Chapter 7 – Nutrition in Plants

Subject content

Content

- Leaf Structure
- Photosynthesis

Learning outcomes

(a) identify and label the cellular and tissue structure of a dicotyledonous leaf, as seen in transverse section using the light microscope and describe the significance of these features in terms of their functions, such as the
  - distribution of chloroplasts in photosynthesis
  - stomata and mesophyll cells in gaseous exchange
  - vascular bundles in transport

(b) state the equation, in words and symbols, for photosynthesis

(c) describe the intake of carbon dioxide and water by plants

(d) state that chlorophyll traps light energy and converts it into chemical energy for the formation of carbohydrates and their subsequent uses

(e) investigate and discuss the effects of varying light intensity, carbon dioxide concentration and temperature on the rate of photosynthesis (e.g. in submerged aquatic plant)

(f) discuss light intensity, carbon dioxide concentration and temperature as limiting factors on the rate of photosynthesis

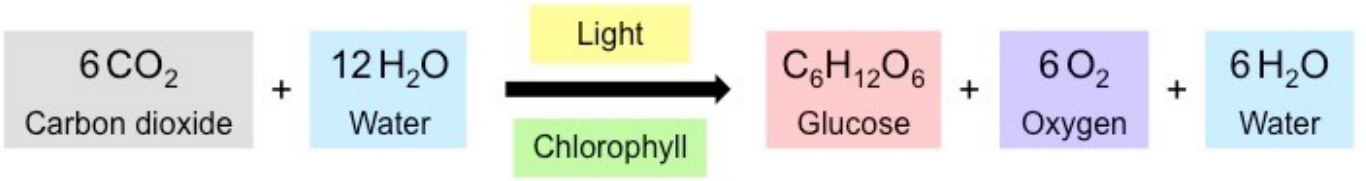
Use the knowledge gained in this section in new situations or to solve related problems.

Definition

Phrase	Definition
Photosynthesis	Process in which light energy absorbed by chlorophyll is converted into chemical energy. The chemical energy is used to synthesise carbohydrates from water and carbon dioxide (raw materials). Oxygen is released during the process.

7.1 Photosynthesis

Equation

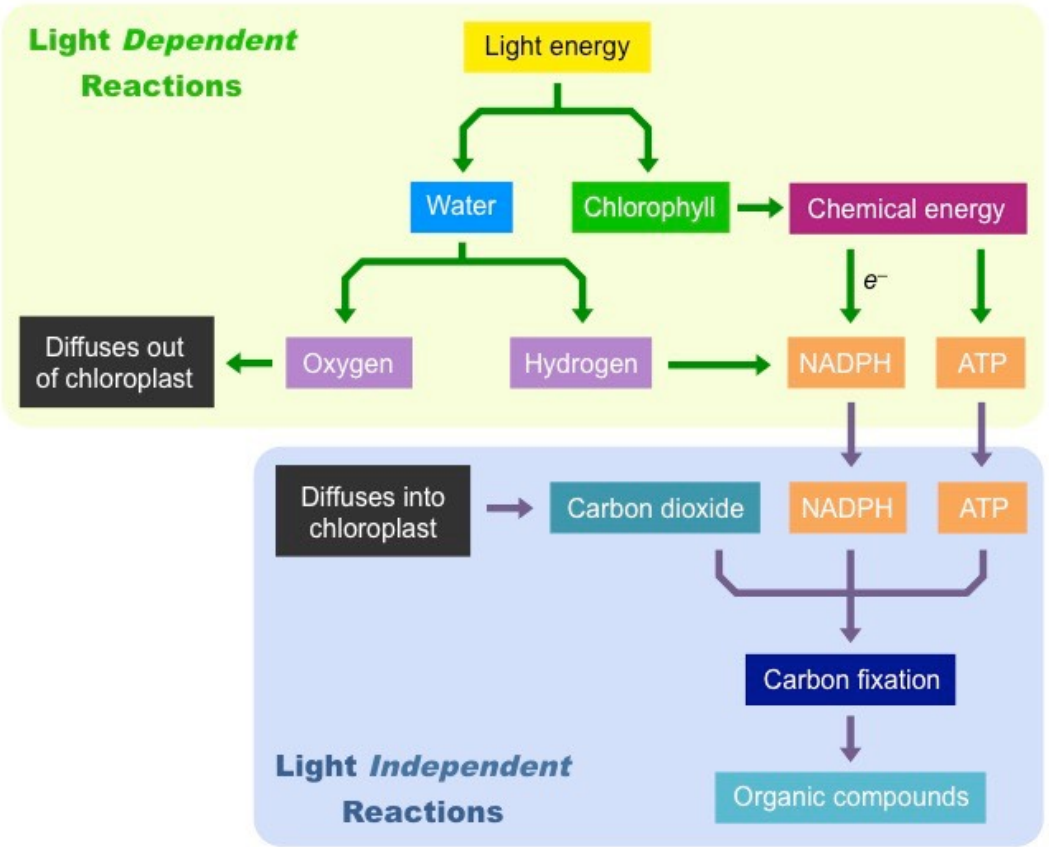


Light-dependent and light-independent stages

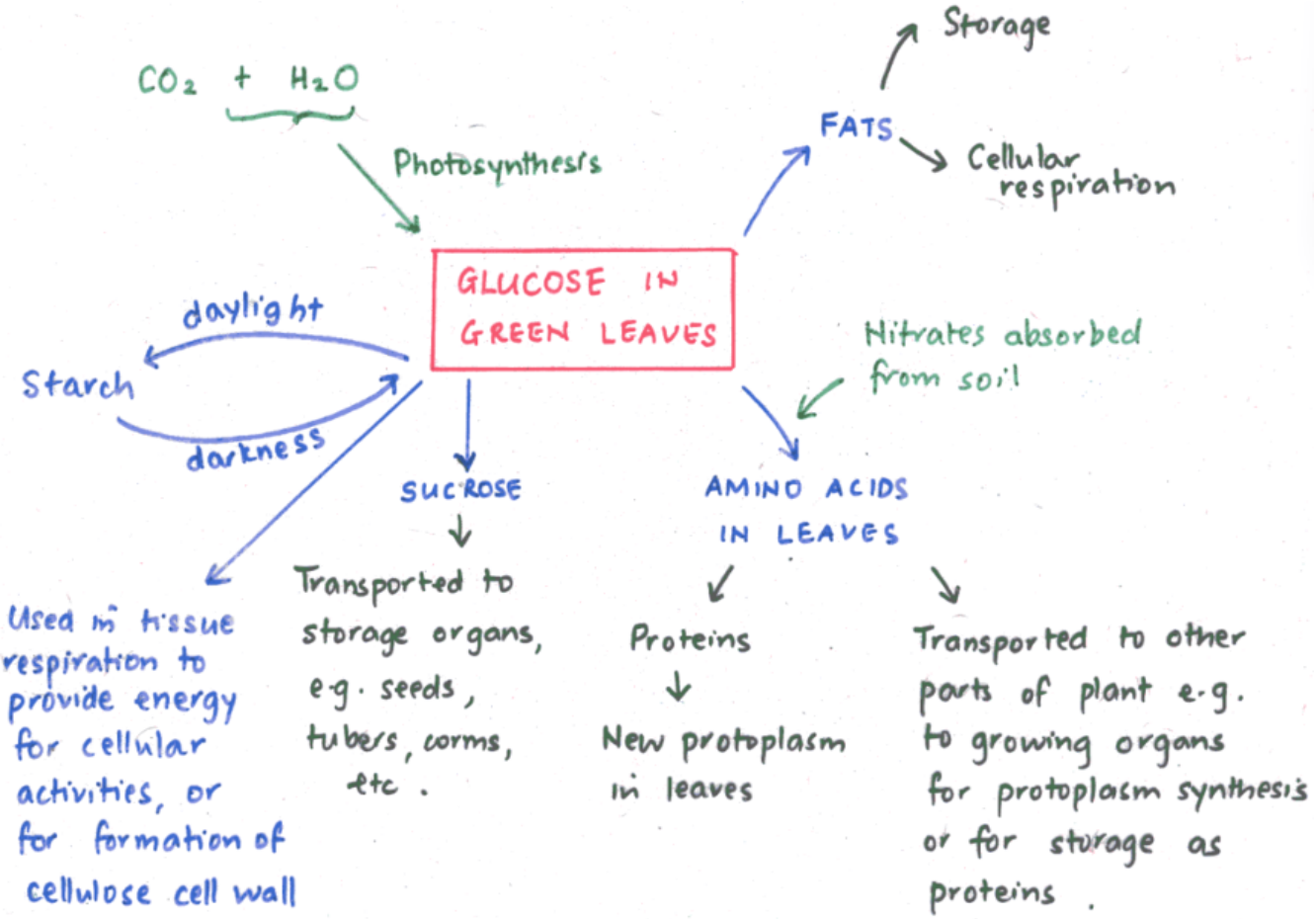
Stage	Explanation	Equation

1. **Light-dependent**	• Chlorophyll: absorb light energy
	  ○ convert → chemical energy
	  ○ photolysis of water: split water mol → oxygen + hydrogen atoms
	• Enzymes involved in chloroplast
		light → chemical energy
		12 H_2O → 6 O_2 + 24 H

2. **Light-independent**	• Hydrogen reduce carbon dioxide to carbohydrates • Chemical energy required comes from light-dependent stage + X require light • Enzymes involved in chloroplast	6 CO_2 → $C_6H_{12}O_6$ + 6 H_2O



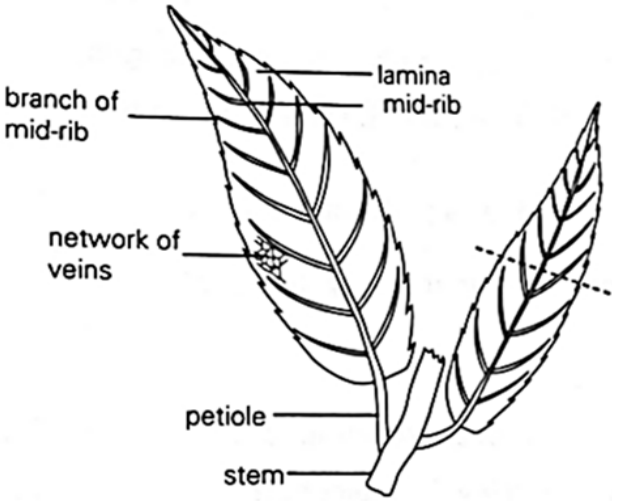
Glucose in leaves



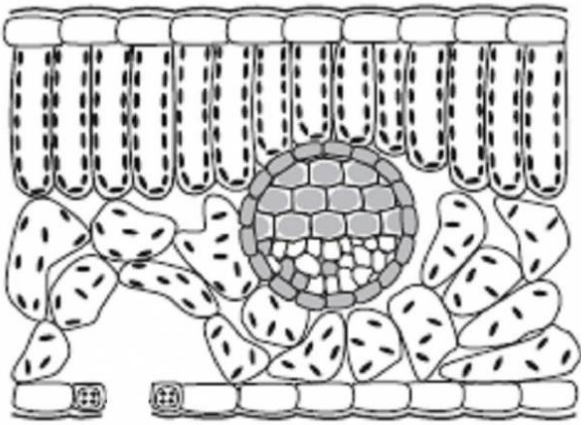
Importance of photosynthesis

Importance	Explanation
1. **Make chemical energy available to animals and other organisms**	• Photosynthesis: light → chemical energy (stored within carbohydrate mol) • Become food of other organisms → obtain chemical energy from plants (*producers*)
2. **Remove carbon dioxide and provide oxygen**	• Photosynthesis: remove CO_2 + produce O_2 • O_2: used by living organisms for cellular respiration • Maintain constant level of CO_2 and O_2 in atm
3. **Store energy in fossil fuels**	• Energy: from Sun, captured through photosynthesis • Burn → release energy for daily use

7.2 Leaf Structure and Function



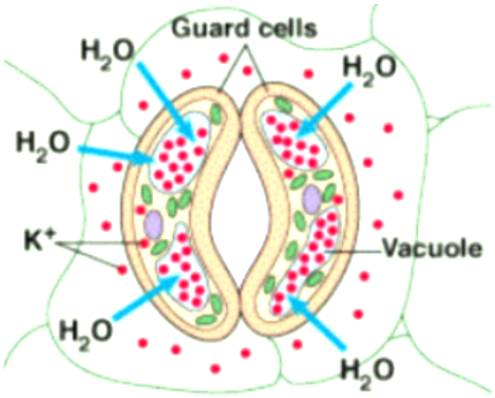
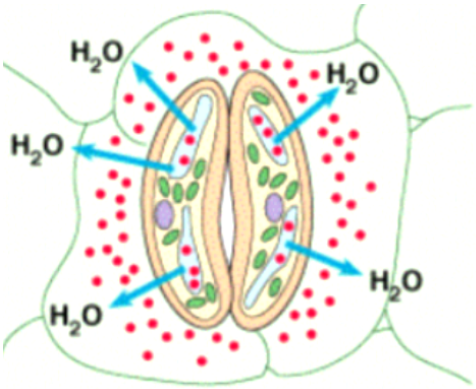
Structure	Characteristic	Function
1. **Lamina**	● Large flat ● Large thin	● Increase SA:V → increase absorption of sunlight for photosynthesis ● CO_2 diffuse over shorter distance, reach inner cells rapidly
2. **Petiole**	● Hold lamina away from stem	● Increase absorption of sunlight + air
3. Network of **veins**	● Main vein (mid-rib) divide repeatedly → network of fien veins	● Xylem: transport water + dissolved mineral salts from roots → leaf ● Phloem: transport sucrose + aa from leaf → parts of plant
4. Leaf arrangement	● Pairs ● Singly in alternate arrangement	● Leaves X overlap → block each other from sunlight ● Receive max amount of sunlight



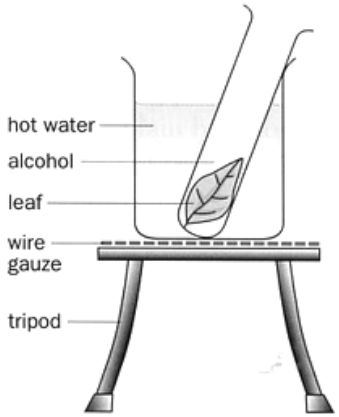
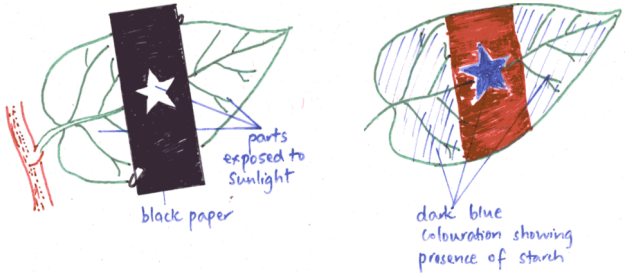
Structure		Characteristic	Function / adaptation
1. **Epidermis**	Upper	● No chloroplasts ● Covered by waxy transparent cuticle	Cuticle 1) protect internal leaf tissues 2) waxy: reduce water loss via evaporation 3) transparent - allow sunlight to penetrate leaf into photosynthesising cells 4) keep out pathogens
	Lower	● Contain stomata ● Covered by waxy transparent cuticle	
2. **Mesophyll**	Palisade	● Many chloroplasts ● Closely packed, long cylindrical cells	● Main site of photosynthesis → more light energy absorbed near leaf surface
	Spongy	● Few chloroplasts ● Cells irregular in shape ● Cells covered with thin film of moisture	1) Contain vascular bundle (xylem + phloem) 2) Interconnecting system of air spaces → rapid diffusion of CO_2 and O_2
3. **Stoma** (plural: stomata)		● Minute opening	● Open in presence of light: allow CO_2 diffuse in + O_2 diffuse out
4. **Guard cell**		● Some chloroplasts ● Cell wall has uneven thickness	● Control opening of stomata

Guard cells

Contain chlorophyll → can photosynthesise

Day	Night
	
• Guard cell photosynthesise: convert light → chemical energy • Chemical energy pump K^+ into guard cell from surrounding epidermal cells	• Accumulated K^+ move out of guard cells [diffusion + active transport]
• Decrease wp of guard cells • Water: neighbouring epidermal cells → guard cell [osmosis] • Increase turgidity → swollen	• Increase wp of guard cells • Water: guard cell → neighbouring epidermal cells [osmosis] • Decrease turgidity → flaccid
• Guard cell have thicker cell wall on the inside around stoma) • Uneven swelling → more curved → pull stoma open	• Stoma close

7.3 Study of Photosynthesis

<table>
<tr><th>Test for</th><th>Procedure</th><th>Figure</th></tr>
<tr><td>Starch
(converted from glucose)</td><td>
1. Expose plant to strong sunlight for few hrs
2. Remove green leaf
3. Immediately put leaf into boiling water for 2 mins
 ● starch present is due to glucose formed previously
 ● kill leaf (denature enzymes to stop photosynthesis)
 ● make cell membrane permeable
4. Put boiled leaf into boiling tube containing alcohol + place boiling tube in beaker of hot water
 ● chlorophyll dissolve in alcohol + diffuse out → remove chlorophyll from cells → leaf becomes <u>decolourised</u>
 ● higher temp for higher rate of dissolving
 ● X heat tube of alcohol directly (highly flammable)
5. Gently remove leaf + put back into hot water
 ● alcohol is a dehydrant (remove water from leaf) → rehydrate
 ● soften leaf + more permeable to iodine solution
6. Remove leaf + spread evenly on white tile
7. Test for starch: add few drops of iodine solution
<table>
<tr><td>blue-black colour</td><td>starch is present</td></tr>
<tr><td>brown colour</td><td>starch is absent</td></tr>
</table>
</td><td> 
</td></tr>
<tr><td>Sunlight
(absorbed)</td><td>
1. Destarch potted plant (place in the dark for 2 days)
2. Control: remove a leaf + test for starch
3. Sandwich a leaf attached to plant b/w two pieces of black paper + place plant in strong sunlight for few hrs
4. Remove leaf + decolourise + test for starch
</td><td> 
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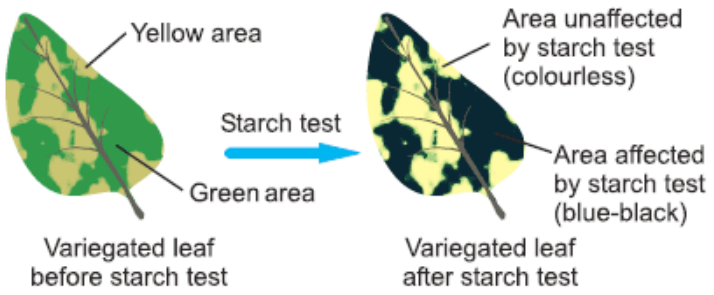
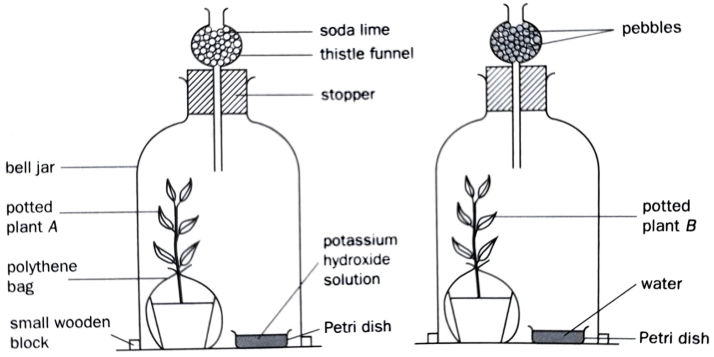
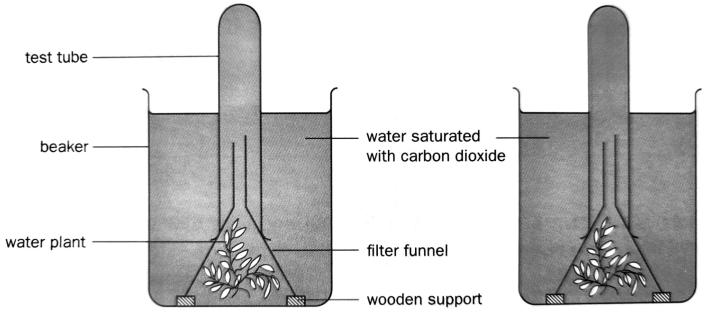
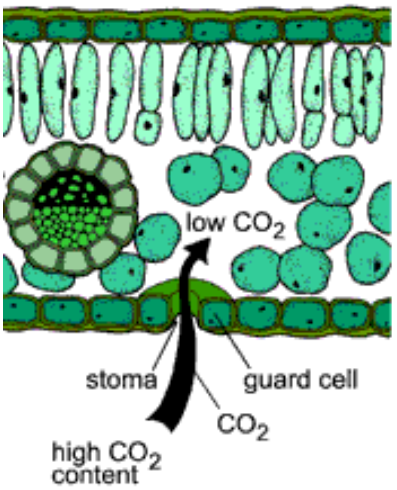
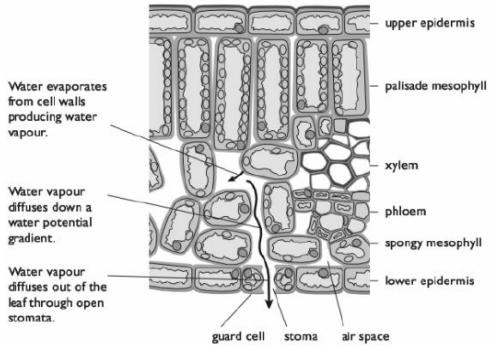
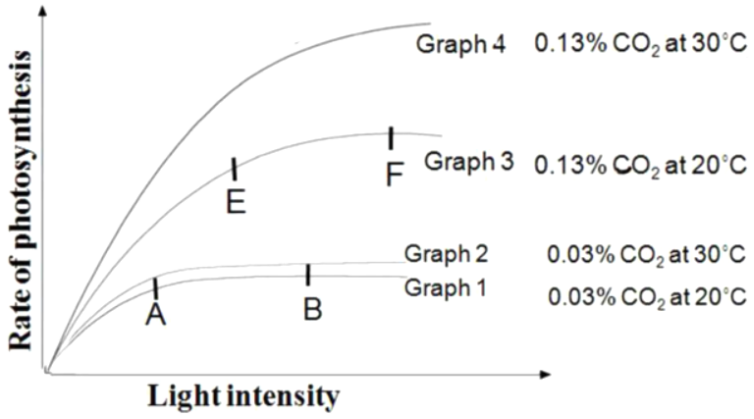
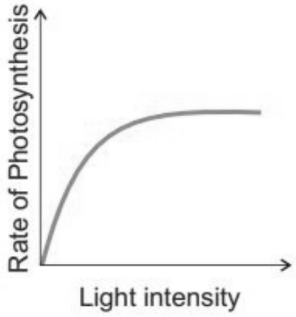
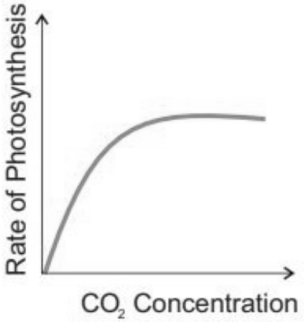
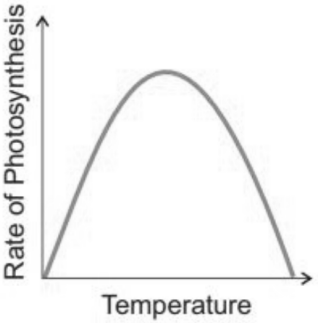
	1. Destarch plant with variegated leaves (place in the dark for 2 days) 2. Place plant in strong sunlight for few hrs 3. Remove leaf + decolourise + test for starch	
Carbon dioxide (used)	1. Destarch 2 potted plants (place in the dark for 2 days) 2. Enclose pots in polythene bags + secure bags to plant stems 3. Plant X supply of CO_2 (soda lime + potassium hydroxide: absorb CO_2) 4. Control: use pebbles + water 5. Leave in strong sunlight for few hrs 6. Remove leaf + decolourise + test for starch	
Oxygen (released)	1. Set up freshwater plant (e.g. Hydrilla / Elodea) 2. Dissolve sodium hydrogencarbonate in water in beaker → provide CO_2 3. Place in strong sunlight for few hrs 4. Gas bubbles form on leaves → rise up → displace water downwards 5. Tube half-filled: remove tube + test gas (oxygen) with glowing spinter	

7.4 Movement of Substances Into and Out of A <u>Leaf</u>

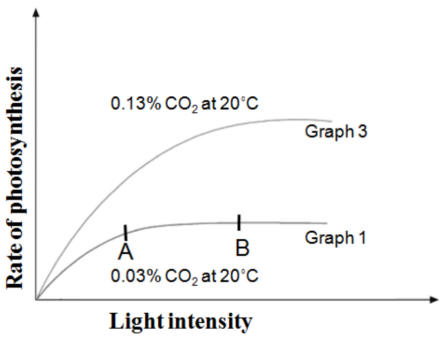
Substance	Steps	Figure
1. **Carbon dioxide**	**<u>INTO</u>** leaf 1) Photosynthesis → CO_2 in leaf rapidly used up ● [CO_2] in leaf < atm air → conc gradient ● CO_2 diffuse: surrounding air → stomata → intercellular air spaces 2) CO_2 dissolve in thin film of water on surface of mesophyll cells 3) Dissolved CO_2 diffuse into cell	
2. **Water and dissolved mineral salts**	**<u>OUT OF</u>** leaf 1) Xylem: transport water + dissolved mineral walts from roots → leaf 2) Move from cell to cell through mesophyll	

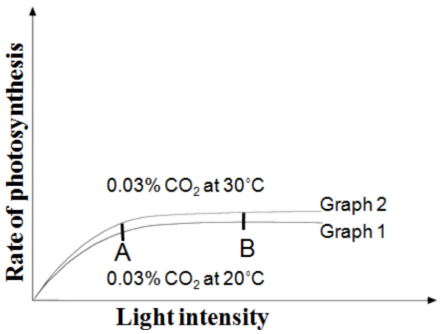
7.5 Limiting Factors in Photosynthesis

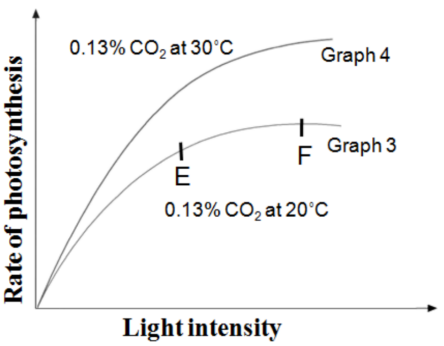


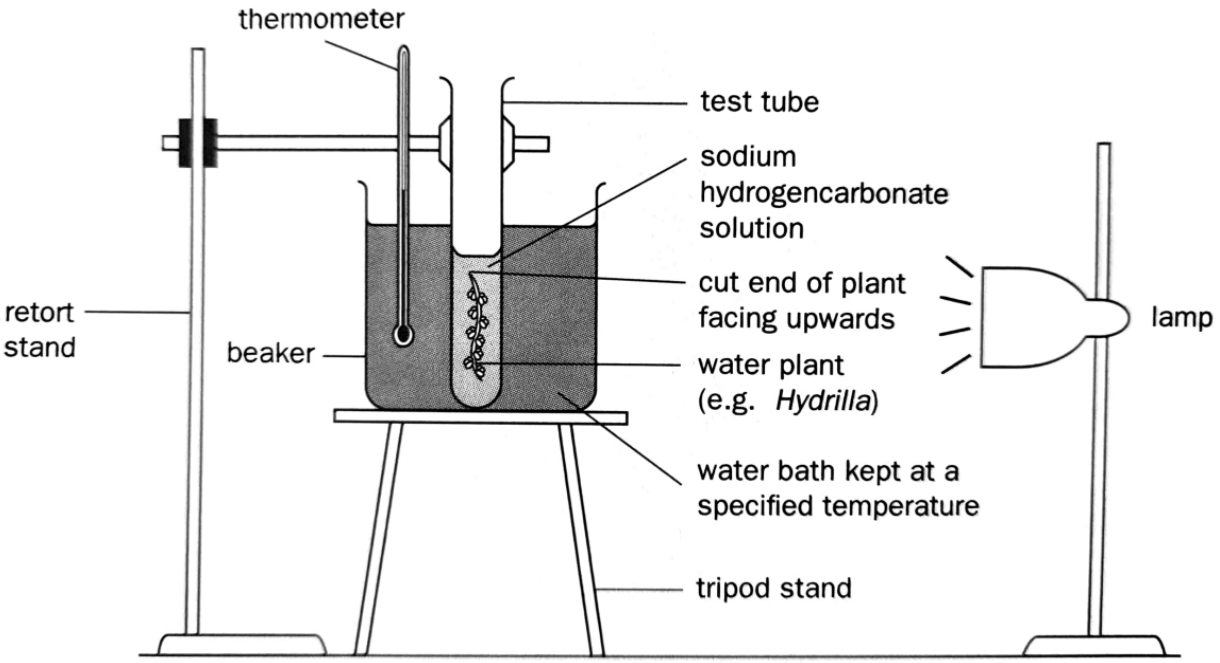
Light intensity	CO_2 concentration	Temperature
		

• Rise: rate increase
• Rise: rate remain constant
  ○ light intensity is no longer limiting
  ○ other factors become limiting
• High: rate decrease
  1) Increased transpiration rate reduce wp of guard cells → stomata close → cut off CO_2 supply
  2) Chlorophyll bleached
	Major limiting factor
	• CO_2 conc in atm: 0.03 ~ 0.04%
	• Rise: rate increase
		• Light-independent stage: enzyme-controlled → sensitive to temp
		• Rise: rate increase
		• High: enzyme denature above optimum temp







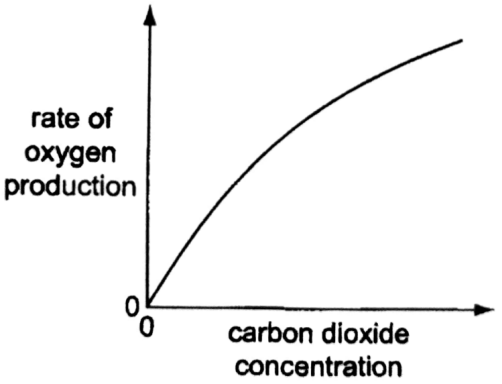


Factor	Procedure
Light intensity	1. Conduct expt at room temp 2. Allow 10 mins for plant to adapt to conditions provided 3. Bubbles produced at regular rate: count no. of bubbles over 1 min + repeat few times to obtain average 4. Vary distance b/w light source & plant → vary light intensity
Carbon dioxide concentration	1. Conduct expt at room temp 2. Allow 10 mins for plant to adapt to conditions provided 3. Bubbles produced at regular rate: count no. of bubbles over 1 min + repeat few times to obtain average 4. Vary conc of sodium hydrogencarbonate sol → vary CO_2 conc
Temperature	1. Conduct expt at constant light intensity → keep lamp at constant distance away from plant 2. Add ice-cold water to water bath, keep temp at 5°C 3. Allow 10 mins for plant to adapt to conditions provided 4. Bubbles produced at regular rate: count no. of bubbles over 1 min + repeat few times to obtain average 5. Vary temp of water bath → vary temp

Typical questions

Multiple choice questions

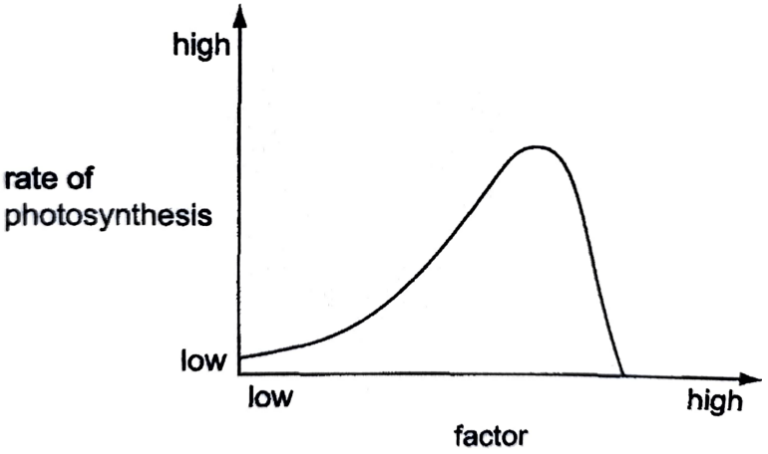
1 Some students investigated gaseous exchange in a green plant. The rate of oxygen production was plotted against carbon dioxide concentration.



What explains these results? (N2011/P1/Q10)

A Carbon dioxide controls the rate of respiration.
B Carbon dioxide controls the rate of photosynthesis.
C Oxygen controls the rate of photosynthesis.
D Oxygen controls the rate of respiration.

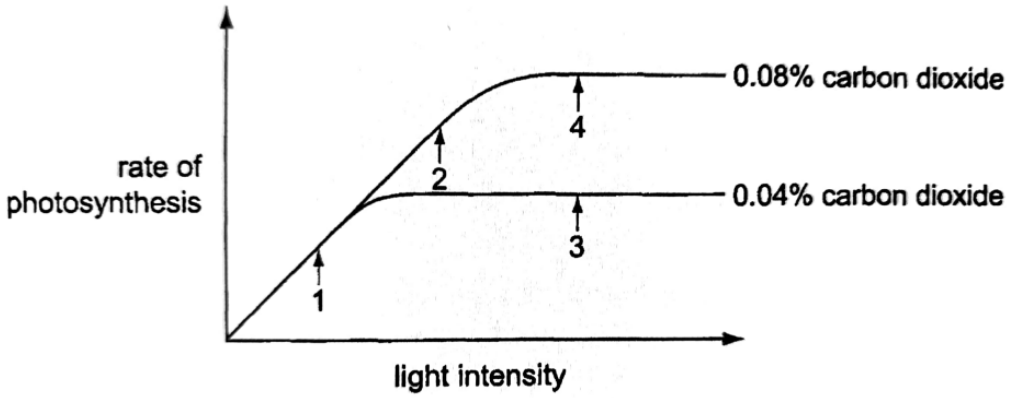
2 The graph shows the rate of photosynthesis plotted against an unknown factor.



Which factor is limiting the rate of photosynthesis as shown in the graph? (N2012/P1/Q10)

A carbon dioxide concentration
B light intensity
C number of chloroplasts
D temperature

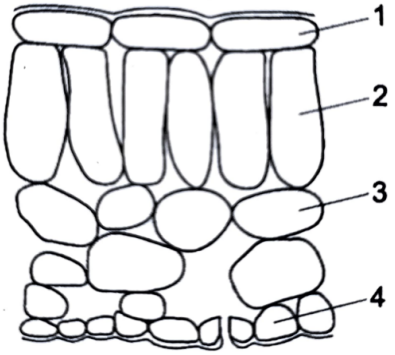
3 The graph shows the rate of photosynthesis at two different carbon dioxide concentrations and at varying light intensities at an optimum temperature of 25℃.



Which factors are limiting at the points indicated? (N2013/P1/Q10)

	light intensity	carbon dioxide concentration
A	1	2
B	3	4
C	1 and 2	3 and 4
D	2 and 3	1 and 4

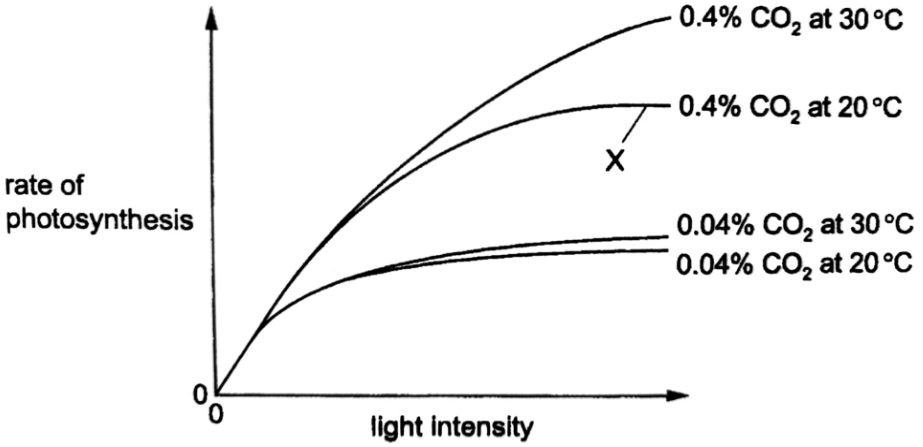
4 The diagram shows part of a transverse section of a leaf.



Which cells contain chloroplasts? (N2015/P1/Q9)

A 1 and 2 only
B 2 only
C 3 and 4 only
D 2, 3 and 4 only

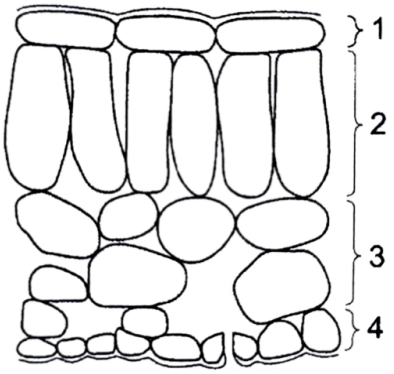
5 The graph shows the effect of various factors on the rate of photosynthesis.



Which factor is the limiting factor at X? (N2015/P1/Q10)

A carbon dioxide concentration
B light intensity
C temperature
D water

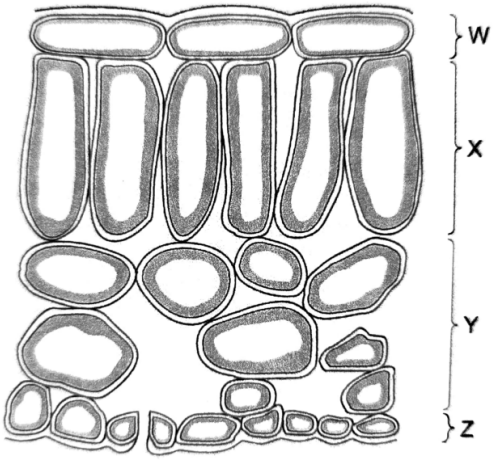
6 The diagram shows a section through a leaf with four layers of cells labelled.



What is the correct comparison between the layers? (N2016/P1/Q10)

	layer with many chloroplasts in cells	layer with some chloroplasts in cells	layer with no chloroplasts in cells
A	2	1	4
B	2	3	4
C	3	1	2
D	3	4	1

7 The diagram shows the tissues in a cross-section of a leaf.
The four tissue layers are labelled W, X, Y and Z.



Starting with the layer containing the highest number of chloroplasts first and ending with the layer containing no chloroplasts, which sequence of letters shows the distribution of chloroplasts in a leaf? (N2017/P1/Q9)

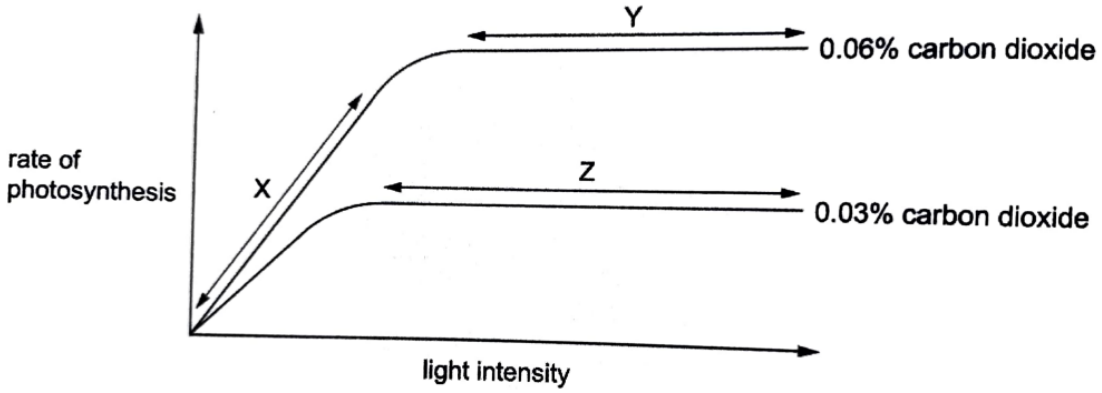
A X → Y → W → Z
B X → Y → Z → W
C Y → X → W → Z
D Z → Y → X → W

8 Green plants use carbon dioxide.
How do plant cells in a leaf obtain carbon dioxide? (N2017/P1/Q10)

1. active transport across the cells of the lower epidermis
2. diffusion through the stomata
3. from respiration
4. osmosis through the upper and lower epidermal cells

A 1 and 3
B 1 and 4
C 2 and 3
D 2 and 4

9 The graph shows the rate of photosynthesis of a plant, in increasing light intensity, at two different carbon dioxide concentrations. The temperature was kept constant.



What may be limiting the rate of photosynthesis at X, Y and Z? (N2018/P1/Q11)

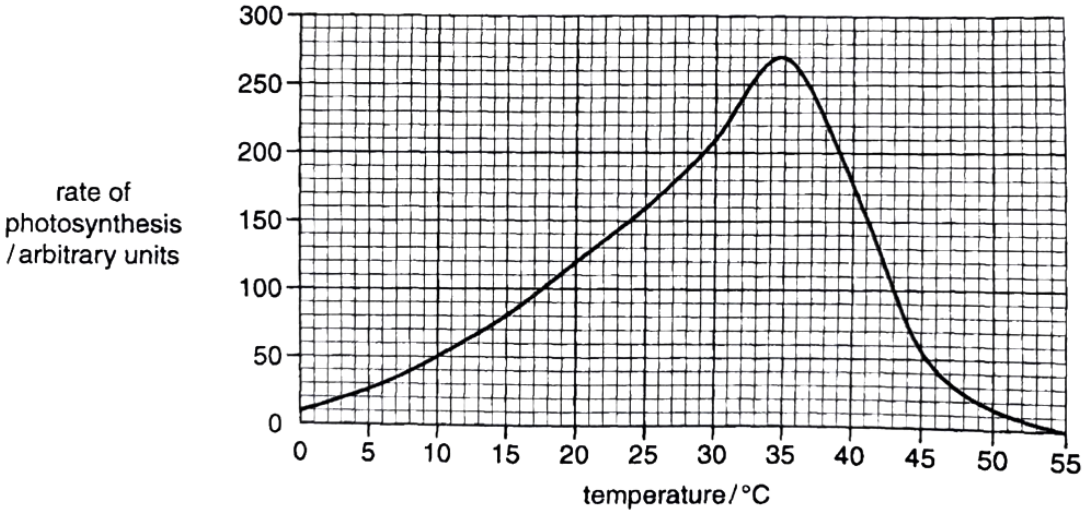
	X	Y	Z
A	carbon dioxide	light intensity	carbon dioxide
B	carbon dioxide	light intensity	light intensity
C	light intensity	carbon dioxide	carbon dioxide
D	light intensity	carbon dioxide	light intensity

10 When plants carry out photosynthesis, they produce a carbohydrate.
Which row gives the ways the plant may then use this carbohydrate? (N2019/P1/Q10)

	converted to protein	stored as starch	used for making cellulose	used to release energy
A	yes	yes	yes	yes
B	yes	no	yes	no
C	no	yes	no	yes
D	no	yes	yes	no

Structured questions

1 The figure below shows the effect of temperature on photosynthesis.



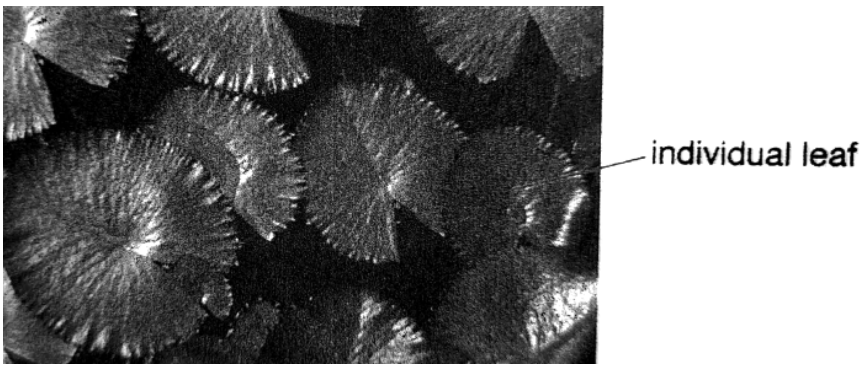
State and explain the relationship between temperature and photosynthesis. [4]

(N2011/P2/A6)

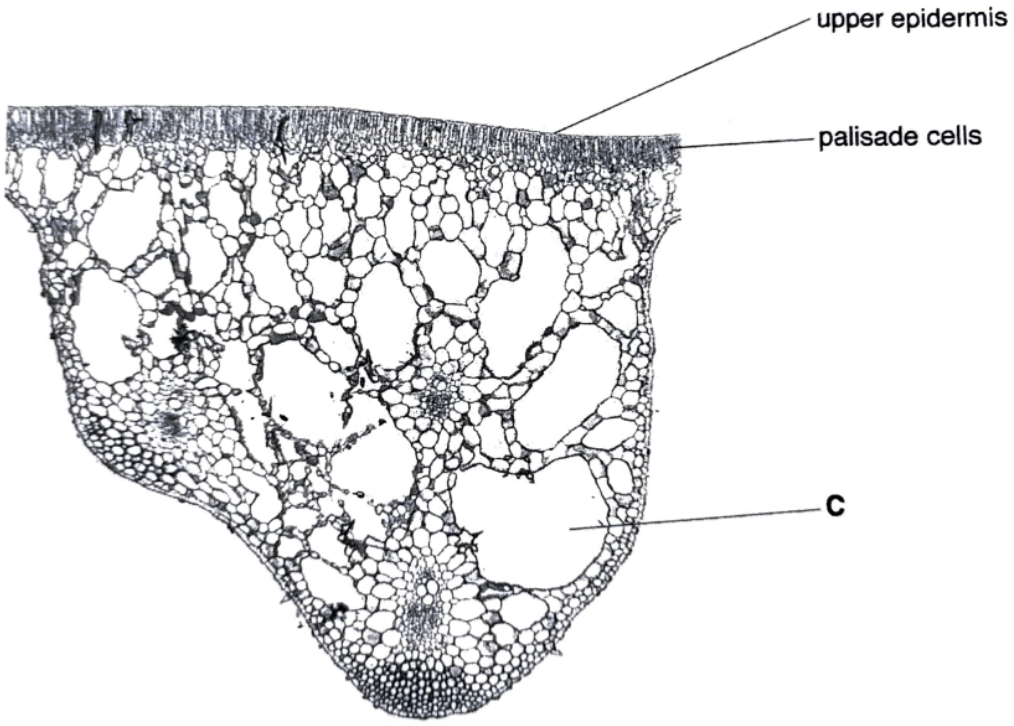
Enzymes are needed to carry out photosynthesis.
They are very sensitive to changes in temperature.

Temperature	Photosynthesis rate	Explanation
0°C	very low	Most enzymes are inactive.
0°C → 35°C	increases	Enzymes and substrates have more kinetic energy, thus more enzyme-substrates are formed.
35°C	highest	Enzymes are the most active and catalyst reactions at the highest rate.
35°C → 55°C	decreases	Rate of enzyme activity decreases as enzymes are denatured by the high temperatures.
55°C	zero	All the enzymes are denatured.

2 The figure below shows the leaves of water lilies growing on the surface of a pond.



The figure below shows a transverse section of the leaf on a water lily viewed through a microscope.



(N2017/P2/A2)

(a) Suggest the function of part C. [1]

Keeps the leaf afloat on the water surface.

(b) State a reason for the position of the palisade cells within the leaf. [1]

Found directly under the upper epidermis
So that they can capture as much sunlight as possible for photosynthesis

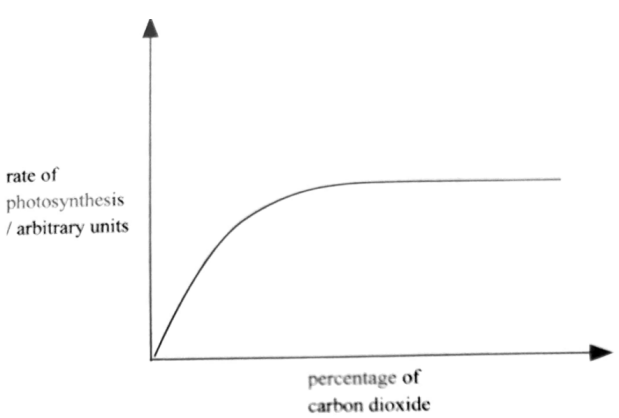
(c) State the role of chlorophyll in photosynthesis. [3]

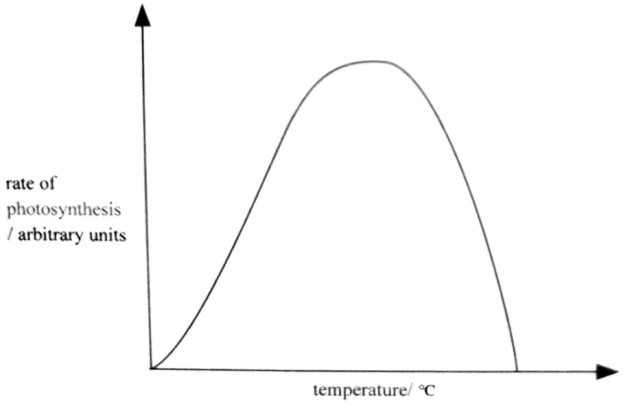
- The process of photosynthesis occurs in two stages, i.e. light-dependent and light-independent stage.
- In light-dependent stage, light energy is trapped by chlorophyll and converted into chemical energy. Water molecules are split into oxygen and hydrogen atoms. The oxygen produced is released as a by-product.
- In light-independent stage, enzymes use hydrogen atoms and chemical energy from light-dependent stage to convert carbon dioxide into glucose.

(d) Sketch a line graph on each pair of axes to show:

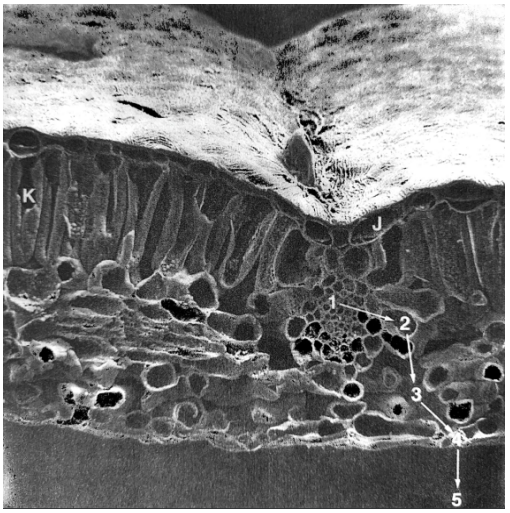
1. the effect of carbon dioxide on the rate of photosynthesis
2. the effect of temperature on the rate of photosynthesis

Assume all other factors are kept constant. [2]





3 The figure below is a photomicrograph showing a cross-section of part of a dicotyledonous leaf.



(N2019/P2/A3b,c)

(a) Identify cells J and K. Explain how they are adapted for their roles in photosynthesis. [4]

Cell J: upper epidermal cell

Adaptation: Transparent to enable sunlight to pass through it to reach mesophyll cells beneath. Has a waxy cuticle layer to minimise water loss to surroundings.

Cell K: palisade mesophyll cell

Adaptation: Has highest concentration of chloroplast to absorb and convert light energy to chemical energy via photosynthesis.

(b) The stomata of most plants stay open in daylight.
Explain why having stomata open in daylight is an advantage to plants. [4]

- Keeping stomata open in daylight facilitates gaseous exchange, allowing more carbon dioxide to diffuse into the leaf. This allows for increased rate of photosynthesis to produce glucose when there is presence of sunlight.
- Opening of stomata also leads to increased transpiration rate as water vapour in intercellular air space can diffuse out of leaf via stomata. This leads to the generation of transpiration pull, which enables water to be transported from the roots up xylem to other parts of plant. This also keeps plant cells turgid and the plant can remain upright to capture sunlight for photosynthesis.

4 (N2014/P2/B9)

(a) Describe how light energy is converted to chemical energy and stored in carbohydrates in plants. [4]

- The process of photosynthesis occurs in two stages, i.e. light-dependent stage and light-independent stage.
- In the light-dependent stage, light energy is trapped by chlorophyll and converted into chemical energy. Water molecules are split into oxygen and hydrogen atoms. The oxygen produced is released as a by-product.
- In the light-independent stage, enzymes use hydrogen atoms and chemical energy from light-dependent stage to convert carbon dioxide into glucose.
- Overall, light energy from the Sun is trapped by chlorophyll and stored as chemical energy in carbohydrates.

(b) The figure below shows plants growing in a glasshouse.

Suggest how conditions in a glasshouse can be controlled to ensure the maximum growth of the plants. [5]

- Conditions in a glasshouse such as light intensity, temperature, amount of carbon dioxide, amount of water, concentration of mineral salts in soil and soil pH can be optimised to ensure the maximum growth of the plants.
- A computerised system can be used to monitor the conditions frequently so that the factors that affect the rate of photosynthesis of the plants are kept at optimal levels.
- In particular, the plants have to be kept at an optimum temperature because enzymes are involved in photosynthesis and are highly sensitive to temperature changes. More carbon dioxide can also be supplied to the plants to increase the rate of photosynthesis of the plants.

5 (N2018/P2/B10 EITHER)

(a) Describe the process of photosynthesis. [6]

- The process of photosynthesis occurs in two stages, i.e. light-dependent stage and light-independent stage.
- In the light-dependent stage, light energy is trapped by chlorophyll and converted into chemical energy. Water molecules are split into oxygen and hydrogen atoms. The oxygen produced is released as a by-product.
- In the light-independent stage, enzymes use hydrogen atoms and chemical energy from light-dependent stage to convert carbon dioxide into glucose.
- Overall, photosynthesis is a proess whereby light energy from the Sun is trapped by chlorophyll and used to convert inorganic carbon dioxide and water into organic carbohydrates (glucose) and oxygen. Light energy from the Sun is converted into chemical energy and stored in carbohydrates.

(b) Explain why the rate of photosynthesis is faster on a warm day than on a cold day. [4]

- Enzymes are needed to carry out photosynthesis and they are very sensitive to temperature changes.
- On a cold day, most enzymes are inactive, thus the rate of photosynthesis is low.
- As the temperature increases, the rate of photosynthesis increases. The enzymes and substrates have more kinetic energy, thus more enzyme-substrate complexes are formed and more products are formed per unit time.
- On a warm day, the rate of photosynthesis is faster than on a cold day because the enzymes are more active and catalyse reactions at a higher rate.

6 Explain the functions of the cuticle of a leaf. [3]

- keep out pathogens
- keep in water / reduce loss of water / prevent excessive loss of water (Reject: prevent water loss / because it is impermeable to water)
- transparent so lets light through to palisade cells/photosynthesising cells;

7 Unlike their surrounding epidermal cells, the guard cells contain chloroplast. Explain how this feature of the guard cells is useful to allow carbon dioxide to enter the leaf in the daytime. [6]

- in daylight, chloroplast absorbs light for photosynthesis + glucose formed
- lowers water potential of cell sap of guard cells
- water molecules enters from epidermal cells into guard cells by osmosis
- guard cells expand / increase in volume
- uneven thickening of cell wall causes thinner wall opposite stoma to expand more than thicker wall around stoma
- guard cells curves and pulls open stoma

8 Describe how carbon dioxide enters the leaf in daylight and reaches the photosynthetic cell. [4]

- CO_2 molecules in the leaf are rapidly used up for photosynthesis
- CO_2 concentration in the leaf becomes lower than that in the atmospheric air
- CO_2 molecules diffuse into the leaf through the open stomata down a concentration gradient into the intercellular air spaces
- CO_2 molecules dissolve in the film of moisture surrounding the mesophyll cells and then diffuse through the cell membrane into the mesophyll cell

9 Describe three possible fates of the sugar formed in photosynthesis. [3]

- used immediately for respiration to release energy
- excess converted to starch in the leaves
- converted to sucrose and transported to other parts of plant or to storage organs
- combines with nitrogen in nitrates to form amino acids which are used to form proteins
- converted fats for synthesis of new protoplasm or for storage

10 How are spongy mesophyll cells adapted for their function? [3]

- spaced further apart than palisade mesophyll cells and the spaces in between allow oxygen and carbon dioxide molecules to diffuse in and out of the leaf easily
- contain chlorophyll and thus are able to carry out photosynthesis
- covered with a thin film of moisture, to allow gases to diffuse into it for faster diffusion in and out of the cells

11 Briefly explain the role of guard cells in gaseous exchange for photosynthesis. [5]

- guard cells contain chlorophyll + photosynthesise to produce glucose
- water potential of cell sap of guard cell decreases below surrounding epidermal cells
- water molecules move into guard cells by osmosis (through a partially permeable cell membrane) + guard cells swell & expand + become turgid
- uneven thickening of cell wall + guard cells become more curved
- stomata pulled open + increasing rate of gaseous exchange