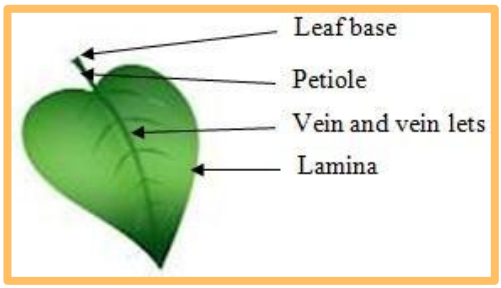
CHAPTER 2.1 – STRUCTURE OF A LEAF

The external structure of a leaf

The external structure of a green leaf consists of

- ❖ Lamina
- ❖ Petiole



LAMINA

- ♥ Lamina is flat, thin, smooth and green part of the leaf
- ♥ Lamina is flat-shaped to provide a wide surface in order to expose the cells containing chloroplasts to the maximum amount of sunlight
- ♥ Lamina is also thin to allow gases involved in photosynthesis to diffuse efficiently in the leaf

PETIOLE

- ↘ Petiole is the leaf stalk that connects the lamina to the stem of the plant
- ↘ The petiole stretches out into the lamina producing a network of middle veins to support the lamina

The internal structure of a leaf lamina

- → In most plants, the leaves grow without overlapping to enable them to receive optimum light to carry out photosynthesis
- → The arrangement of the leaf is called leaf mosaic
- → The lamina consists of
  1. Cuticle
  2. Upper epidermis
  3. Lower epidermis
  4. Palisade mesophyll
  5. Spongy mesophyll
  6. Vascular bundle

CUTICLE

- ⌂ Cuticle is waxy, waterproof and transparent layer which covers the upper and lower parts of the leaf epidermis
- ⌂ The cuticle layer also reduces excessive loss of water through evaporation (transpiration)
- ⌂ The transparent cuticle allows sunlight to pass through it

UPPER EPIDERMIS

- » Upper epidermis is located on the upper surface of the leaf which is under the cuticle layer
- » This layer does not contain any chloroplasts and it is transparent so that light can pass through it

LOWER EPIDERMIS

- Lower epidermis is located at the lower surface of the leaf
- This layer consists of stomata
- Each stoma is guarded by a pair of guard cells

PALISADE MESOPHYLL

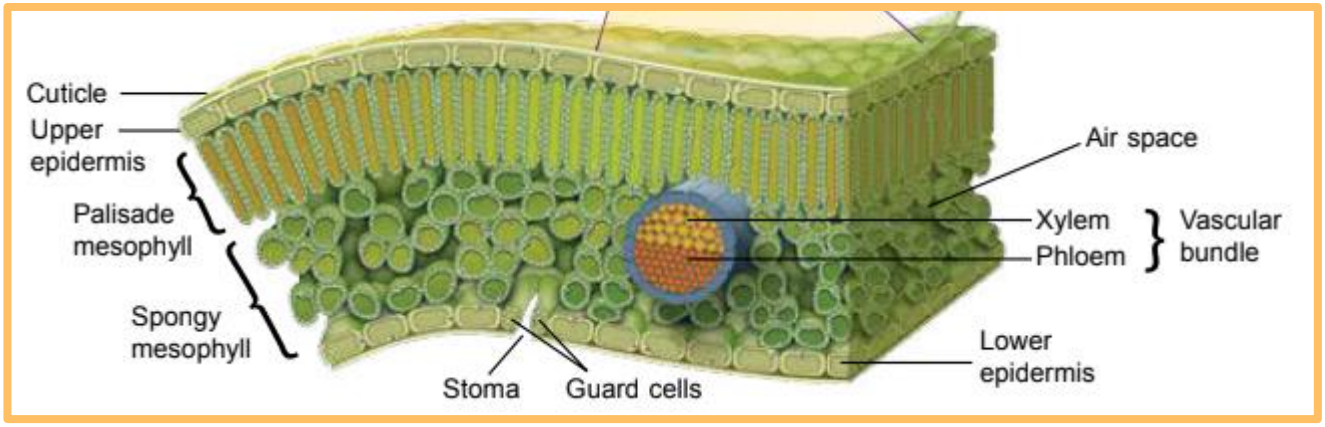
- Palisade mesophyll cells are arranged vertically and closely-packed to receive maximum light exposure
- These cells are the sites for photosynthesis
- Therefore, they contain many chloroplasts

SPONGY MESOPHYLL

- Spongy mesophyll cells are irregular-shaped that increases the internal surface area for gaseous exchange
- These cells are loosely arranged and they have many intercellular air spaces
- It can ease carbon dioxide and water absorption through the leaves to palisade mesophyll cells during photosynthesis
- Spongy mesophyll has a smaller number of chloroplasts than palisade mesophyll

VASCULAR BUNDLE

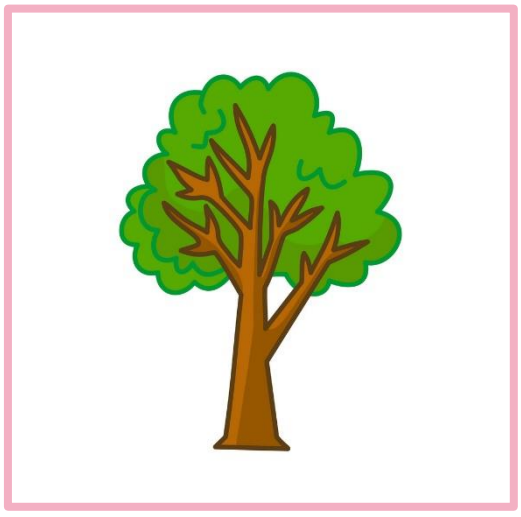
- Xylem
  - Xylem transports water and mineral salts absorbed from the roots to the leaf
  - The walls of the xylem are lignified (thickened with lignin) to provide mechanical support and strength to the plants
- Phloem
  - Phloem transports organic substances produced during photosynthesis from the leaves to other parts of the plants



CHAPTER 2.2 – MAIN ORGAN FOR GASEOUS EXCHANGE

The necessity of gaseous exchange in plants

- In order to carry out photosynthesis efficiently, plants need to exchange gases and absorb light
- The exchange of oxygen and carbon dioxide between plants and the surroundings occurs through stomata
- Stomata are the pores located on the lower epidermis of the leaf
- Each stoma is guarded by a pair of guard cells that controls the opening and closing of the stoma by changing their shapes
- The guard cells contain chloroplasts to carry out photosynthesis



The mechanism of stomatal opening and closing

The condition of the guard cells depends on

- ✓ The potassium ion (K^+) uptake by the cells
- ✓ The sucrose concentration in the guard cell sap

UPTAKE OF POTASSIUM IONS BY GUARD CELLS

- ➢ The accumulation or elimination of potassium (K^+) in the guard cells changes the solute potential
- ➢ This increases or decreases the water potential in the guard cells
- ➢ Water is diffused out or into the guard cells through osmosis
- ➢ This condition determines whether the guard cells are turgid or flaccid

SUCROSE CONCENTRATION IN THE GUARD CELL SAP

- Δ During day time or in the presence of light, photosynthesis takes place and produces dissolved sugar (sucrose)
- Δ During night time or in the absence of light, sugar in the guard cells converts into starch

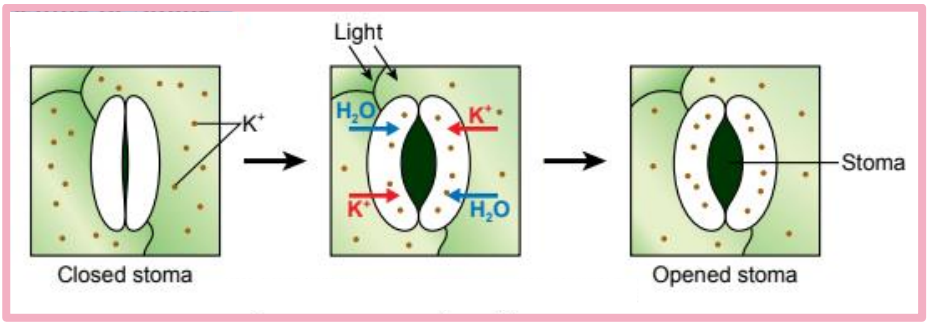
The opening of stoma

UPTAKE OF POTASSIUM IONS BY GUARD CELLS

» The potassium ions enter the guard cells
» The solute potential in the guard cells increases
» The water potential in the guard cells decreases
» The water molecules from the epidermal cells diffuse into the guard cells by osmosis
» The guard cells become turgid and curve outwards
» The stoma opens

SUCROSE CONCENTRATION IN THE GUARD CELL SAP

- In the presence of light, photosynthesis occurs
- The concentration of sucrose in the guard cells becomes high
- The water potential in the guard cells decreases
- The water molecules from the epidermal cells diffuse into the guard cells by osmosis
- The guard cells become turgid and curve outwards
- The stoma opens



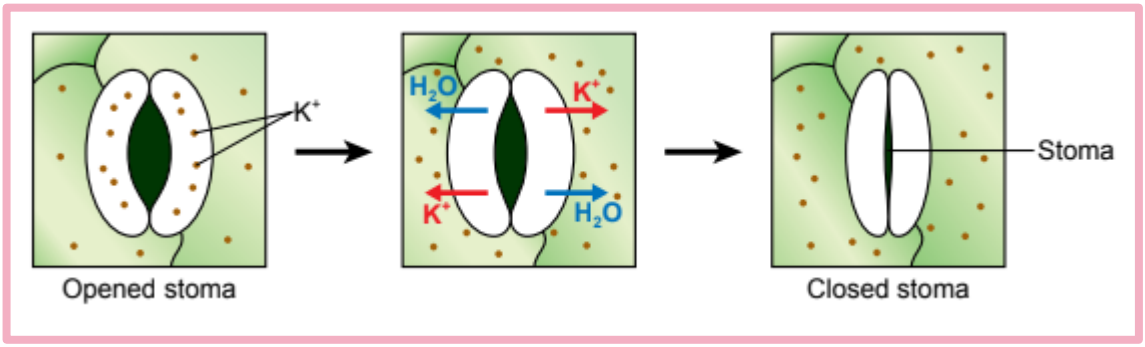
The closing of stoma

UPTAKE OF POTASSIUM IONS BY GUARD CELLS

♥ The potassium ions move out from the guard cells
♥ The solute potential in the guard cells decreases
♥ The water potential in the guard cells increases
♥ The water molecules diffuse out from the guard cells to the epidermal cells by osmosis
♥ The guard cells become flaccid
♥ The stoma closes

SUCROSE CONCENTRATION IN THE GUARD CELL SAP

❖ In the absence of light, photosynthesis does not occur
❖ The sucrose concentration in the guard cells becomes low
❖ The water potential in the guard cells increases
❖ The water molecules diffuse out from the guard cells to the epidermal cells by osmosis
❖ The guard cells become flaccid
❖ The stoma closes

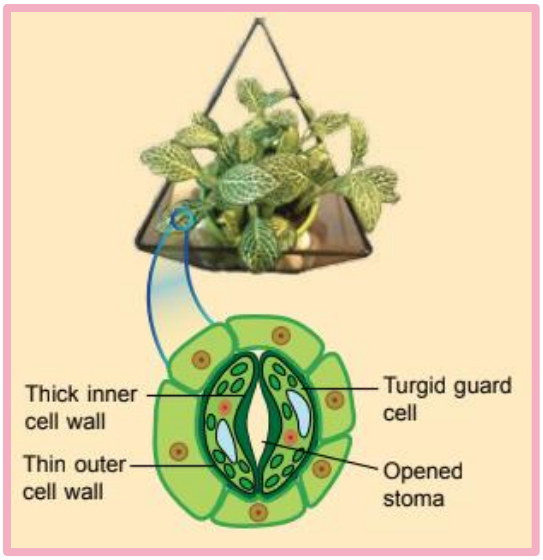


The effect of water deficiency in plants on stomatal opening and closing

- ↘ Water from plants is lost in the form of water vapour to the surroundings through the stomata
- ↘ When stoma opens widely, the rate of water loss from the plants is high
- ↘ The opening and closing of the stoma are dependent on the turgor pressure of the guard cells

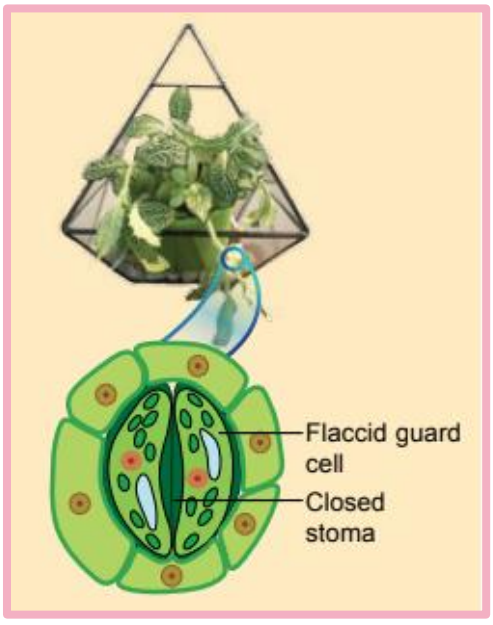
FRESH PLANTS

- ❑ When the plant obtains enough water, the guard cells become turgid
- ❑ The inner cell wall of the guard cells is thick and less elastic as compared to the outer cell wall
- ❑ The thin and more elastic outer cell wall causes the guard cells to curve outwards and the stoma to open



WILTED PLANTS

- → When the plant lacks water, the guard cells become flaccid
- → The thin and more elastic outer cell wall causes the guard cells to lose turgidity and the stoma to close



CHAPTER 2.3 – MAIN ORGAN FOR TRANSPIRATION

Transpiration

- Transpiration is a process of water loss in the form of water vapour through evaporation from the plants to the atmosphere
- Even though the transpiration process takes place through the stem and flower, 90% of water diffuses out through stomata pores in the leaves
- Water diffuses into the root system by osmosis continuously

PATH OF WATER MOVEMENT IN PLANTS

- Roots absorb water from the soil
- The xylem transports water upwards in the plant stem
- Leaf veins transport water to the leaves
- Water evaporates to the atmosphere through stomata

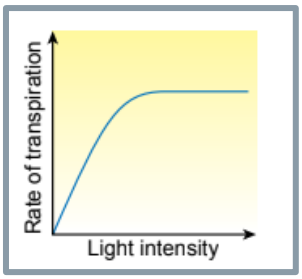
THE NECESSITY OF TRANSPIRATION IN PLANTS

- Plant roots absorb water and mineral salts from soil
- Water absorbs heat energy from leaves and evaporates as water vapour to give cooling effect
- Produces a pulling force that moves the water and mineral salts continuously in the xylem vessels from the roots to all plant cells

The environmental factors that affect the rate of transpiration

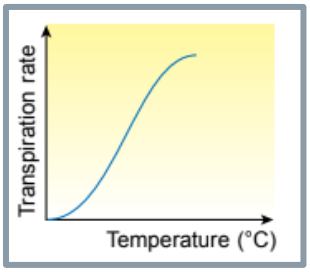
LIGHT INTENSITY

- The higher the light intensity, the higher the rate of transpiration
- If the light intensity increases, the rate of transpiration will increase until it becomes constant
- The rate of transpiration is constant because the relative air humidity, temperature and air movement become the limiting factors



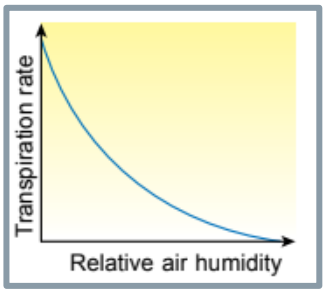
TEMPERATURE

- An increase in temperature increases the kinetic energy of water molecules thus increasing the rate of transpiration



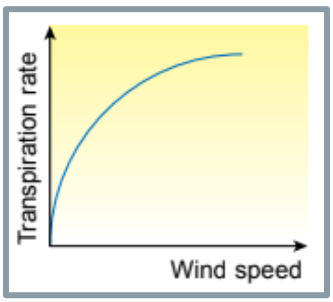
RELATIVE AIR HUMIDITY

- The lower relative air humidity of the surrounding atmosphere, the faster water vapour escapes from the stomata
- Therefore, the rate of transpiration becomes higher



AIR MOVEMENT

- The movement of air carries away water molecules that have been diffused out from the leaves
- Hence, the faster the air movement, the faster the rate of transpiration

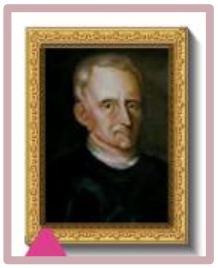


CHAPTER 2.4 – MAIN ORGAN FOR PHOTOSYNTHESIS

The necessity of photosynthesis in plants

- ✓ Plants are autotrophic organisms that produce their own food through photosynthesis
- ✓ The product of photosynthesis, which is glucose is used by other organisms to generate energy through oxidation of food
- ✓ Energy is needed to carry out living processes such as growth and reproduction

Brief history of discovery of photosynthesis



JAN-BAPTISTA VAN HELMONT

- ⊕ In 1640s, Jan-Baptista van Helmont carried out an experiment to test the idea that plants obtained their food from the soil
- ⊕ Helmont's conclusion:
  - The plant had grown by only being watered and not from the water of the soil

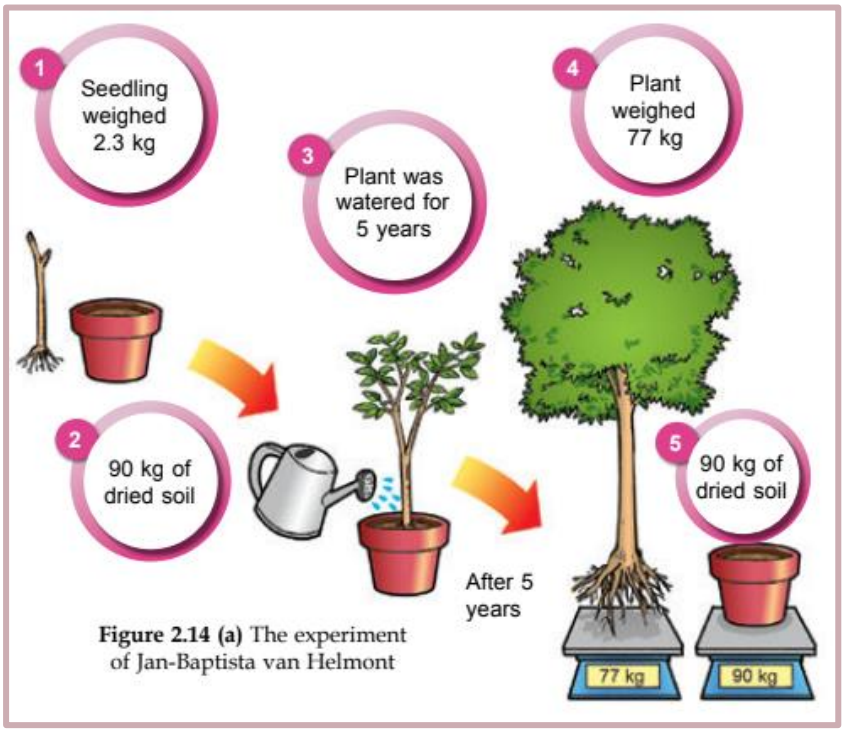
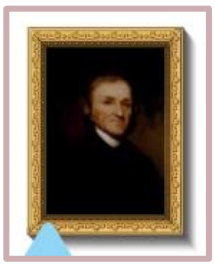


Figure 2.14 (a) The experiment of Jan-Baptista van Helmont

JOSEPH PRIESTLY



- ↘ In the year 1772, an experiment conducted by Joseph Priestly showed that plants released oxygen to the atmosphere
- ↘ Priestly's conclusion:
  - Plants release oxygen

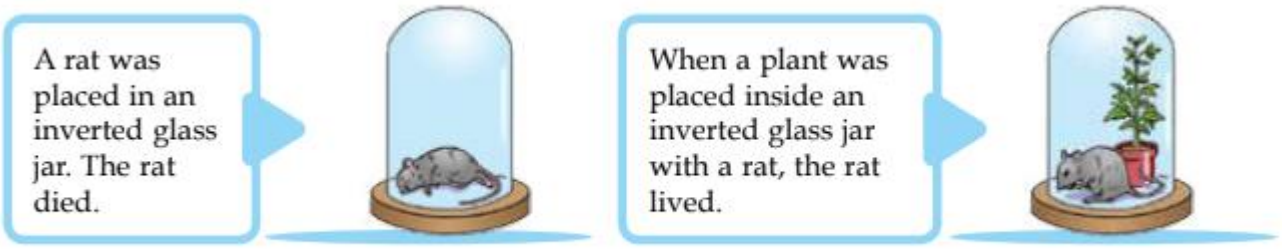


Figure 2.14 (b) The experiment of Joseph Priestly

The adaptation of the internal structure of a leaf to photosynthesis

- ◊ Photosynthesis needs chlorophyll to absorb light energy from the sun, carbon dioxide from the atmosphere and water from the soil
- ◊ Oxygen is released as a by-product
- ◊ Besides the leaf being the main photosynthesis organ, young stem and other green parts of the plants are also able to carry out photosynthesis

UPPER EPIDERMIS AND LOWER EPIDERMIS (1) & (3)

- ❑ Transparent waxy cuticle on the upper and lower epidermis allow sunlight to penetrate the upper and lower epidermis into the palisade mesophyll
- ❑ Stomata are present in the lower epidermis:
  - In the presence of light, stomata open and allow gaseous exchange to occur

PALISADE MESOPHYLL (2a)

- ⌂ Packed with chloroplasts:
  - Enables sunlight to be absorbed at a maximum rate
- ⌂ Chloroplast contain chlorophyll:
  - Chlorophyll absorbs light energy for photosynthesis

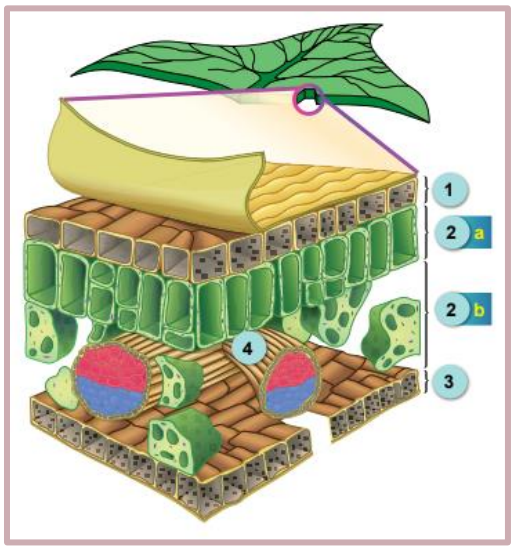
SPONGY MESOPHYLL (2b)

- Δ Contains a lesser number of chloroplasts compared to palisade mesophyll
- Δ Contains air spaces:
  - Allow efficient gaseous exchange during photosynthesis

VASCULAR BUNDLES (4)

- » Xylem
  - Transports water and mineral salts absorbed from the root to the leaf
- » Phloem

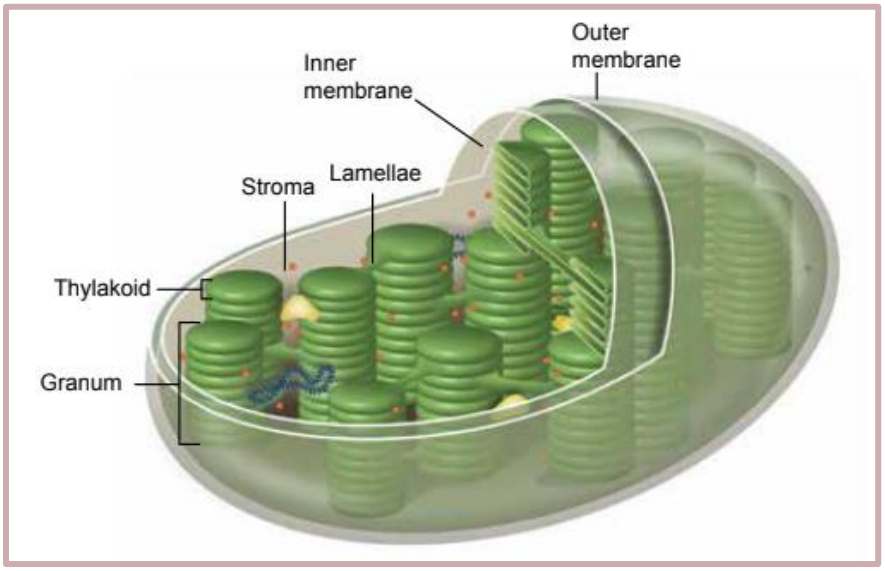
- Transports sucrose produced by photosynthesis from the leaf to all parts of the plant



Chloroplast structure

→ A chloroplast contains chlorophyll to absorb sunlight and converts it into chemical energy during photosynthesis

→ A chloroplast consists of
- i) Thylakoids
- ii) Grana
- iii) Stroma
- iv) Lamellae



THYLAKOID

- Disc-shaped sacs containing chlorophyll
- In thylakoid membrane, there are photosynthetic pigments that trap sunlight
- Light-dependent reaction occurs in the thylakoid

GRANUM

- A disc-shaped stack of thylakoids
- This arrangement increases the surface area for optimal photosynthesis

STROMA

- Colourless fluid surrounding granum in the chloroplast
- Site for light-independent reaction to take place which produces glucose

Light-dependent and light-independent reactions in photosynthesis

LIGHT-DEPENDENT REACTIONS

- Occurs in the thylakoids
- Photosynthetic pigments on the surface of the thylakoids absorb light energy
- Light energy excites electrons in chlorophyll pigments to a higher level
- The excited electrons from the chlorophyll go through a series of electron carriers
- The energy from the electrons is used to generate energy in the form of ATP
- Eventually, these electrons are accepted by the last electron acceptor, which is $NADP^+$
- The $NADP^+$ then combines with H^+ from photolysis and forms NADPH which is a reducing agent
- Chlorophyll pigment attracts electrons from water via photolysis to become stable
- Photolysis is a process whereby water molecules are broken down to form hydrogen ions (H^+) and hydroxide ions (OH^-) in the presence of light energy and chlorophyll
- Hydroxide ions lose electrons and form oxygen and water

LIGHT-INDEPENDENT REACTIONS

- 5-carbon organic compounds fix carbon dioxide gases to form 6-carbon organic compounds
- NADPH and ATP from the light-dependent reaction reduces the organic compounds to glucose monomers
- Glucose monomers condensate to form starch molecules
- Starch granules are stored in the stroma of chloroplasts

OVERALL REACTION FOR PHOTOSYNTHESIS

- Nicotinamide adenine dinucleotide phosphate ($NADP^+$) is a coenzyme in cells that functions as a hydrogen carrier
- In the photosynthesis, $NADP^+$ is an oxidising agent which receives hydrogen ions in the light-dependent reaction, while NADPH is a reducing agent in the light-independent reaction

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

Comparison between light-dependent and light-independent reactions in photosynthesis

SIMILARITIES

SIMILARITIES
⊕ Both reactions are catalysed by enzyme ⊕ Both reactions take place in chloroplast

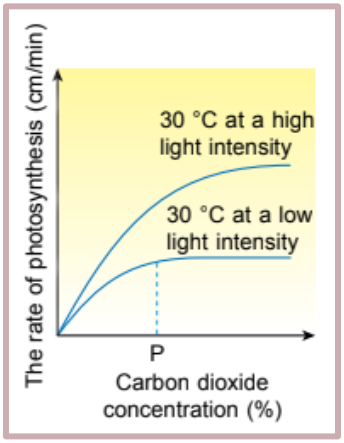
DIFFERENCES

LIGHT-DEPENDENT REACTIONS	ASPECTS	LIGHT-INDEPENDENT REACTIONS
Produce ATP molecules	ATP molecules	Use ATP molecules
water	Reaction substance	Carbon dioxide
Oxygen and water molecules	Reaction product	Glucose
Thylakoids	Site of reaction	Stroma
Involve photolysis of water	Process involved	Involve reduction of carbon dioxide

Environmental factors that affect the rate of photosynthesis

CARBON DIOXIDE CONCENTRATION

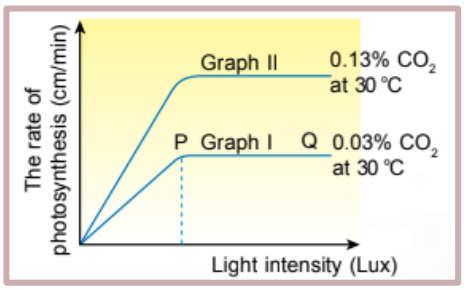
- ↘ The increase in carbon dioxide concentration increases the photosynthesis rate as long as there are no surrounding temperature and light intensity as limiting factors
- ↘ At P, photosynthesis rate is constant
- ↘ As the concentration of carbon dioxide increases after P, the rate of photosynthesis remains unchanged due to light intensity becoming the limiting factor



LIGHT INTENSITY

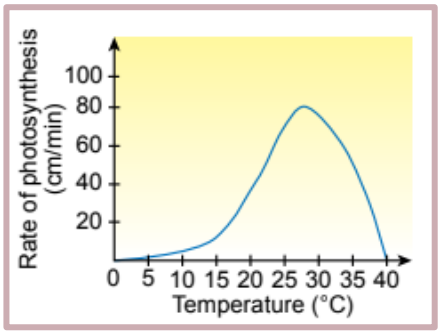
- ❑ Light is needed in the light-dependent reaction
- ❑ If the concentration of carbon dioxide and temperature are constant, the rate of photosynthesis increases until it reaches its maximum point at noon
- ❑ After point P, the increase in light intensity (from P to Q) is no longer increases the rate of photosynthesis because it is limited by temperature

and carbon dioxide as limiting factors



TEMPERATURE

- The reactions in photosynthesis are catalysed by enzymes
- Therefore, changes of surrounding temperature will affect enzyme activity and also the rate of photosynthesis
- The optimum temperature in general is between 25°C to 30°C
- A very high temperature denatures the enzymes and the process of photosynthesis is stopped



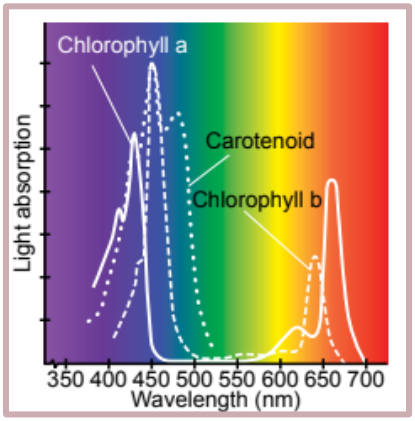
The effect of different light intensities and light colours on the rate of photosynthesis

DIFFERENT LIGHT INTENSITIES

- ✓ The rate of photosynthesis in plants is different throughout the day
- ✓ Other than the light intensity factor, the rate of photosynthesis is also affected by the colour of light

DIFFERENT LIGHT COLOURS

- ♥ Light spectrum consists of seven colours
  a) Violet
  b) Indigo
  c) Blue
  d) Green
  e) Yellow
  f) Orange
  g) Red
- ♥ Each colour has a different wavelength
- ♥ The rate of photosynthesis is the highest in red and blue light
- ♥ This is because all of the red light is absorbed by chlorophyll
- ♥ The blue light is absorbed by carotenoid pigments before being transferred to the chlorophyll
- ♥ These two lights have enough amount of energy to excite electrons in the light-dependent reaction



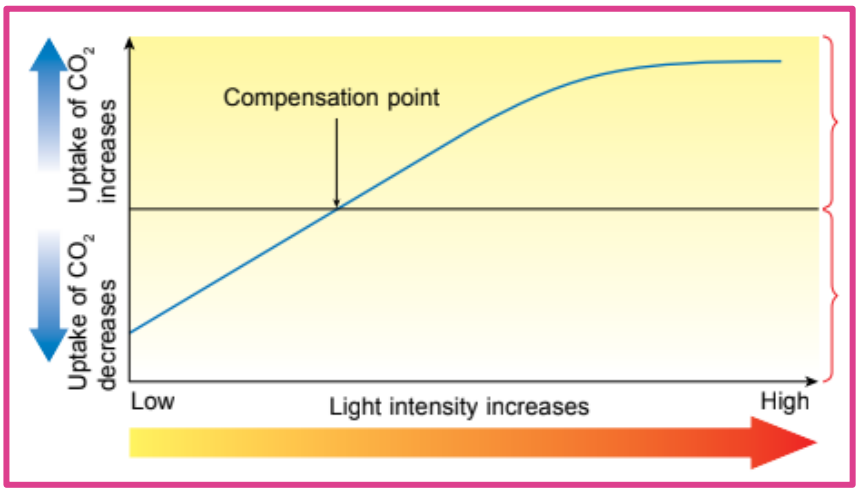
CHAPTER 2.5 – COMPENSATION POINT

Compensation point

» Compensation point is the level of light intensity when the rate of respiration equals to the rate of photosynthesis

Light intensity and attainment of compensation point

- At the compensation point, the rate of photosynthesis is the same as the rate of respiration
- Glucose produced in photosynthesis is used in the respiration of plants
- When the light intensity continues to increase beyond the compensation point, the rate of photosynthesis becomes faster compared to the rate of respiration
- At this time, carbon dioxide needs to be absorbed from the atmosphere to compensate the rate of its usage in photosynthesis
- Excessive oxygen is released into the atmosphere
- At the same time, the rate of glucose production exceeds the rate of glucose usage, where the excess glucose is stored in the form of starch by the plants
- If the rate of respiration and the rate of photosynthesis remains the same at the compensation point, the products of photosynthesis will be fully used for the plant respiration
- The rate of photosynthesis must exceed the rate of respiration every day to ensure the growth and production of flowers, seeds and fruits to occur
- This enables the rate of glucose production to exceed the rate of glucose usage and the excess glucose can be used for growth and development processes in the plant
- At the same time, the excess oxygen from the photosynthesis is then released into the atmosphere to support other organisms



NET GAIN

→ Net gain in glucose
→ The rate of photosynthesis exceeds the rate of respiration

NET LOSS

- Net loss in glucose
- Glucose used in respiration is faster than glucose produced in photosynthesis

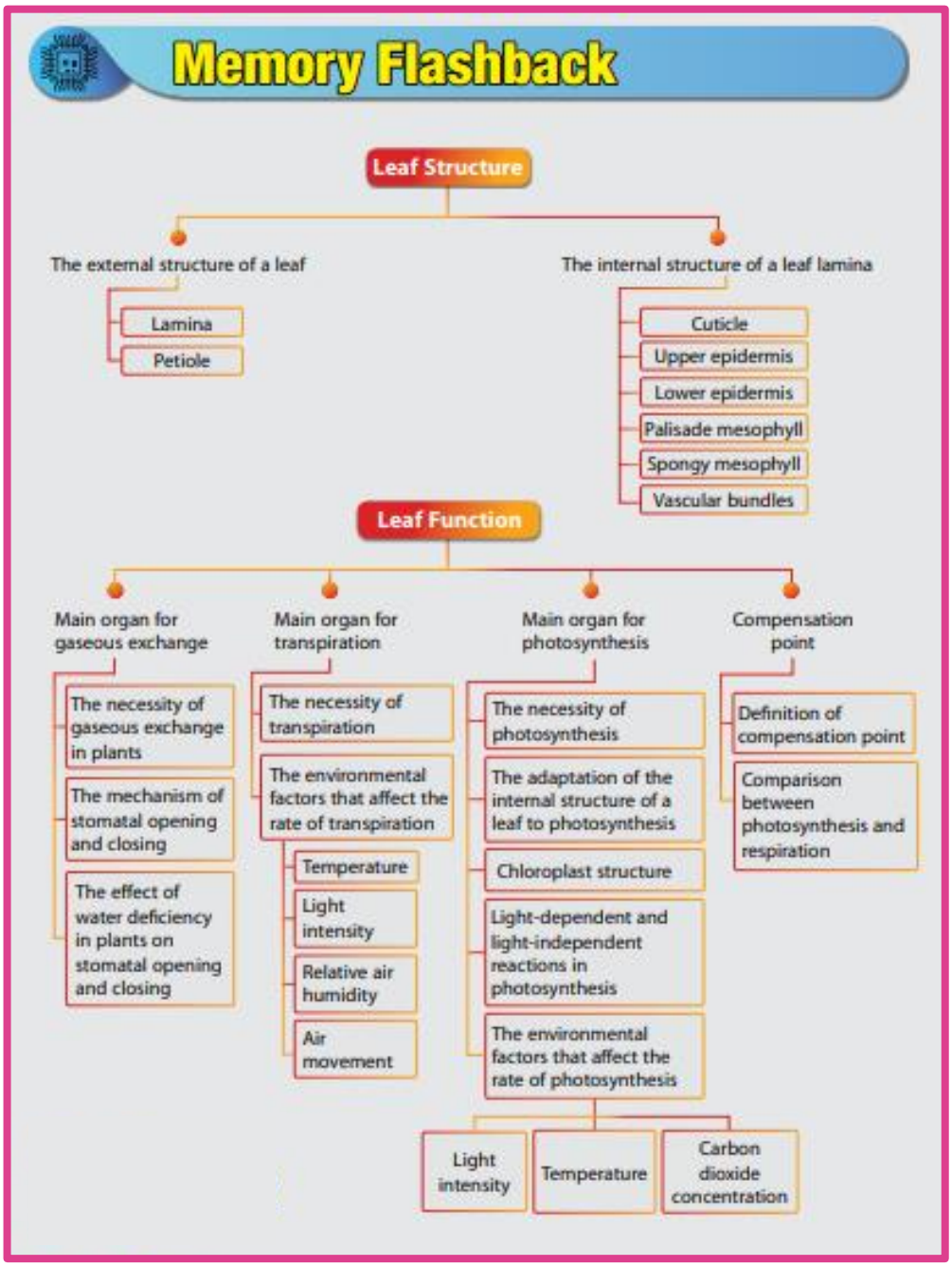
Comparison between photosynthesis and respiration in plants

SIMILARITIES

SIMILARITIES
Δ Both processes take place in living organisms Δ Both processes involve the uptake and release of gases

DIFFERENCES

PHOTOSYNTHESIS	ASPECT	RESPIRATION
Green plants and photosynthetic bacteria	Organisms involved	All living organisms
Happens in the cells containing chlorophyll	Type of cells	Happens in all cells
Anabolism process happens which is the synthesis of glucose using carbon dioxide and water	Type of metabolism	Catabolism process happens which is the breakdown of glucose to produce energy
Chloroplast	Site	Mitochondria
Carbon dioxide and water	Reaction substance	Oxygen and glucose
Glucose	Products	Energy
Oxygen and water	By-products	Carbon dioxide and water
Light energy is absorbed and converted into chemical energy	Energy involvement	Chemical energy in converted to ATP and heat energy is released
Needs light	Light requirement	Does not need light


Memory Flashback
Leaf Structure
The external structure of a leaf
Lamina
Petiole
The internal structure of a leaf lamina
Cuticle
Upper epidermis
Lower epidermis
Palisade mesophyll
Spongy mesophyll
Vascular bundles
Leaf Function
Main organ for gaseous exchange
The necessity of gaseous exchange in plants
The mechanism of stomatal opening and closing
The effect of water deficiency in plants on stomatal opening and closing
Main organ for transpiration
The necessity of transpiration
The environmental factors that affect the rate of transpiration
Temperature
Light intensity
Relative air humidity
Air movement
Main organ for photosynthesis
The necessity of photosynthesis
The adaptation of the internal structure of a leaf to photosynthesis
Chloroplast structure
Light-dependent and light-independent reactions in photosynthesis
The environmental factors that affect the rate of photosynthesis
Light intensity
Temperature
Carbon dioxide concentration
Compensation point
Definition of compensation point
Comparison between photosynthesis and respiration