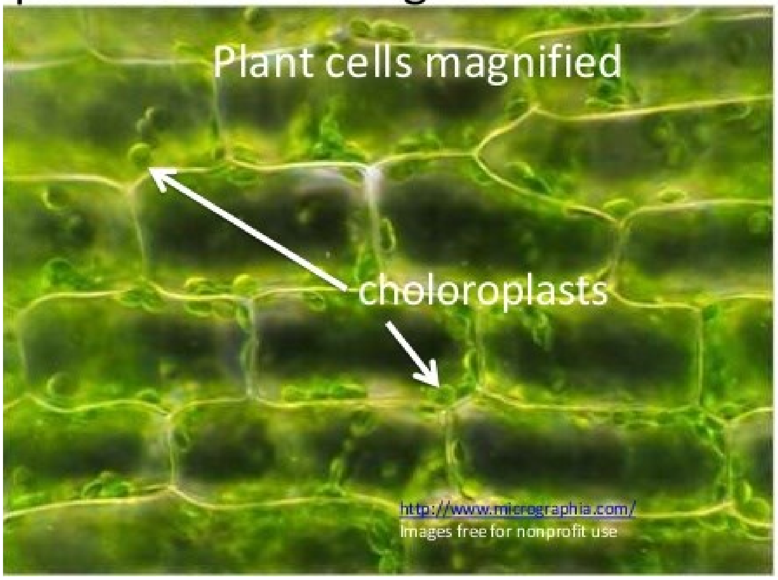
These are the things a plant needs for photosynthesis-- the process by which a plant makes its own food.

1. water
2. carbon dioxide
3. light energy from the Sun

Twenty-percent of soil is made up of water that is stored between the particles of weathered rock. The plant roots absorb this water.



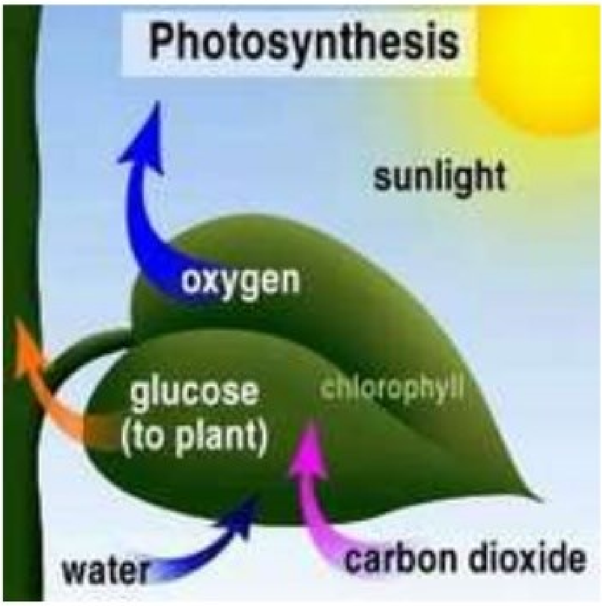
Plant cells have cell structures called **chloroplasts** which contain chlorophyll, a green substance that <u>absorbs light energy</u>. Chlorophyll is what gives plant leaves their green color.



Plants use the light energy from the Sun to change carbon dioxide and water into food.

When plants make food in their leaves, the “waste” product is oxygen—the gas we must breathe in to stay alive.

The plant gives off oxygen through the stomata in its leaves.

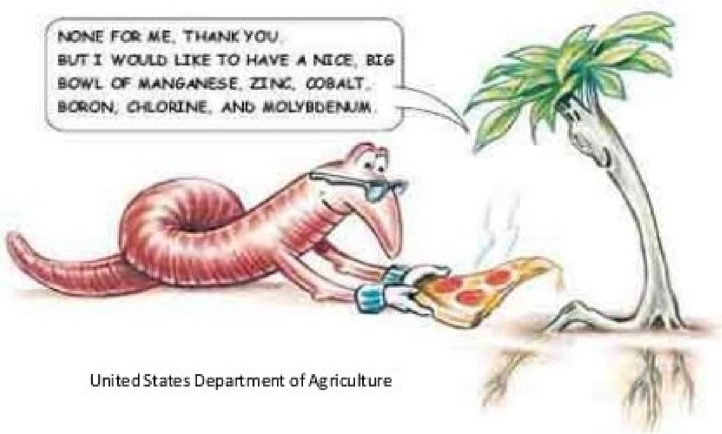


Here is photosynthesis in a nutshell.

Can you explain what is happening?

Do plants need anything else besides water, carbon dioxide and sunlight?

Yes, plants also need 13 different minerals such as
nitrogen, phosphorous, potassium, magne sium, boron.
Plants **do not need** these minerals **to make food**. These minerals are important for plant growth
, flowering, seed production and general health.



United States Department of Agriculture

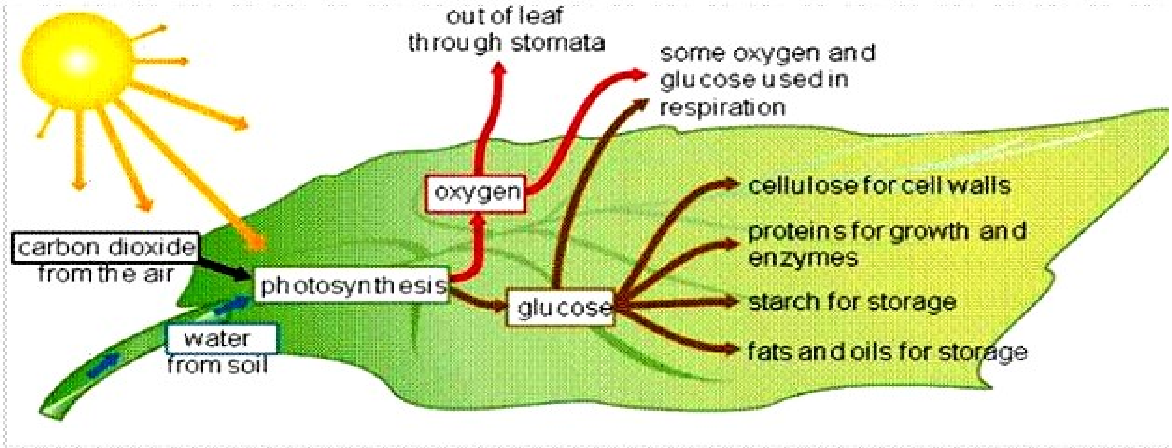
These minerals which come from the soil are dissolved in water and are absorbed through the plant's roots.

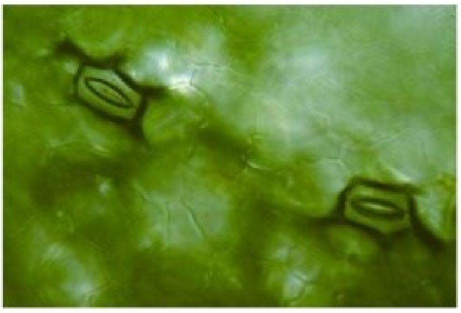
A plant changes some of the glucose it manufactures into substances such as starch, fats, and oils.

It uses these substances for **two things**.

1. For storing food in seeds and roots. Before winter, some plants store starch in their roots so they can survive the winter and start growing again quickly in the spring. Fats and oils are stored in seeds to use for germination.

2. To build plant tissues such as leaves, wood, flowers, fruit and roots.



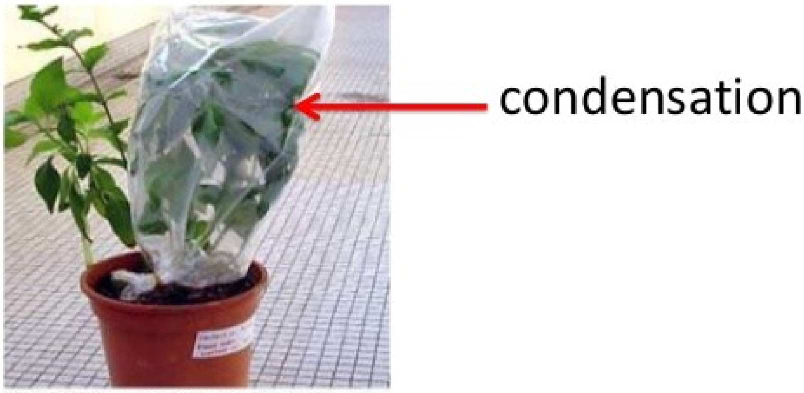


transpiration

The loss of water vapor through the stomata.

Transpiration mainly takes place when the stomata on the bottom of the leaf are open to let carbon dioxide in or oxygen out during the process of photosynthesis.

The picture below shows condensed water vapor given off from the leaves of the plant. When the water vapor hits the cool sides of the plastic bag it condensed and changed into droplets of liquid water.



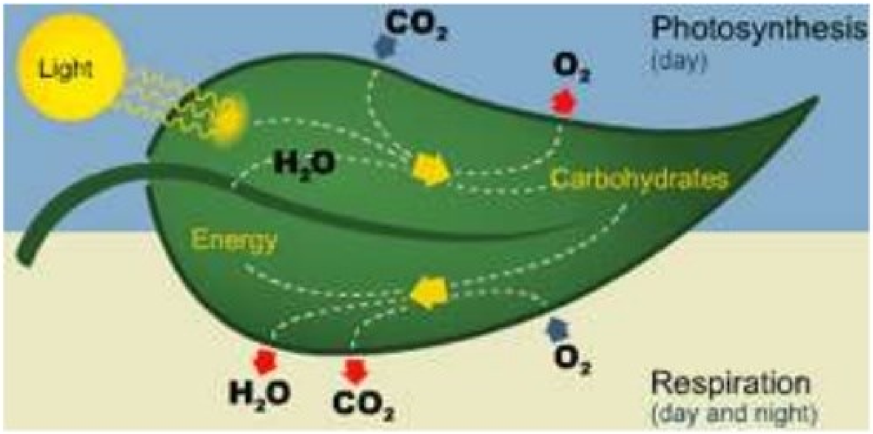
Credit: Ming kei College, Hong Kong
http://ga.water.usgs.gov/

As usual, things are not as simple as it may seem.

Plants do not make food for animals. They make it for themselves so that they can grow and carry out their life processes.

Like animals they need to absorb oxygen. Plants take oxygen in through the stomata and through their roots and use it to burn their food for energy.

The process of using oxygen to burn food for energy is called **respiration.**



http://ecosys.cfl.scf.rncan.gc.ca/
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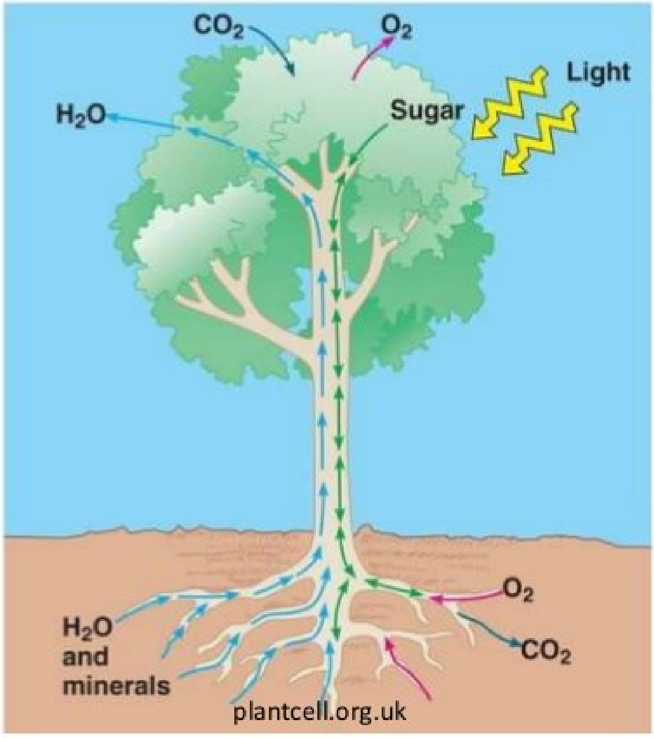
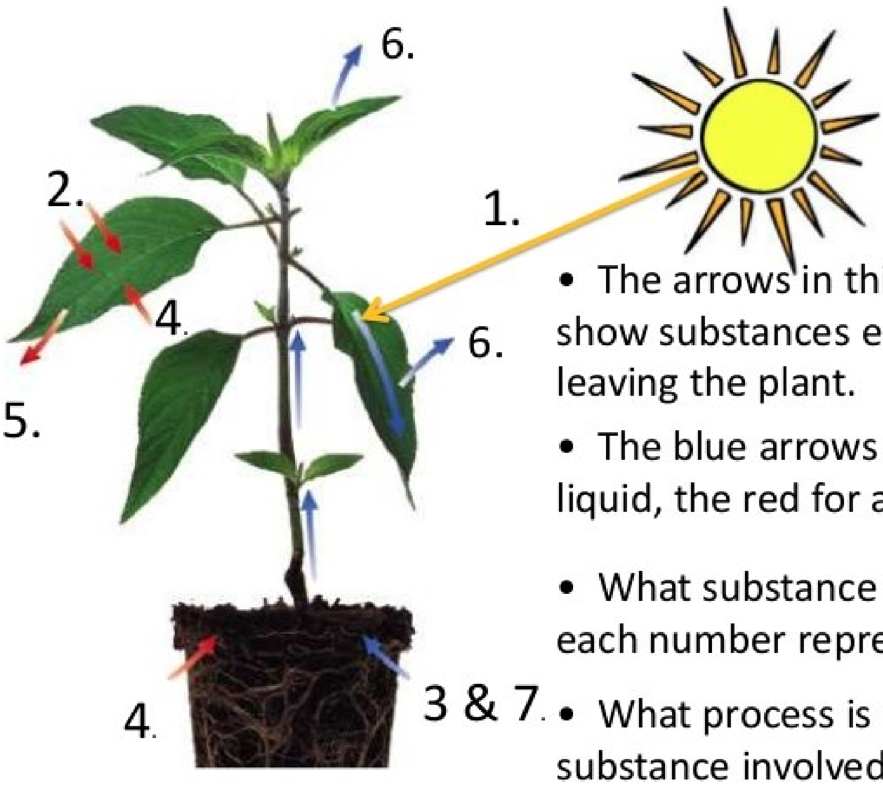
Here we can see the two processes—photosynthesis and respiration occurring in a leaf.

Comparison of Photosynthesis & Respiration

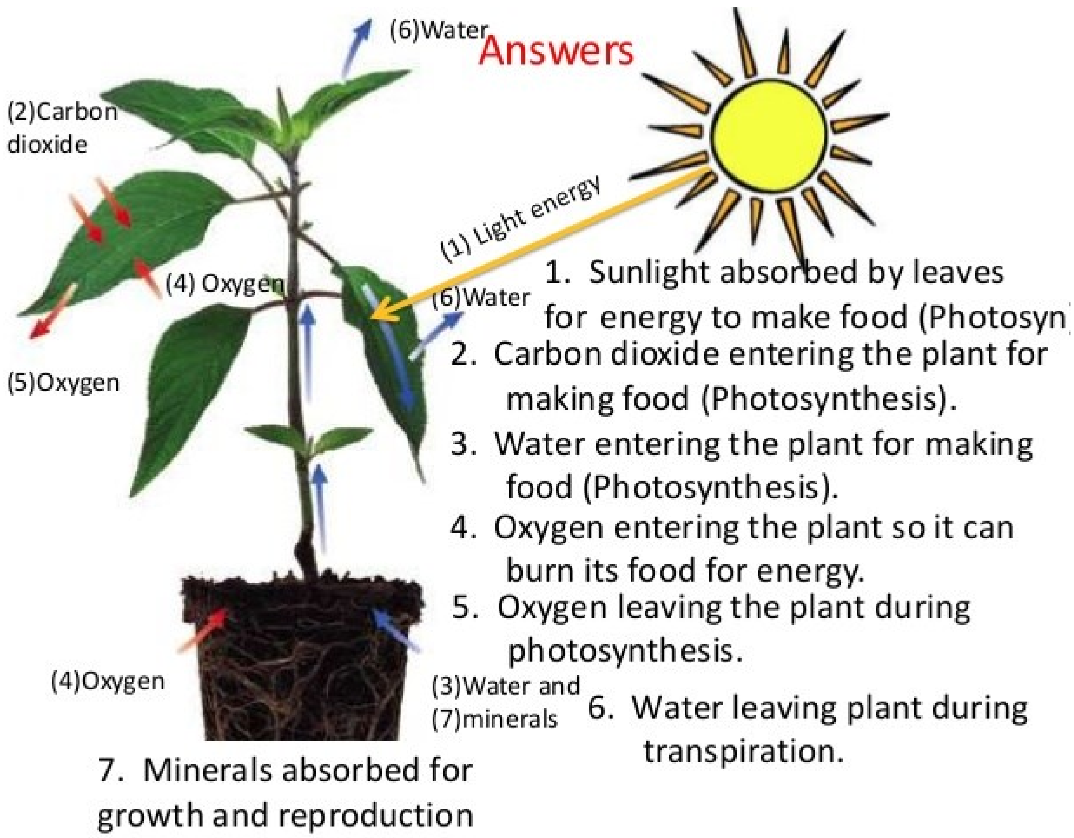
Photosynthesis	**Respiration**
Produces sugars from energy	Burns sugars for energy
Energy is stored	Energy is released
Occurs only in cells with chloroplasts (plants)	Occurs in most cells
Oxygen is produced	Oxygen is used
Water is used	Water is produced
Carbon dioxide is used	Carbon dioxide produced
Requires light light	Occurs in both dark and



Look at this drawing and explain what is happening.



- The arrows in this diagram show substances entering and leaving the plant.
- The blue arrows stand for a liquid, the red for a gas.
- What substance does each number represent?
- What process is each substance involved in?



What important thing can plants do that animals cannot?

a. move from place to place
b. survive with very little water
c. make their own food
d. grow

The process by which plants make their own food is called

a. photosynthesis
b. respiration
c. reproduction
d. transpiration

Plants use the following substances to make their food:

a. carbon dioxide and oxygen
b. oxygen and water
c. water and carbon dioxide
d. water and nitrogen

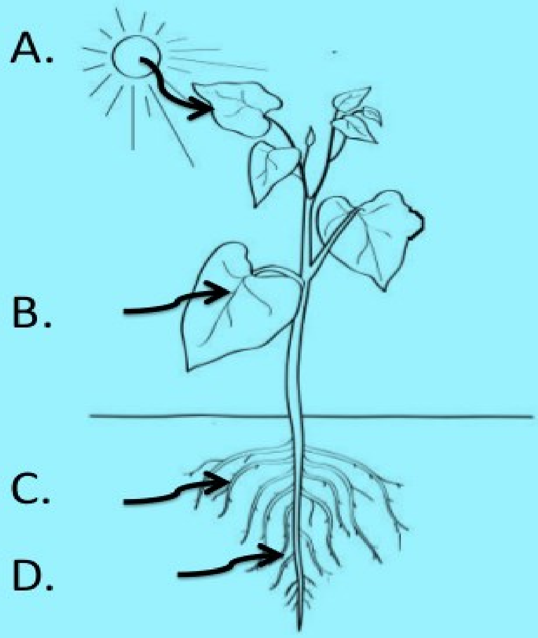
What do plants need?

A. Sunlight

B. Carbon dioxide

C. water

D. Oxygen and Minerals

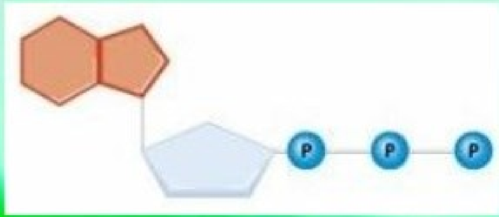


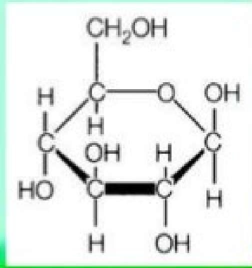
The Light Reactions

- Almost all of the energy in living systems comes from the <u>sun</u>.
- Sunlight energy enters living systems when plants and some other organisms absorb light in the process of <u>photosynthesis</u>.

The Light Reactions

- During photosynthesis, <u>light</u> energy from the sun is converted into <u>chemical</u> energy in the form of molecules such as ATP and glucose.



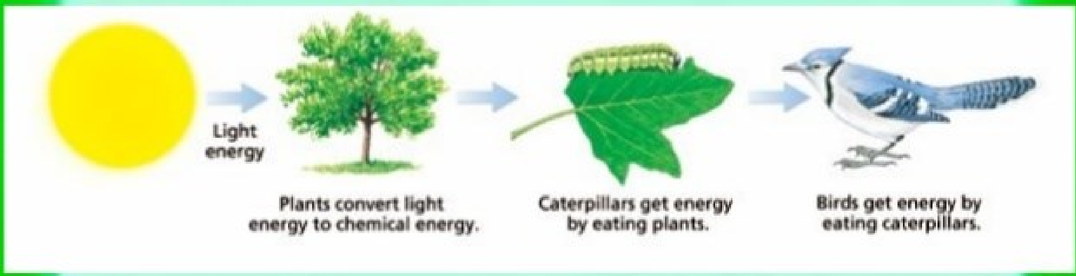


Obtaining Energy

- Organisms can be classified according to how they get <u>energy</u>.
- Those that obtain their energy from the sun are called <u>autotrophs</u>.
  - Some examples include <u>plants</u>, <u>algae</u>, and some bacteria.

- Organisms that obtain their energy from the foods they consume are called <u>heterotrophs</u>.
  - Some examples include <u>animals</u>, <u>fungi</u>, and some bacteria.

Obtaining Energy

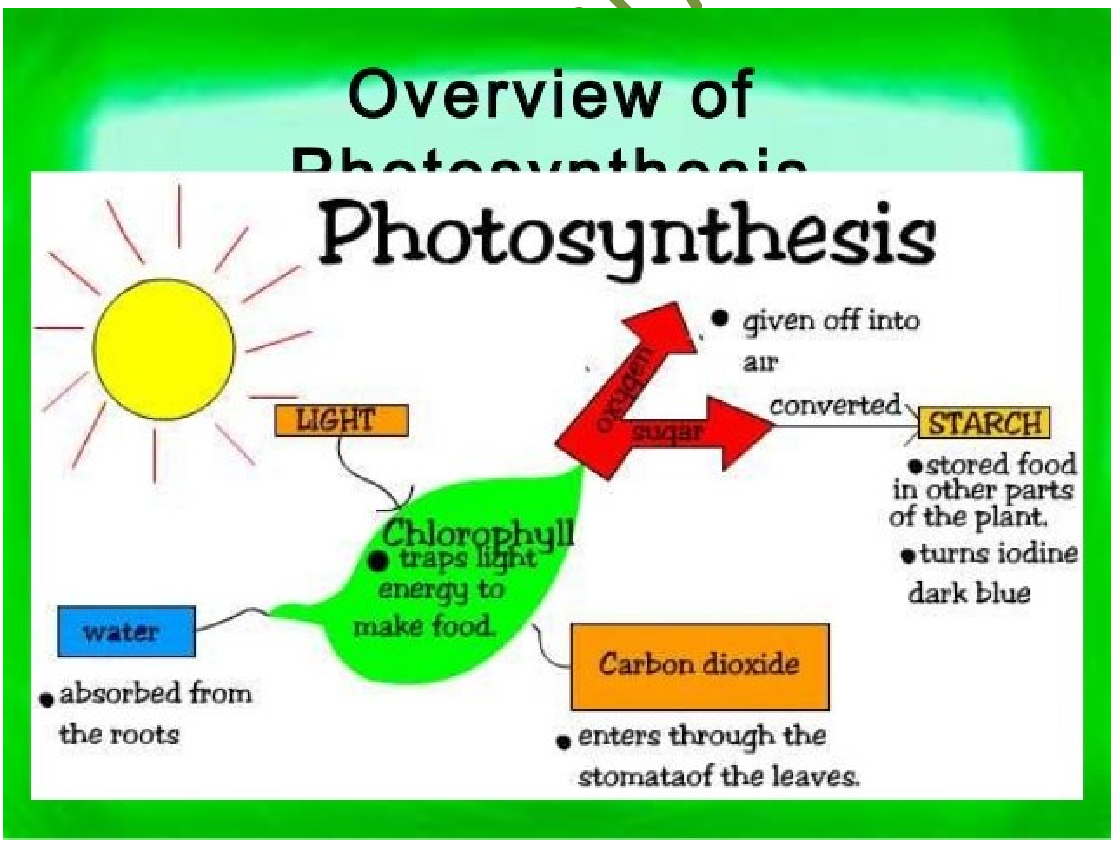


Overview of Photosynthesis

- Photosynthesis involves the use of light energy to <u>convert</u> water (H_20) and carbon dioxide (CO_2) into oxygen (O_2) and high energy <u>sugars</u> (e.g. Glucose).

Overview of Photosynthesis

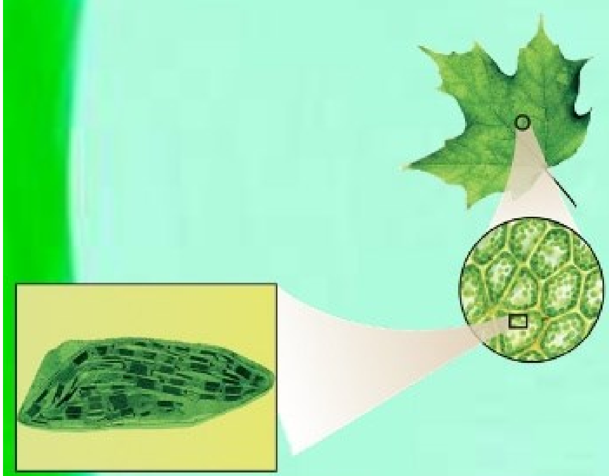
- Photosynthesis can be divided into 2 stages:
  - **Light Reactions** – Light energy is converted to chemical energy, which is temporarily stored in ATP and NADPH.
  - **Calvin Cycle** – Sugars are formed using CO_2 and the chemical energy stored in ATP and NADPH.



Capturing Light Energy

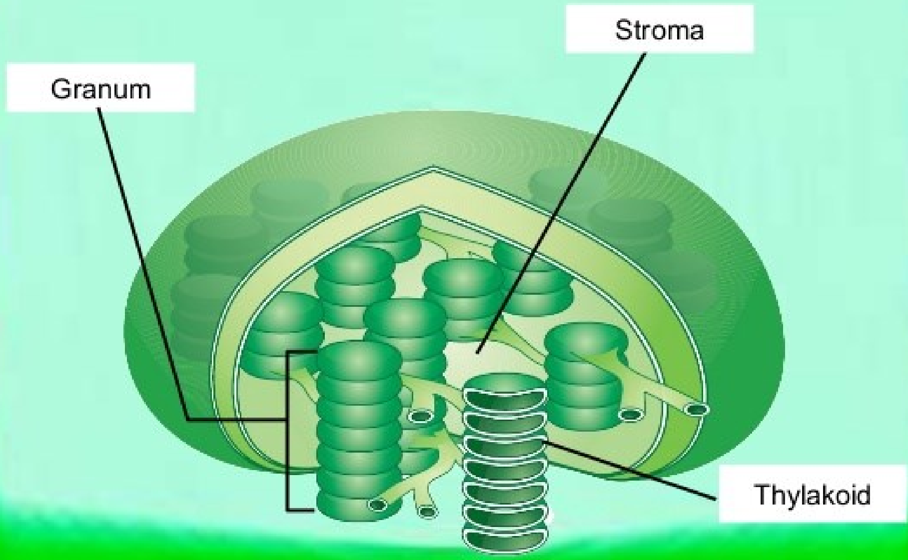
- In addition to water, carbon dioxide, and light energy, photosynthesis requires pigments.
- Chlorophyll is the primary light-absorbing pigment in autotrophs.
- Chlorophyll is found inside chloroplasts.

Parts of the Chloroplast



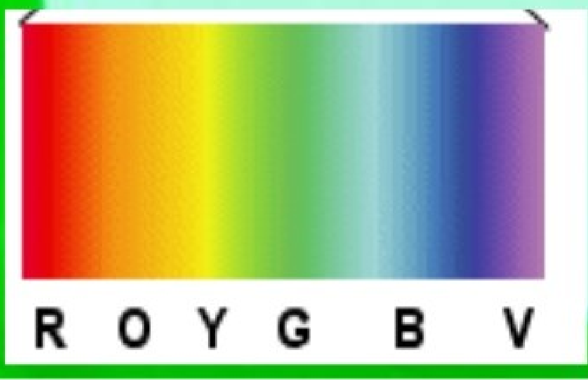
- Chloroplasts – organelles found in the cells of plants and algae
- Thylakoids – membranes arranged as flattened sacs
- Grana – stacks of thylakoids
- Stroma – solution surrounding the grana

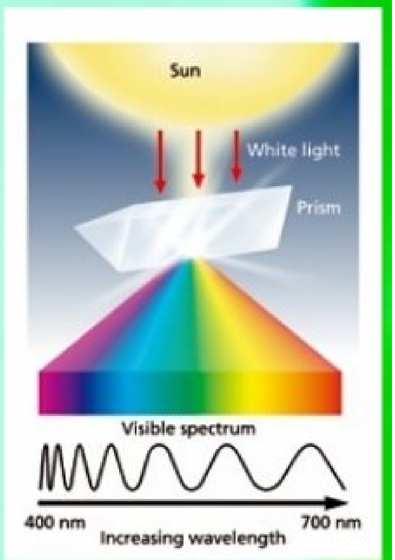
Parts of the Chloroplast



Light and Pigments

- Light from the sun appears white, but it is made of a variety of <u>colors</u> called the <u>visible light spectrum</u>.





Light and Pigments

- Pigments are compounds that absorb light.
- Many objects contain pigments that absorb some colors of light and reflect others.
- The colors that are reflected are the ones you see.

Chloroplast Pigments

- There are several pigments in the thylakoid membranes.
  - Most important are chlorophylls.
    - Chlorophyll *a* absorbs mostly red and violet light and reflects mostly green light.
  - Accessory pigments
    - Chlorophyll *b* assists chlorophyll *a* in capturing light energy. It absorbs mostly blue light, as well as, some violet and orange light and reflects mostly green and yellow light.
    - Carotenoids absorb blue and green light and reflect yellow, orange, and red light.

Chloroplast Pigments

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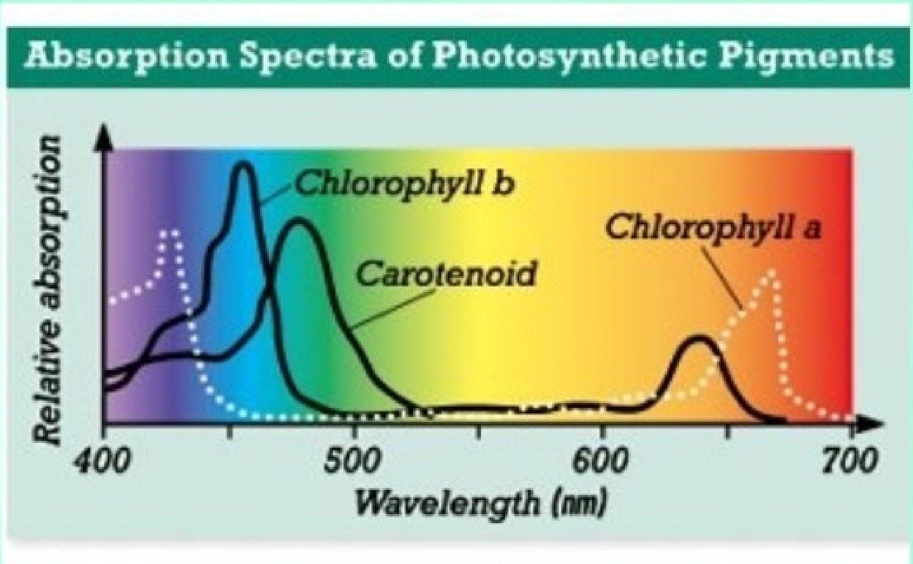
Chloroplast Pigments



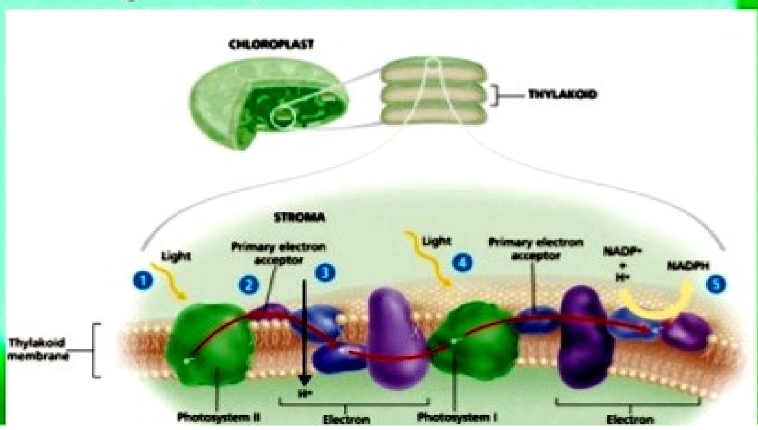
- Spectrum of Light and Plant Pigments

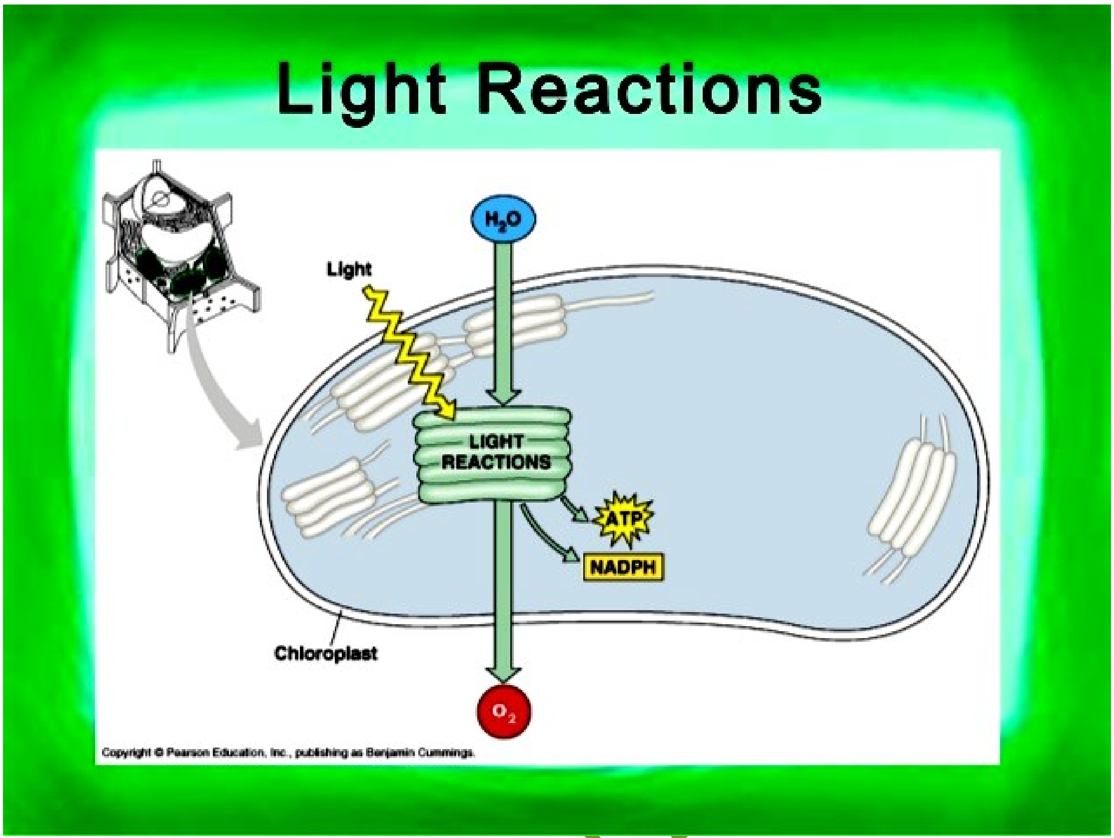
Chloroplast Pigments

- In plant leaves, chlorophylls are the most abundant pigments and therefore mask the colors of the other pigments.
- During the fall, many plants lose their chlorophylls, and their leaves become the color of the carotenoids.

Light Reactions

- The first stage of photosynthesis.
- Take place within the thylakoid membranes of chloroplasts.
- Require light energy to happen and are also referred to as the light-dependent reactions.




Light Reactions
H2O
Light
LIGHT
REACTIONS
ATP
NADPH
Chloroplast
O2
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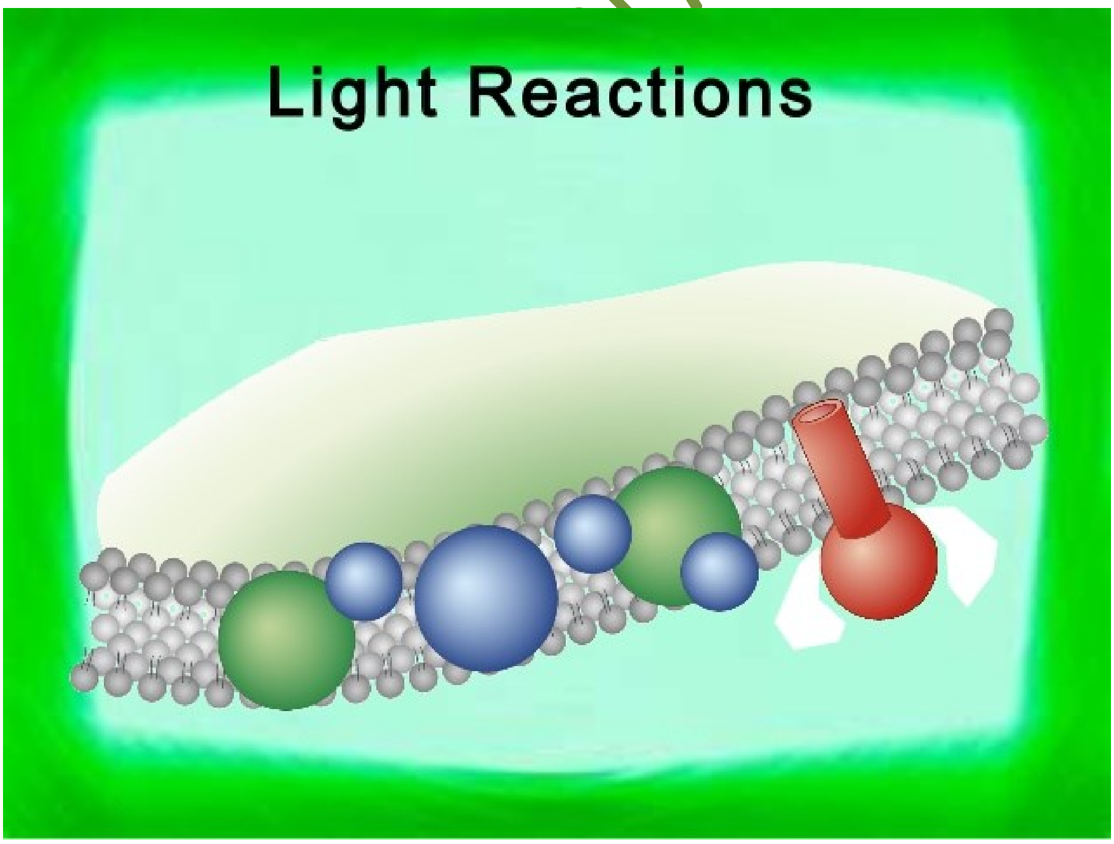
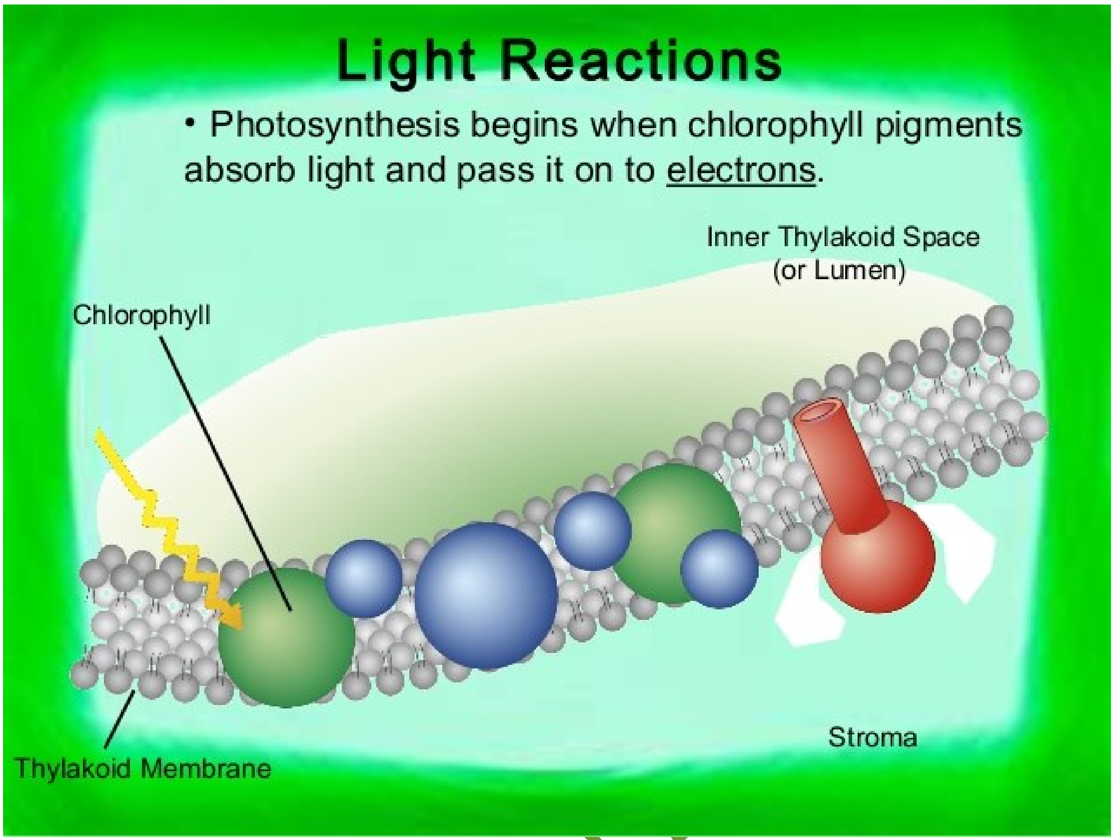
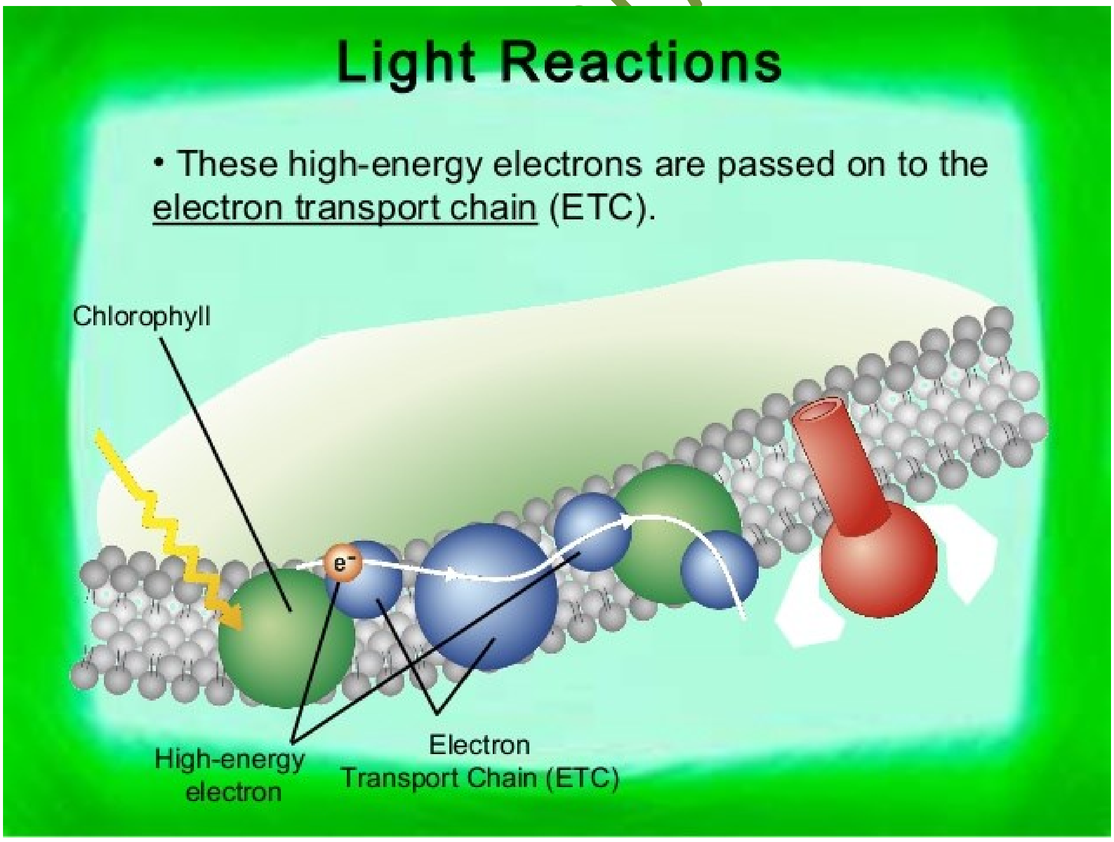
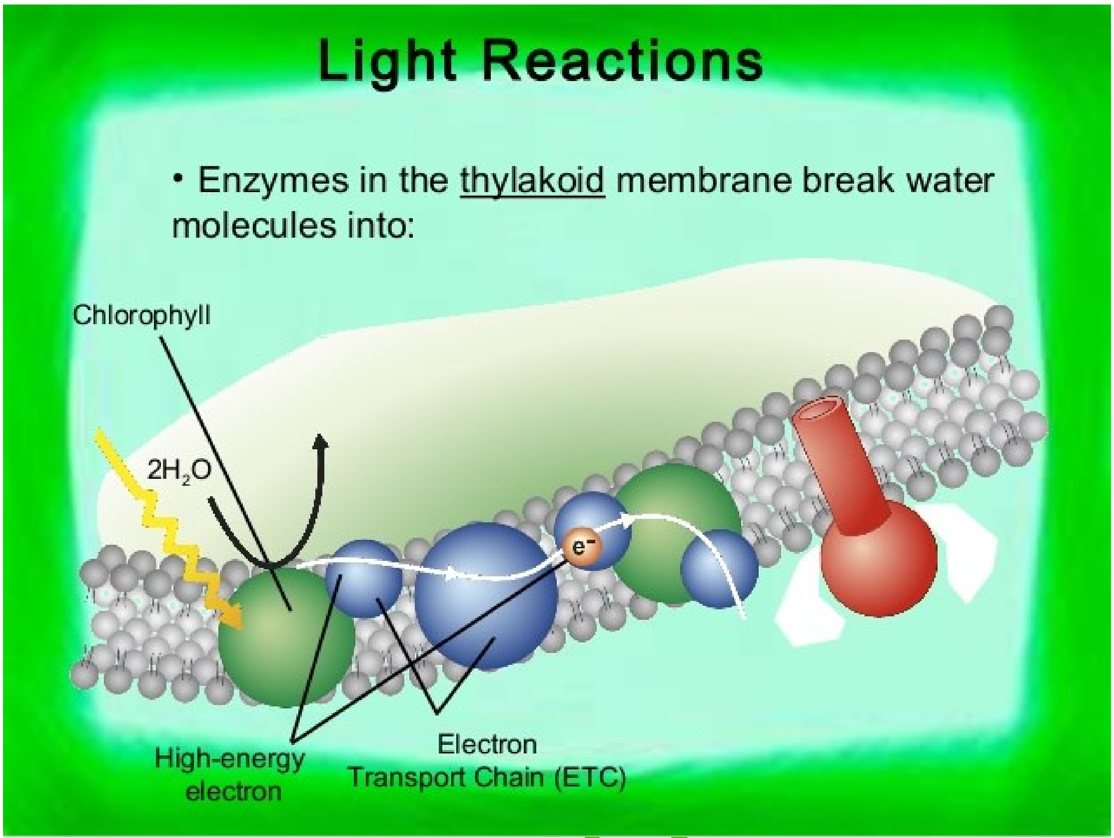
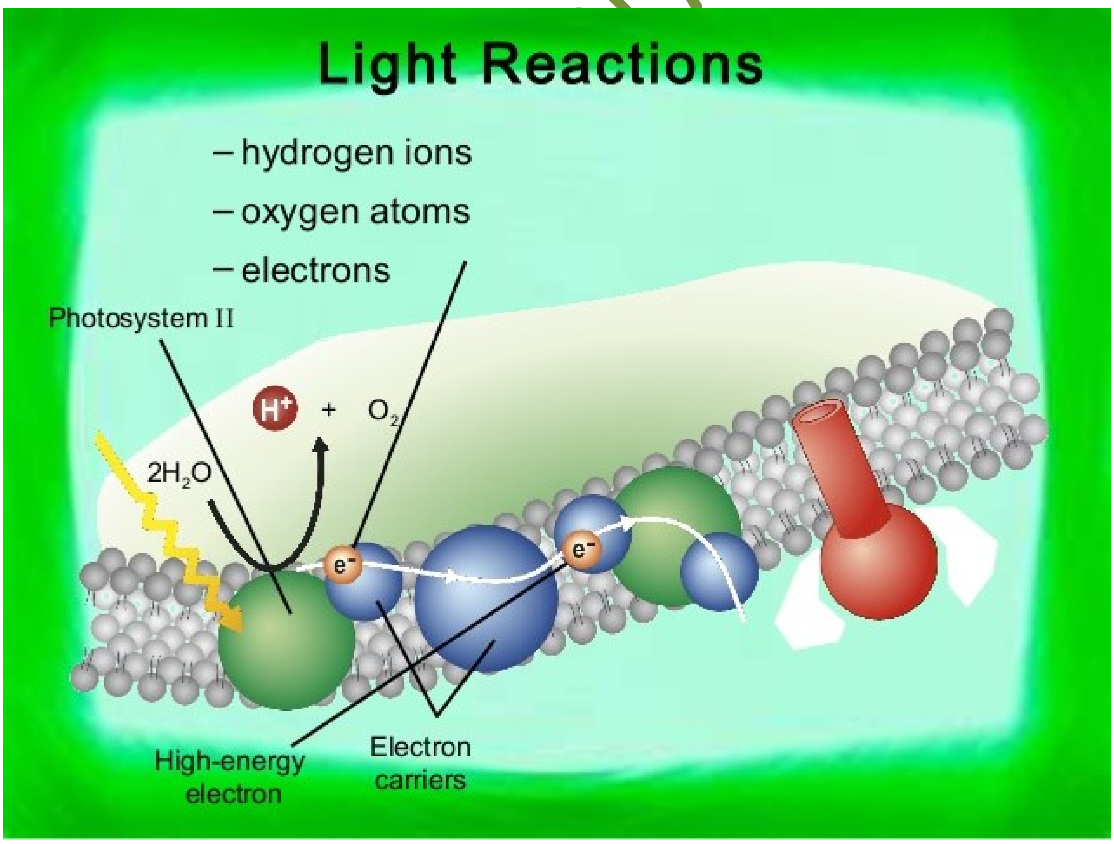

Light Reactions


Light Reactions
• Photosynthesis begins when chlorophyll pigments absorb light and pass it on to electrons.
Inner Thylakoid Space (or Lumen)
Chlorophyll
Thylakoid Membrane
Stroma

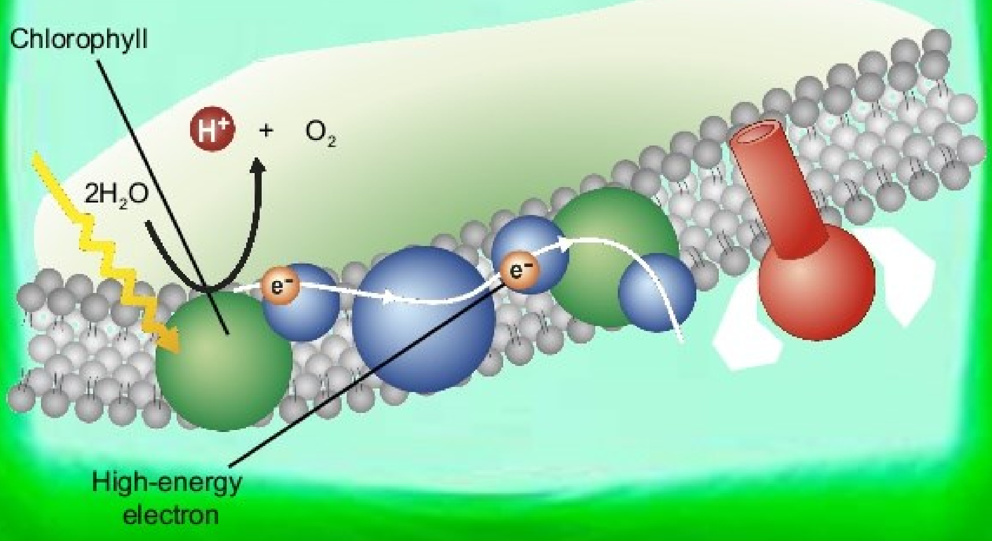

Light Reactions
• These high-energy electrons are passed on to the electron transport chain (ETC).
Chlorophyll
e-
High-energy electron
Electron Transport Chain (ETC)


Light Reactions
• Enzymes in the thylakoid membrane break water molecules into:
Chlorophyll
2H2O
e−
High-energy electron
Electron Transport Chain (ETC)


Light Reactions
– hydrogen ions
– oxygen atoms
– electrons
Photosystem II
H+
+
O2
2H2O
e−
e−
High-energy electron
Electron carriers

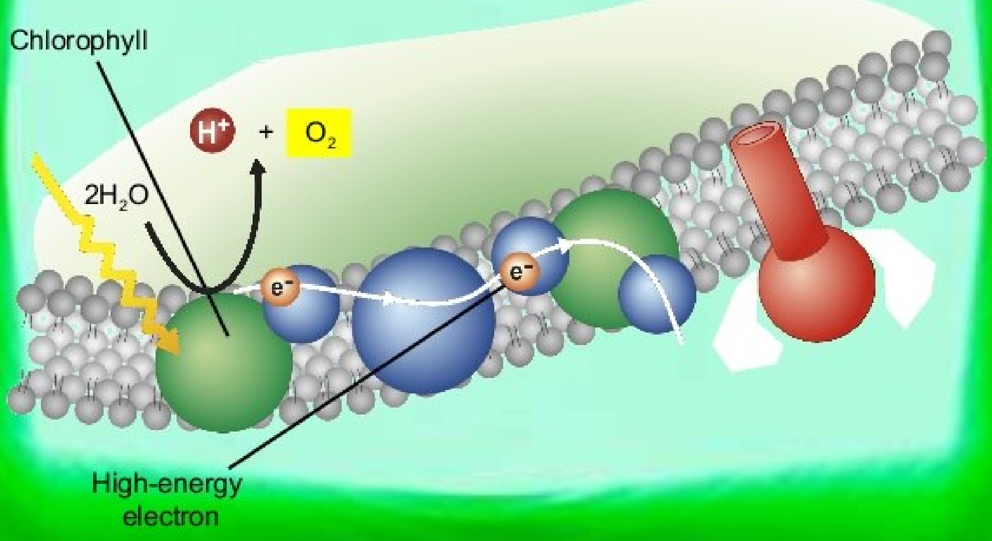
Light Reactions

• The hydrogen ions are released into the inner thylakoid space (or lumen).



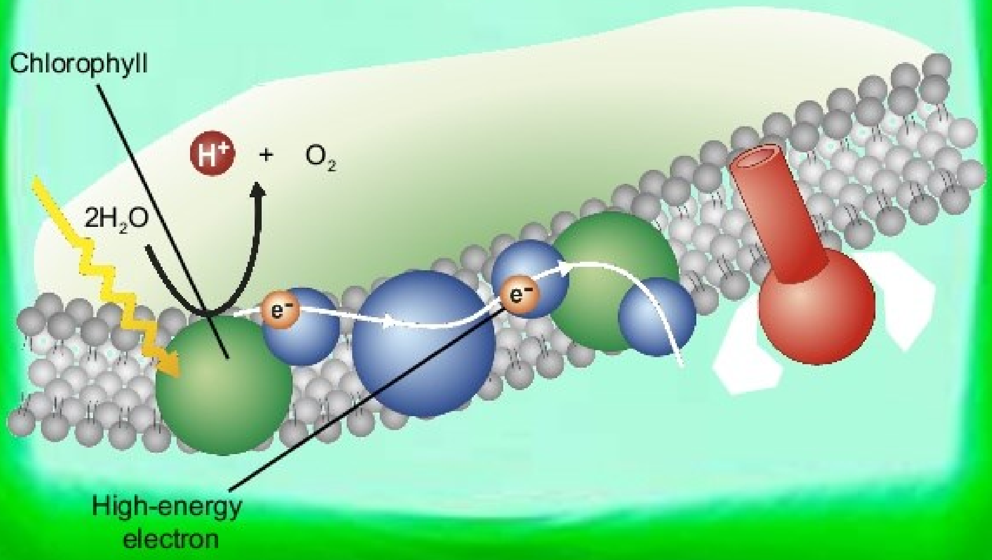
Light Reactions

• Oxygen is left behind and is released into the air.



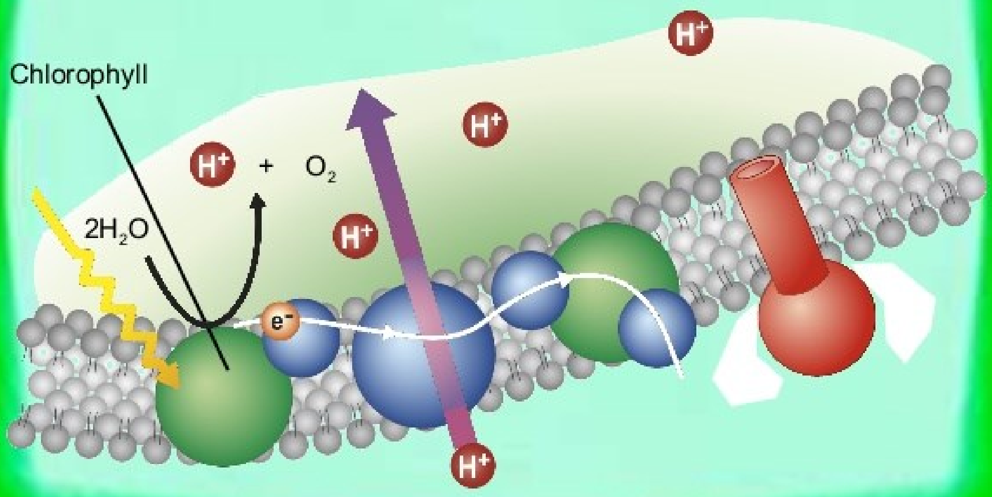
Light Reactions

• The electrons from water replace the electrons that were already energized by chlorophyll.



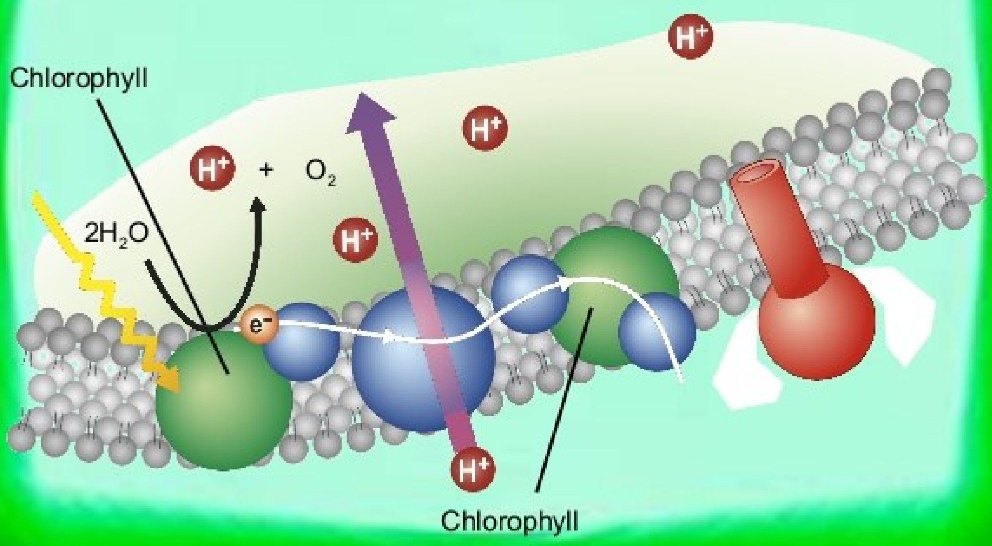
Light Reactions

• Energy from the electrons is used to transport H^+ ions from the stroma into the inner thylakoid space (or lumen).



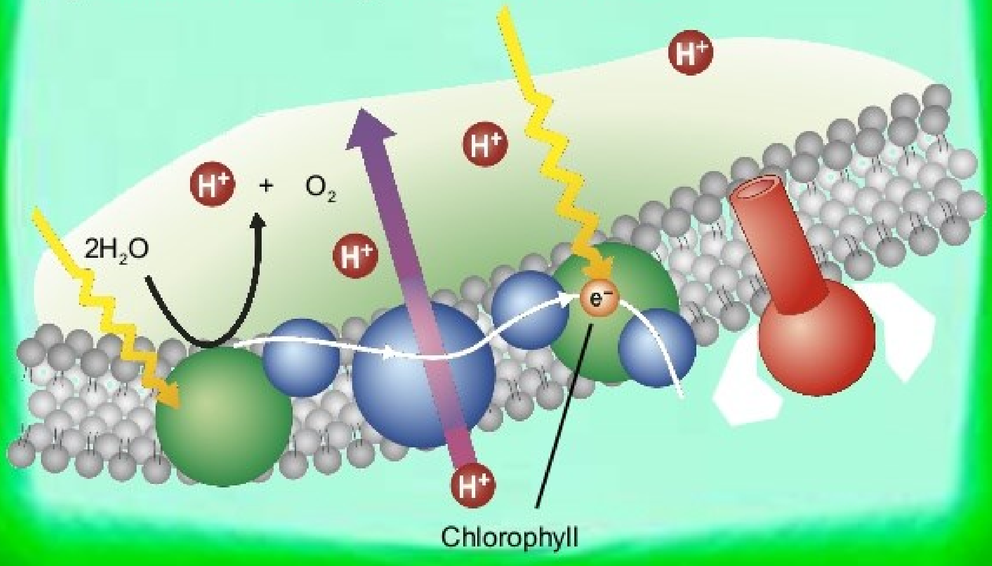
Light Reactions

• High-energy electrons move through the electron transport to a second group of chlorophyll pigments.



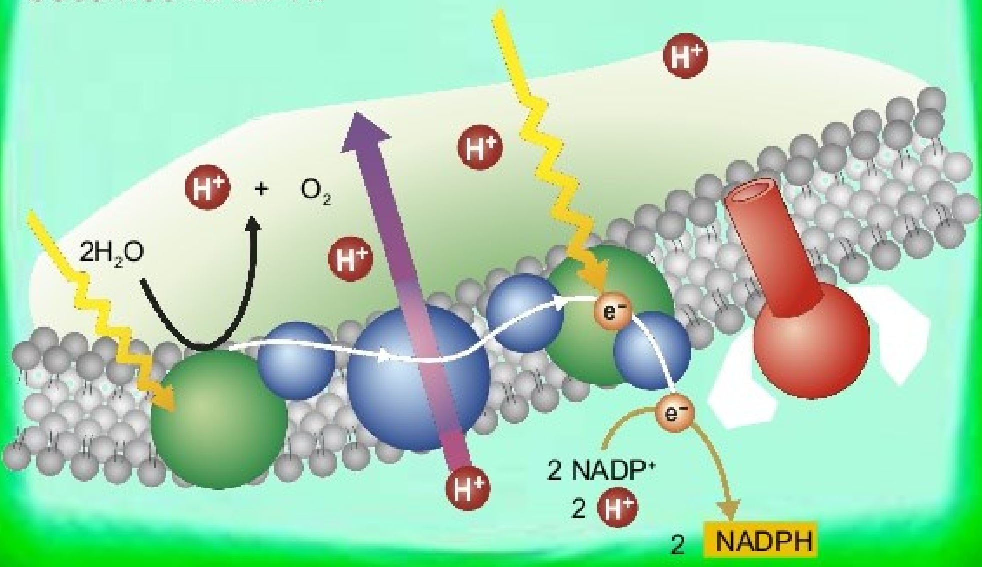
Light Reactions

• Light strikes this second group of chlorophyll pigments to re-energize the electrons.

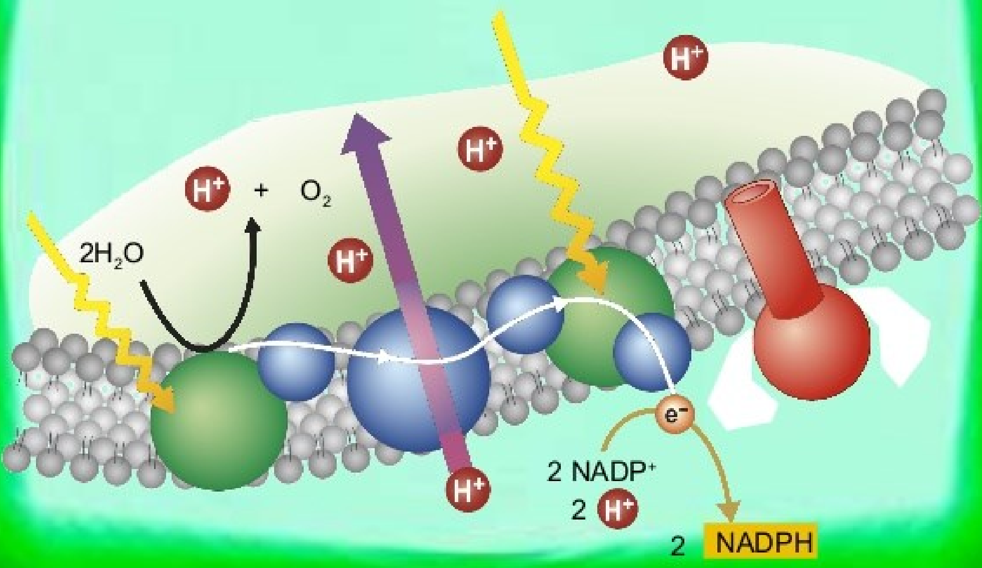


Light Reactions

- $NADP^+$ then picks up these high-energy electrons and becomes NADPH.

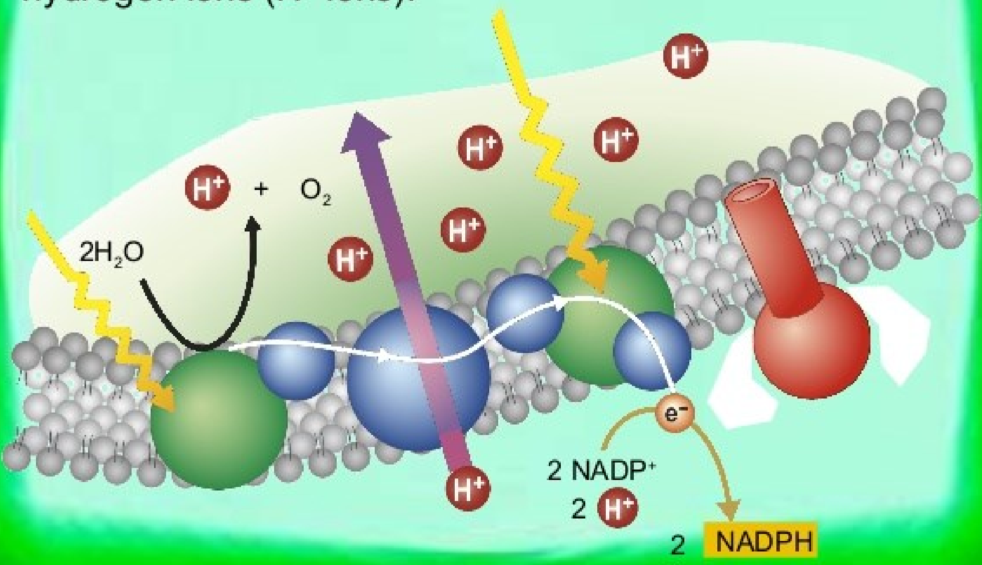


Light Reactions



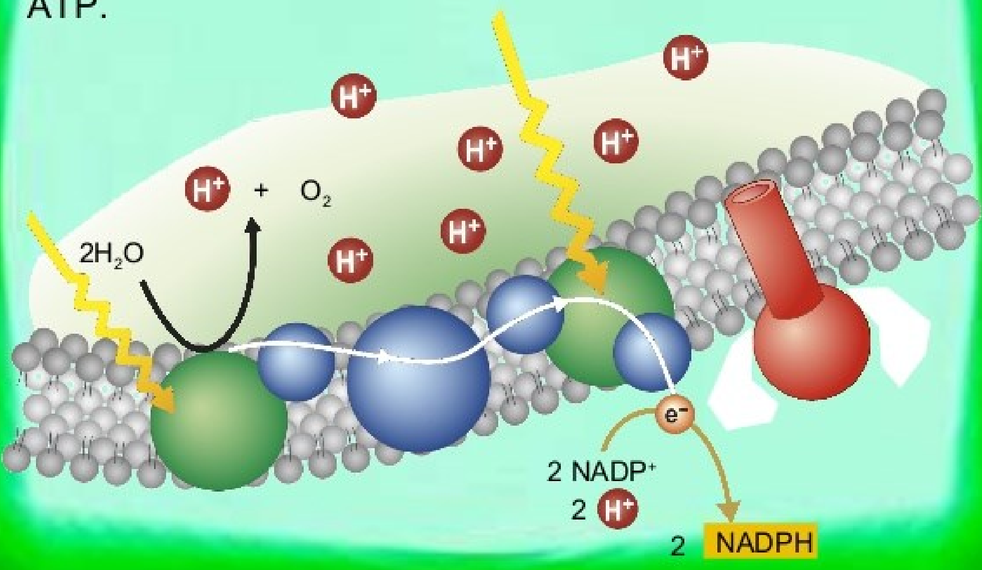
Light Reactions

• Soon, the inner thylakoid space (or lumen) is filled with hydrogen ions (H^+ ions).



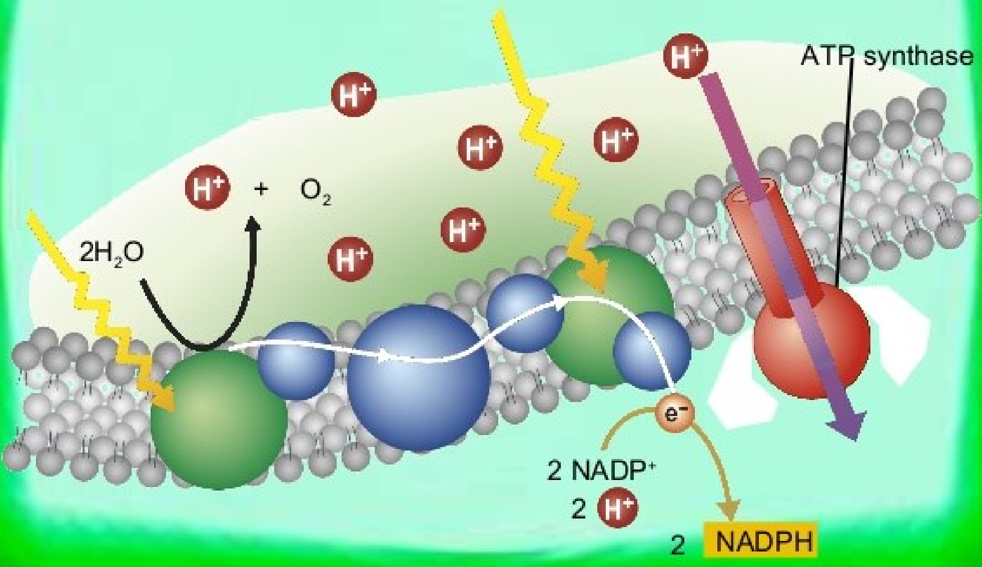
Light Reactions

• The build-up of H^+ ions provides the <u>energy</u> to make ATP.



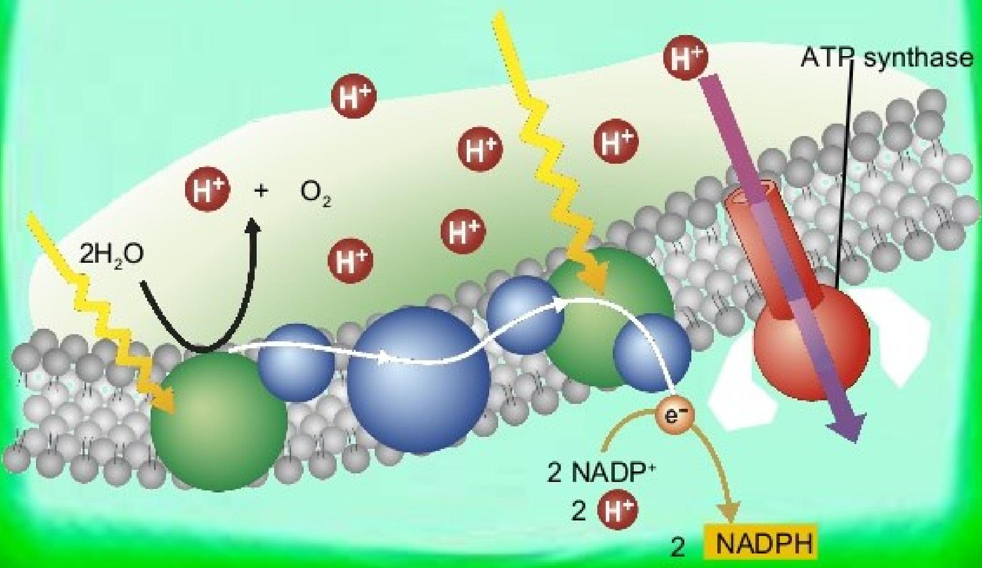
Light Reactions

- H^+ ions cannot cross the membrane directly.



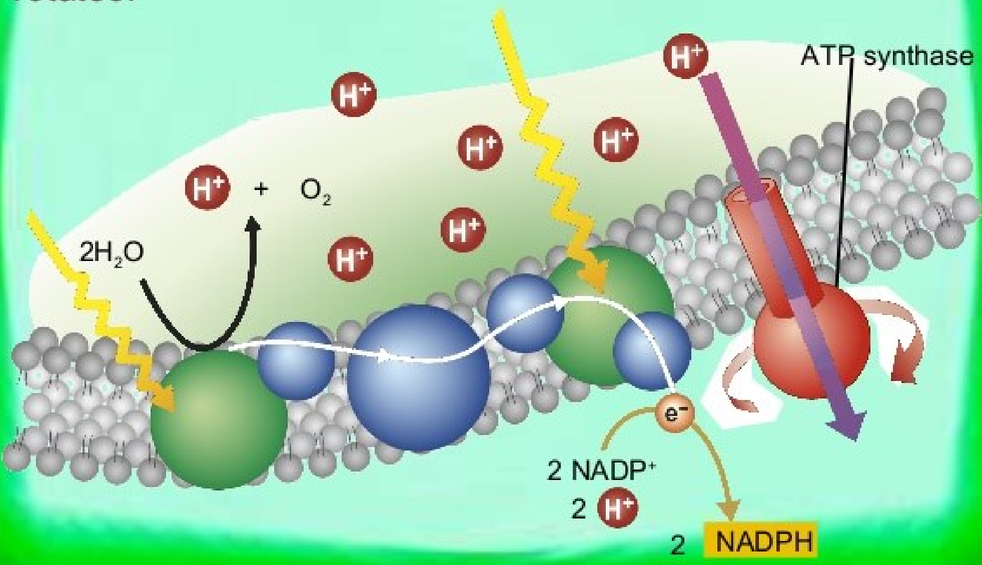
Light Reactions

- The thylakoid membrane contains an <u>enzyme</u> called ATP synthase that allows H^+ ions to pass through it.



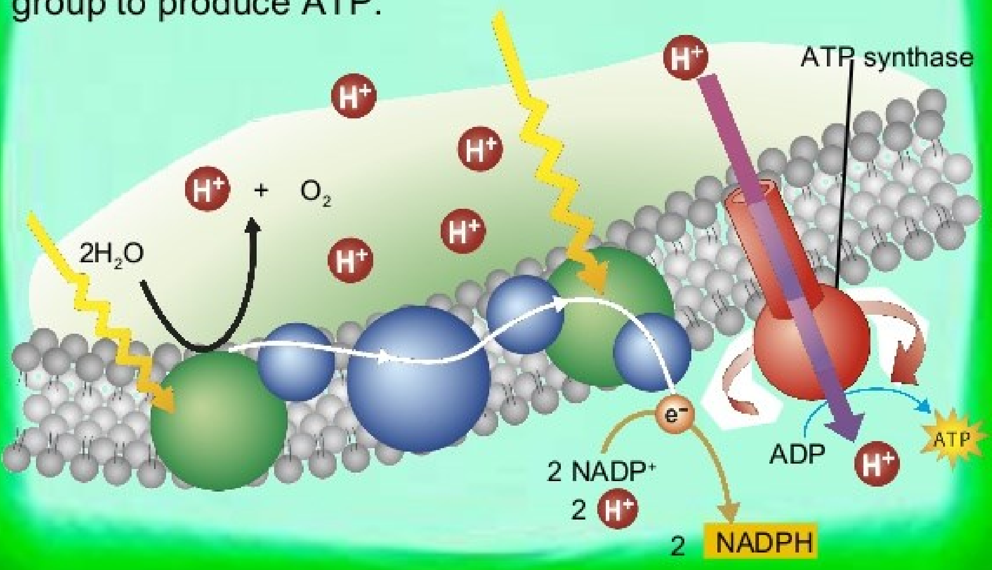
Light Reactions

- As H^+ ions pass through ATP synthase, the protein rotates.



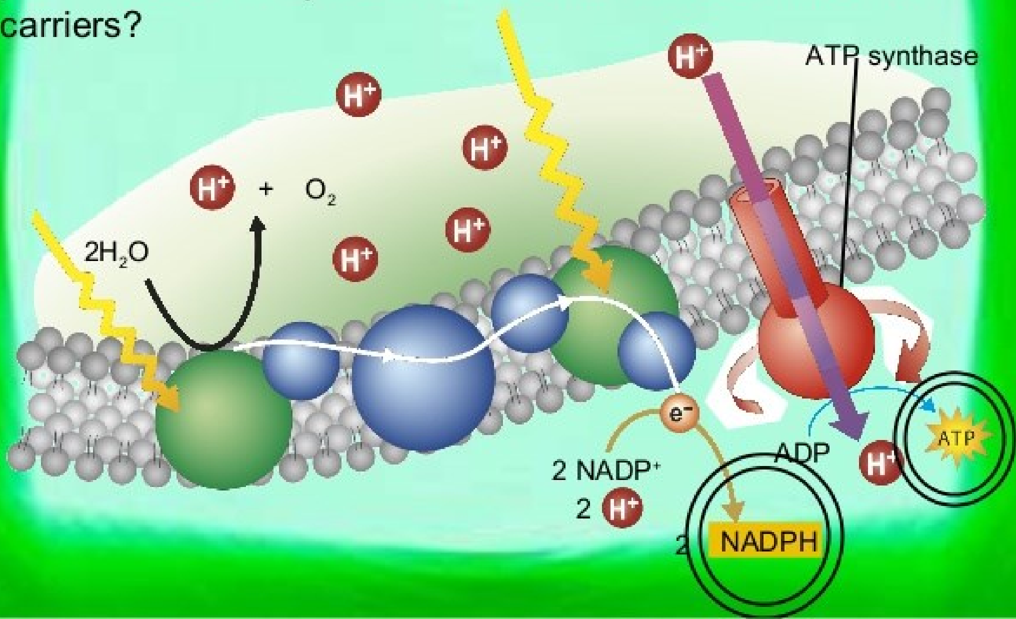
Light Reactions

- As it rotates, ATP synthase connects ADP and a phosphate group to produce ATP.

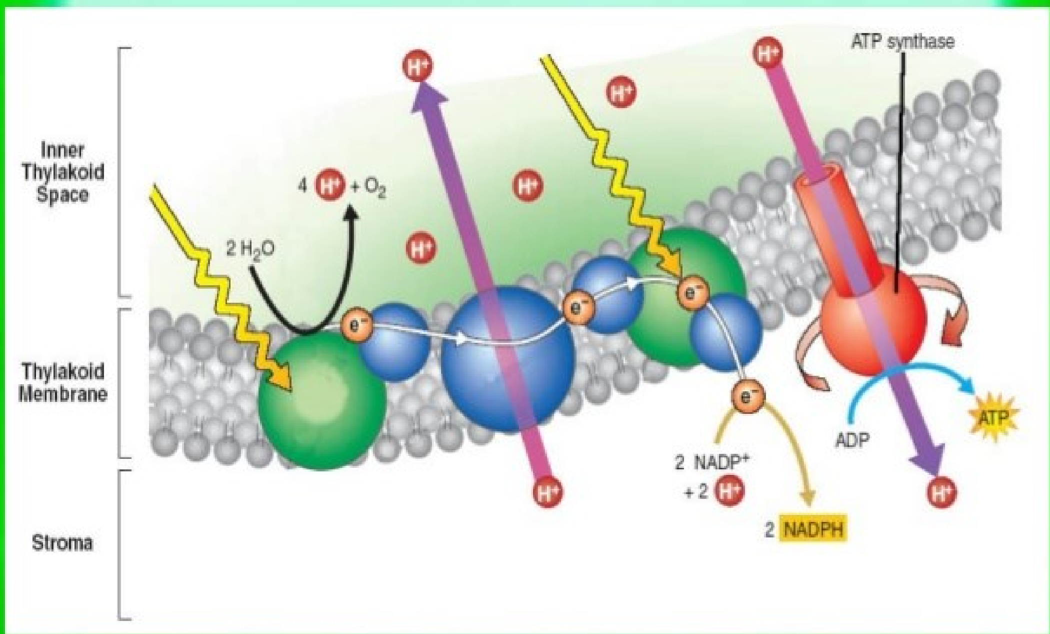


Light Reactions

- At the end of the light reactions, two energy carriers go on to power the Calvin cycle. What are the names of these two carriers?



Light Reactions



Light Reactions Summary

Use:

- H_2O
- Light Energy

Produce:

- ATP
- NADPH

} used in the Calvin Cycle

- O_2 → diffuses out of the chloroplast and enters the atmosphere

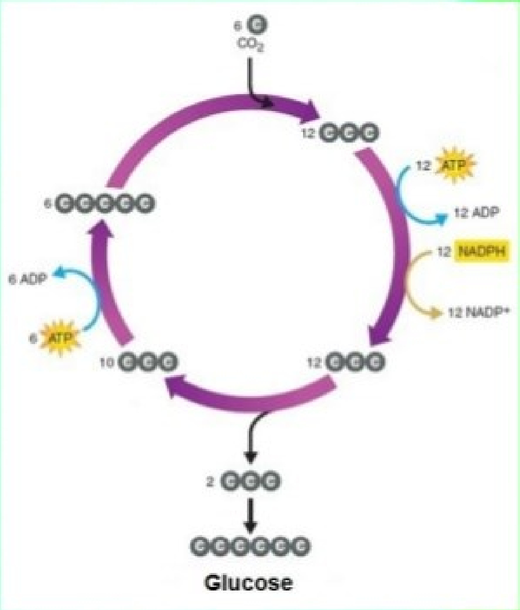
Section 2: The Calvin Cycle

The Calvin Cycle

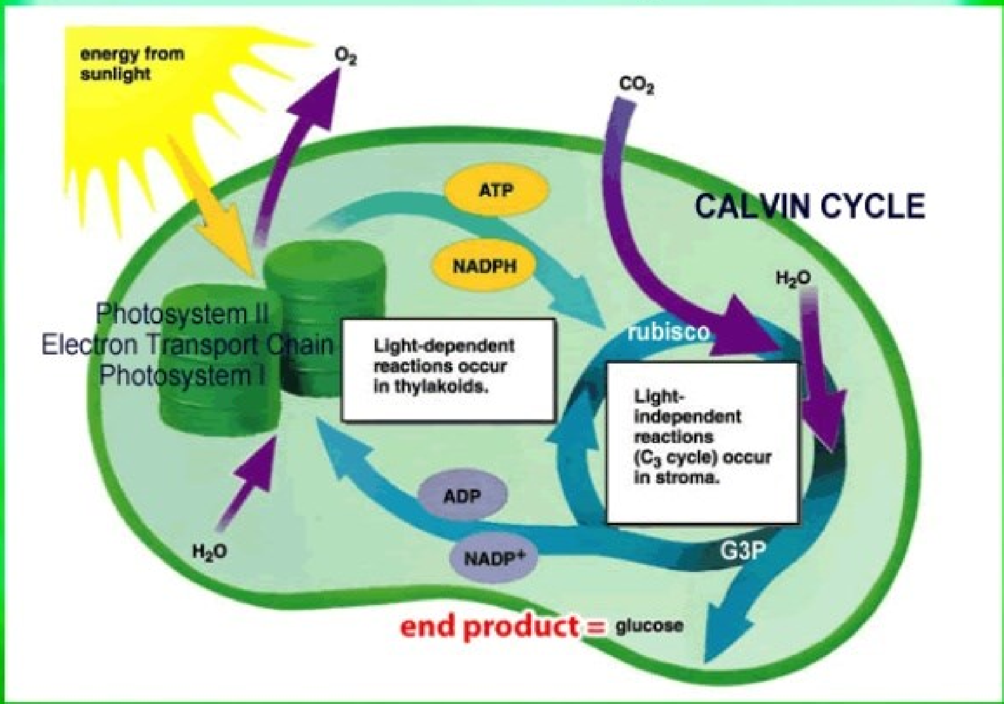
- The <u>second</u> stage of photosynthesis.
  - Named after <u>Melvin Calvin</u> who was named “Mr. Photosynthesis” by Time magazine in 1961.
  - Sometimes referred to as the <u>light-independent reactions</u> or the dark reactions because the Calvin cycle does <u>not</u> require light directly.

The Calvin Cycle

- ATP & NADPH from the <u>light</u> reactions are used as <u>energy</u>.
- <u>Six</u> $C0_2$ molecules from the atmosphere are used to produce a single <u>glucose</u> molecule.
- Takes place in the <u>stroma</u> of chloroplasts.

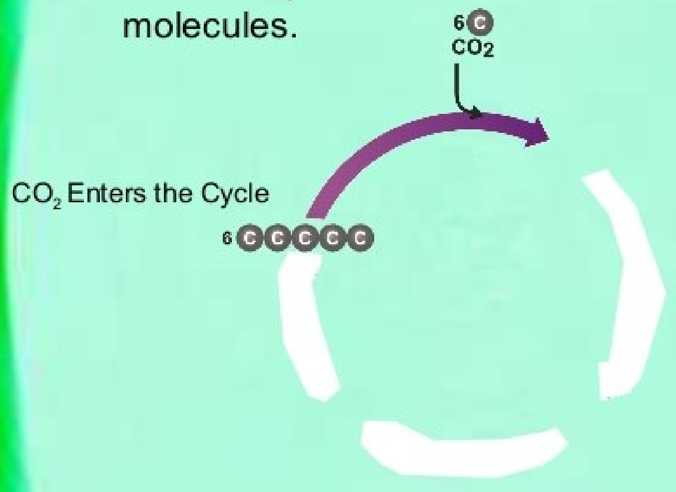


The Calvin Cycle



Steps in Calvin Cycle

- Six carbon dioxide molecules enter the cycle from the atmosphere and combine with six 5-carbon molecules.

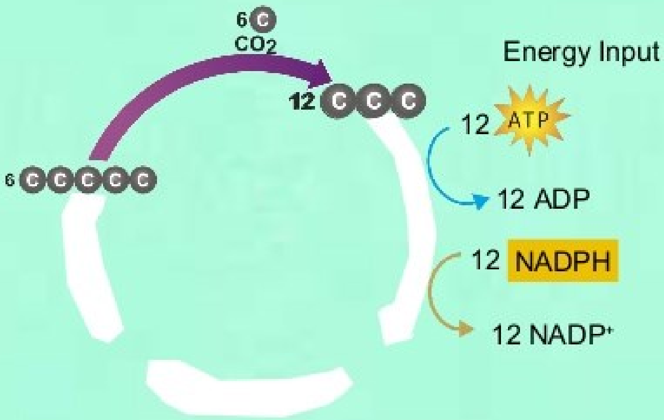


Steps in Calvin Cycle

- The result is <u>twelve</u> 3-carbon molecules, which are then converted into higher-energy forms.

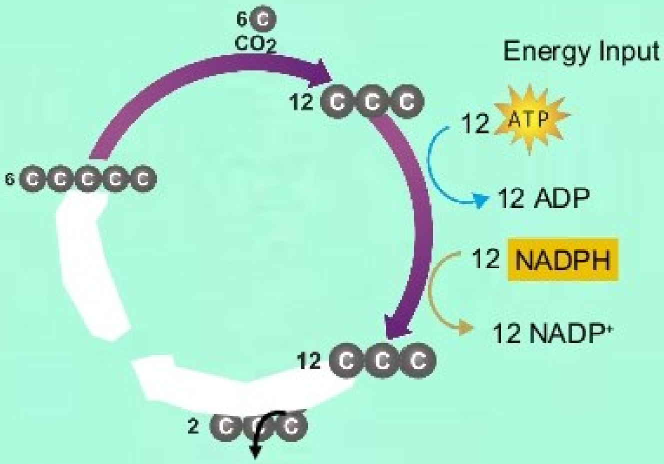
Steps in Calvin Cycle

- The <u>energy</u> for this conversion comes from ATP and high-energy electrons from NADPH.



Steps in Calvin Cycle

- Two of twelve 3-carbon molecules are removed from the cycle.



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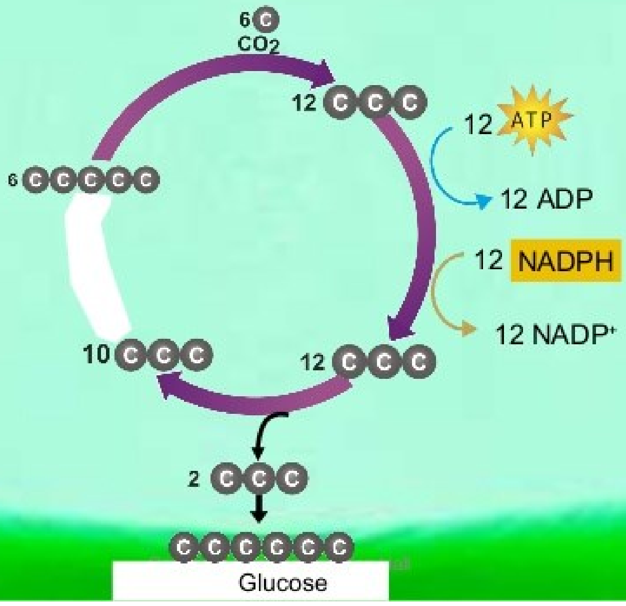
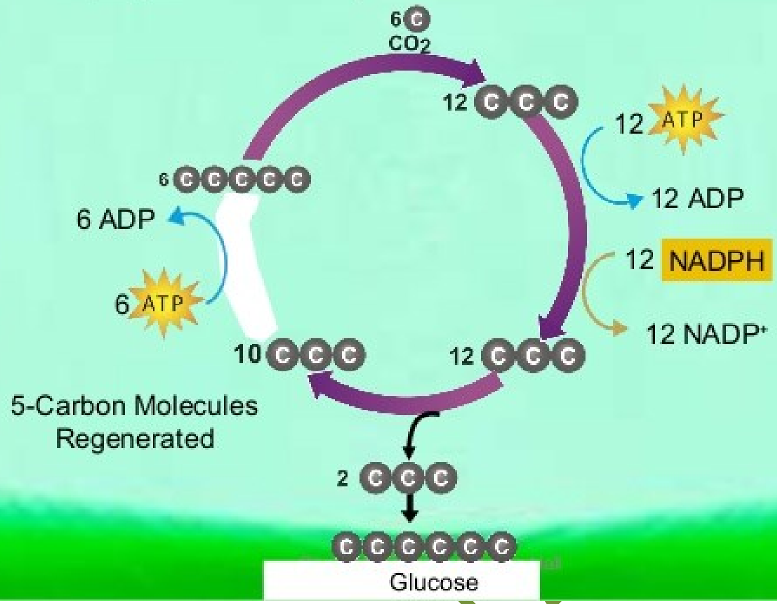
Steps in Calvin Cycle

- The molecules are used to produce glucose.



Steps in Calvin Cycle

- The 10 remaining 3-carbon molecules are converted back into six 5-carbon molecules, which are used to begin the next cycle.



Calvin Cycle Summary

Use:

- ATP
- NADPH
- CO_2

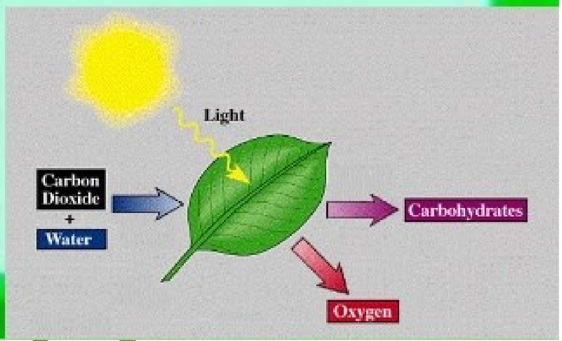
Produce:

- Glucose ($C_6H_{12}O_6$)
- $NADP^+$
- ADP & P

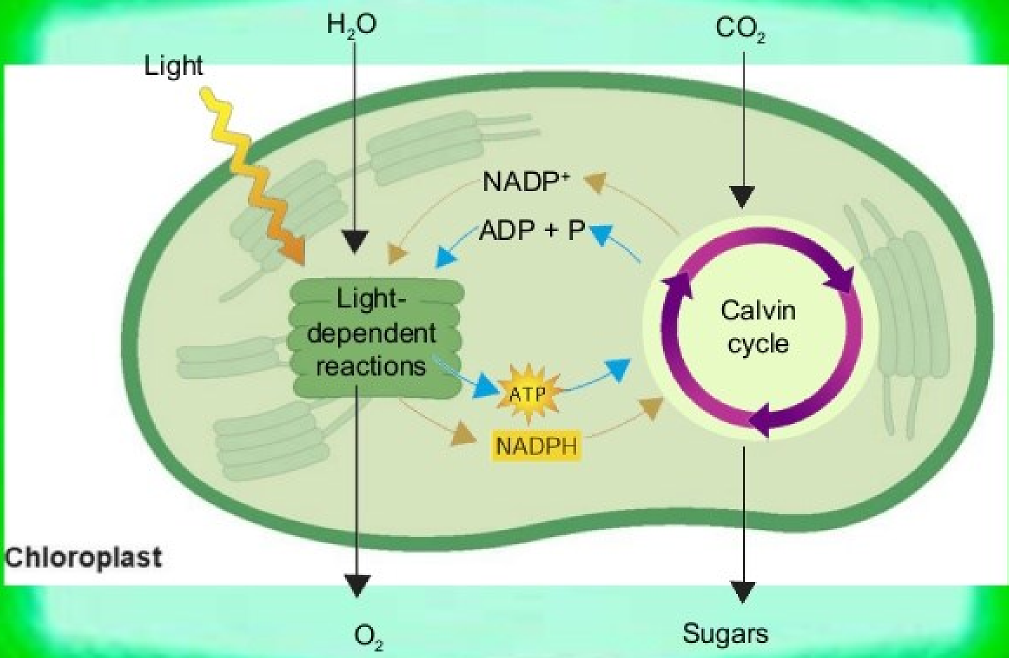
used in the Light Reactions

A Summary of Photosynthesis

- Photosynthesis happens in two stages:
  1. The light reactions – Energy is absorbed from sunlight and converted into chemical energy, which is temporarily stored in ATP and NADPH.
  2. The Calvin cycle – Carbon dioxide and the chemical energy stored in ATP and NADPH are used to form sugars.



A Summary of Photosynthesis



A Summary of Photosynthesis

- The process of photosynthesis can be summed up by the following chemical equation:

$$6\ H_2O + 6\ CO_2 \xrightarrow{\text{Light Energy}} 6\ O_2 + C_6H_{12}O_6$$

(Glucose sugar)

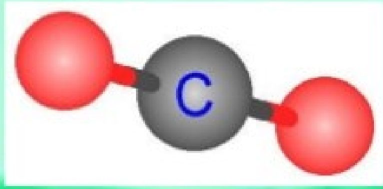
- How does the plant use these sugars?
  - Energy (Cellular Respiration)
  - Storage - Cellulose/Starch

Factors that Affect Photosynthesis

- **Light Intensity**
  - The rate of photosynthesis increases as light intensity increases until all the pigments are being used. At this saturation point, the rate of photosynthesis levels off because pigments cannot absorb any more light.

Factors that Affect Photosynthesis

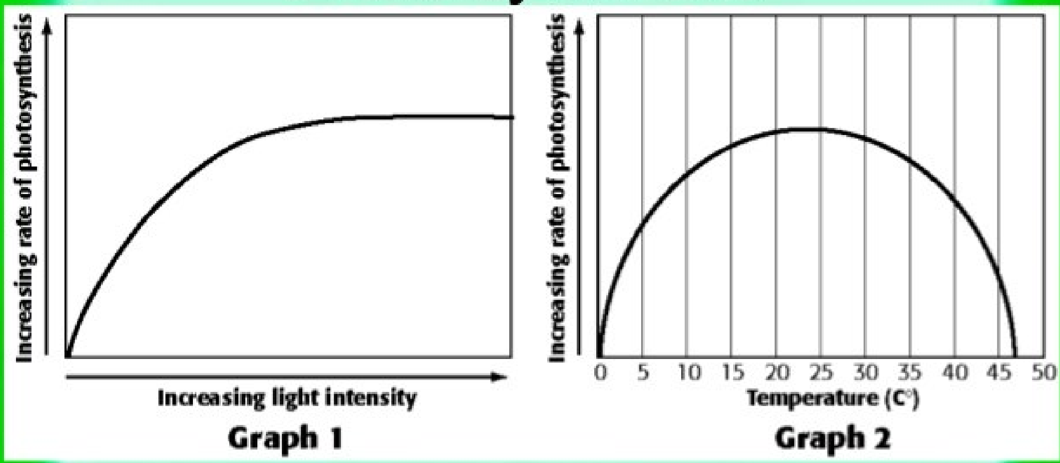
- **Carbon Dioxide Levels**
  - The CO_2 concentration affects the rate of photosynthesis in a similar manner. Once a certain concentration of CO_2 is present, photosynthesis cannot proceed any faster.



Factors that Affect Photosynthesis

- **Temperature**
  - Increasing temperatures accelerates the chemical reactions involved in photosynthesis. As a result, the rate of photosynthesis increases as temperature increases, over a certain range. The rate peaks at a certain temperature, at which many of the enzymes that catalyze the reactions become ineffective. Also, the stomata begin to close, limiting water loss and CO_2 entry into the leaves. These conditions cause the rate of photosynthesis to decrease when the temperature is further increased.

Factors that Affect Photosynthesis



- Environmental Influences on Photosynthesis

Linking Photosynthesis and Cellular Respiration

- The <u>products</u> of photosynthesis are the <u>reactants</u> for cellular respiration.
- The <u>products</u> of cellular respiration are the <u>reactants</u> for photosynthesis.