Chapter: 6 Plant nutrition

- **Book/PDF:** Chapter-6.pdf
- **Pages:** 1-50
- **Exam level:** Cambridge IGCSE (0610)

1) Big-picture overview

This chapter introduces **photosynthesis**, the amazing process plants use to make their own food. Think of a plant as a tiny, solar-powered factory. It takes in simple raw materials—carbon dioxide from the air and water from the soil—and uses energy from sunlight to turn them into glucose, a type of sugar. This process not only feeds the plant but also releases the oxygen we breathe, making it essential for almost all life on Earth. You'll learn the chemical recipe for photosynthesis, see how the leaf is perfectly designed for this job, and discover what happens to the glucose once it's made. We'll also investigate the factors that can speed up or slow down this process, like light, temperature, and carbon dioxide levels, and understand why plants need minerals from the soil to stay healthy.

2) Syllabus mapping

Outcome description	Where covered (page)
Define photosynthesis as the process of making carbohydrates from raw materials using light energy.	p. 1, p. 2
State the word equation and balanced chemical equation for photosynthesis.	p. 3
Explain the function of chlorophyll in converting light energy to chemical energy.	p. 2, p. 4
Describe how the plant uses the glucose produced in photosynthesis.	p. 4–7
Explain the importance of nitrate ions and magnesium ions for plants.	p. 8
Describe the external and internal structure of a dicotyledonous leaf and its adaptations for photosynthesis.	p. 35–43

Outcome description	Where covered (page)
Explain how limiting factors (light intensity, CO_2 concentration, temperature) affect the rate of photosynthesis.	p. 23–24
Describe experiments to investigate the necessity of light, CO_2, and chlorophyll for photosynthesis.	p. 14–17
Describe experiments to investigate the effect of limiting factors on the rate of photosynthesis.	p. 27–34

3) Key terms and definitions

Term	One-sentence definition	First appears (page)	Example/application
Photosynthesis	The process by which plants make carbohydrates from raw materials using energy from light (p. 1).	p. 1	A geranium plant in sunlight produces glucose and oxygen from CO_2 and water.
Chlorophyll	The green pigment in chloroplasts that absorbs sunlight and converts light energy to chemical energy (p. 2).	p. 2	Makes leaves green and is essential for the first stage of photosynthesis.
Starch	An insoluble carbohydrate used for energy storage in plants, made from glucose (p. 4).	p. 4	A potato tuber is rich in stored starch grains.
Sucrose	A soluble sugar transported in the phloem to other parts of the plant (p. 5).	p. 5	Glucose from photosynthesis is converted to sucrose for transport from the leaf to the roots.

Term	One-sentence definition	First appears (page)	Example/application
Cellulose	A tough carbohydrate that makes up plant cell walls (p. 6).	p. 6	Provides structural support to plant cells.
Mineral salts	Ions like nitrates and magnesium that plants absorb from the soil for healthy growth (p. 8).	p. 8	Nitrates are needed to make amino acids and proteins.
Chlorosis	The yellowing of leaves due to a lack of chlorophyll, often caused by magnesium deficiency (p. 8).	p. 8	A plant grown in magnesium-deficient soil will show chlorosis.
Hydroponics	A method of growing plants in a water culture (nutrient solution) without soil (p. 9).	p. 9	Used in glasshouses to grow crops like tomatoes and sage with controlled nutrients.
Control (experiment)	A parallel experiment set up to ensure the results are due to the variable being tested and not some other factor (p. 11).	p. 11	In an experiment testing for light, the control is the part of the leaf exposed to light.
Limiting factor	An environmental factor in such short supply that it restricts the rate of a life process like photosynthesis (p. 23).	p. 23	On a cloudy day, light intensity is often the limiting factor for photosynthesis.
Cuticle	A waxy layer covering the epidermis that helps to reduce water loss from the leaf (p. 37).	p. 37	The shiny surface of many leaves is due to the cuticle.

Term	One-sentence definition	First appears (page)	Example/application
Stomata (sing. stoma)	Pores, usually on the lower leaf surface, that allow for gas exchange (p. 37).	p. 37	Carbon dioxide enters the leaf for photosynthesis through the stomata.
Guard cells	A pair of specialised cells that control the opening and closing of a stoma (p. 37).	p. 37	Guard cells swell with water to open the stoma in daylight.
Mesophyll	The tissue between the upper and lower epidermis of a leaf where most photosynthesis occurs (p. 41).	p. 41	Composed of the palisade mesophyll (upper) and spongy mesophyll (lower).
Xylem	Vessels that transport water and mineral salts from the roots to the leaves (p. 42).	p. 42	Part of the vascular bundle (vein) in a leaf.
Phloem	Vessels that transport sugars (like sucrose) from the leaves to other parts of the plant (p. 43).	p. 43	Transports food to storage organs like roots or growing buds.
Translocation	The transport of sugars and other food substances away from the leaf in the phloem (p. 43).	p. 43	Sucrose is translocated from the leaves to the fruit to make it sweet.

4) Core concepts explained

The Process of Photosynthesis (p. 2-3)

- Photosynthesis is the fundamental process plants use to produce their own food (p. 1).

- It uses simple inorganic raw materials: **carbon dioxide (CO_2)** from the air and **water (H_2O)** from the soil (p. 2).
- The energy for the reaction is provided by **sunlight**, which is captured by the green pigment **chlorophyll** found in chloroplasts (p. 2).
- Chlorophyll's key role is to convert **light energy into chemical energy**, which is then used to synthesize carbohydrates (p. 2).
- The main products are **glucose ($C\_6H\_12O\_6$)**, a sugar used for energy and growth, and **oxygen (O_2)**, which is released as a waste product (p. 3).

Use of Photosynthetic Products (p. 4-7)

The glucose made during photosynthesis is a versatile molecule that the plant uses in several ways:

- **For Respiration:** Glucose is broken down to release chemical energy for all other life processes, such as building proteins (p. 7).
- **For Transport:** It is converted into **sucrose** (a soluble sugar) for transport through the phloem to other parts of the plant like roots, fruits, and flowers (p. 5).
- **For Storage:** Excess glucose is converted into **starch** (an insoluble carbohydrate) and stored in chloroplasts, leaves, stems, or roots (like potato tubers). Being insoluble means it doesn't affect the cell's water balance (osmosis) (p. 4-5).
- **To Build Other Molecules:**
    - **Cellulose:** Glucose molecules are chained together to form cellulose, which builds strong cell walls (p. 6).
    - **Proteins:** By combining sugars with nitrate ions from the soil, plants can make amino acids, the building blocks of proteins (p. 8).
    - **Nectar:** In flowers, sugars like glucose, fructose, and sucrose are used to produce nectar to attract pollinating insects (p. 7).

Mineral Requirements (p. 8)

Plants can't build all the molecules they need from just CO_2 and water. They also need mineral ions absorbed from the soil by their roots.

- **Nitrate ions (NO_3^-):** These are essential for making **amino acids**, which are then joined together to form **proteins**. Proteins are vital for making enzymes and cytoplasm (p. 8). A nitrate deficiency leads to stunted growth and pale leaves (p. 8).
- **Magnesium ions (Mg^{2+}):** These are a central component of the **chlorophyll** molecule. Without magnesium, the plant cannot make chlorophyll, which is needed to absorb light for

photosynthesis (p. 8). A magnesium deficiency causes **chlorosis**, where the leaves turn yellow (p. 8).

Limiting Factors (p. 23-24)

The rate of photosynthesis depends on several external factors. A **limiting factor** is the one in shortest supply that prevents the rate from increasing, even if other factors are optimal.

- **Light Intensity:** As light intensity increases, the rate of photosynthesis increases, but only up to a certain point. After this 'saturation point', another factor (like CO_2 concentration or temperature) becomes limiting (p. 23).
- **Carbon Dioxide Concentration:** Similar to light, increasing CO_2 concentration boosts the rate of photosynthesis until another factor limits it (p. 24). Artificially increasing CO_2 in glasshouses can increase crop yields (p. 24).
- **Temperature:** Photosynthesis is controlled by enzymes, which have an optimal temperature. As temperature increases, the rate increases up to this optimum. Beyond the optimum, enzymes denature and the rate drops sharply. At very low temperatures, the rate is very slow (p. 23).

Leaf Structure and Adaptations for Photosynthesis (p. 35-43)

The leaf is highly adapted to be an efficient photosynthetic organ.

Feature	Adaptation	Function
Broad, flat shape	Large surface area, thin structure.	Maximises light absorption; provides a short diffusion distance for CO_2 (p. 36).
Cuticle	Waxy, transparent outer layer.	Reduces water loss by evaporation; allows sunlight to pass through to the mesophyll (p. 37).
Upper Epidermis	Single layer of thin, transparent cells.	Protects the leaf; allows light to penetrate to the palisade layer (p. 45).
Palisade Mesophyll	Tightly packed, column-shaped cells near the top, full of chloroplasts.	Main site of photosynthesis, positioned to receive maximum sunlight (p. 42, 45).
Spongy Mesophyll	Loosely packed, irregularly shaped cells with large air spaces.	Allows for easy diffusion of gases (CO_2, O_2, water vapour) to and from all photosynthesising cells (p. 42, 45).

Feature	Adaptation	Function
Vascular Bundles (Veins)	Contain xylem and phloem tubes.	**Xylem:** transports water and minerals to the leaf cells. **Phloem:** transports sugars away from the leaf (translocation) (p. 42-43).
Stomata & Guard Cells	Pores on the leaf surface, controlled by pairs of guard cells.	Allow CO_2 to diffuse in and O_2 to diffuse out; control water loss (transpiration) (p. 37, 39).

5) Diagrams and micrographs (figures)

- **Figure 6.2 Photosynthesis in a leaf (p. 6):** Shows a whole plant, a cross-section of a leaf, and a single palisade cell to illustrate the pathway of water (from roots via stem), CO_2 (from air via stoma), and sunlight into a chloroplast where sugar is made.
- **Figure 6.3 Fates of glucose (p. 7):** A flowchart showing that glucose (made from CO_2 and water) can be converted into sucrose, starch, or cellulose, or used in respiration.
- **Figure 6.13 Limiting factors graphs (p. 25):**
  - **(a)** Shows the rate of photosynthesis increasing with light intensity until it plateaus. At the plateau, light is no longer the limiting factor.
  - **(b)** Shows that at a higher temperature (e.g., 25°C), the plateau occurs at a higher rate and higher light intensity compared to a lower temperature (15°C), proving temperature can be a limiting factor.
- **Figure 6.20 Leaf structure (p. 36):** A detailed diagram showing the arrangement of cells in a leaf blade.
  - **Labels:** Cuticle, upper epidermis, palisade mesophyll, spongy mesophyll, lower epidermis, air space, stoma, guard cell, xylem vessel, phloem sieve tube. Each label points to the respective tissue or cell layer, showing their relative positions.
- **Figure 6.23 Stoma (p. 40):** A diagram comparing an open and a closed stoma.
  - **Open stoma:** Guard cells are turgid (swollen with water) and curved, creating a pore.
  - **Closed stoma:** Guard cells are flaccid (have lost water) and less curved, closing the pore.

6) Processes and cycles

Photosynthesis

1. **Inputs:** Carbon dioxide (CO_2) diffuses from the air into the leaf through the stomata. Water (H_2O) is absorbed by the roots and transported to the leaf via the xylem. Light energy is absorbed by chlorophyll in the chloroplasts.
2. **Energy Conversion:** Chlorophyll converts light energy into chemical energy. This energy is used to split water molecules into hydrogen and oxygen (p. 4).
3. **Synthesis:** The hydrogen atoms are combined with carbon dioxide to form glucose ($C_6H_{12}O_6$) (p. 4). This is a complex series of enzyme-controlled reactions.
4. **Outputs:** Glucose is used by the plant. Oxygen (O_2) is released from the leaf into the atmosphere as a waste product (p. 4).

- **Word Equation:**
  carbon dioxide + water $\xrightarrow[\text{chlorophyll}]{\text{light energy}}$ glucose + oxygen (p. 3)
- **Balanced Chemical Equation:**
  $6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light energy}} C_6H_{12}O_6 + 6O_2$ (p. 3)

Testing a Leaf for Starch

This test is used as evidence that photosynthesis has occurred.

1. **Destarch the plant:** Place the plant in complete darkness for 48 hours. This ensures any existing starch is used up or transported away (p. 12).
2. **Kill the leaf:** Dip the leaf in boiling water for about 30 seconds. This stops all chemical reactions by denaturing enzymes (p. 13).
3. **Remove chlorophyll:** Place the leaf in a test tube with ethanol (alcohol) and stand the tube in the hot water bath. The ethanol will boil and dissolve the chlorophyll, turning the leaf pale (p. 14).
   Safety: Turn off the Bunsen burner before using flammable ethanol.
4. **Soften the leaf:** Dip the now brittle leaf back into the hot water briefly to soften it (p. 14).
5. **Add iodine:** Spread the leaf flat on a white tile and add a few drops of iodine solution (p. 14).
6. **Observe:** If starch is present, the iodine will turn from yellow-brown to **blue-black**. If no starch is present, it remains yellow-brown (p. 14).

7) Formulae and calculations

Quantity	Formula / Method	Units	Worked example (from p. 30)
Mean rate of reaction	Mean = (Sum of values) / (Number of values)	bubbles min^{-1}	At 10 cm, the readings are 38, 40, 39. Mean = (38 + 40 + 39) / 3 = 39 bubbles min^{-1} (p. 30).
Identifying an anomaly	A result that does not fit the pattern of the others.	N/A	In the data for 20 cm (15, 17, 26), the value 26 is much higher and is an anomaly. It should be excluded when calculating the mean (p. 30).
Calculating mean with anomaly	Exclude the anomalous result from the calculation.	bubbles min^{-1}	For 20 cm, use only 15 and 17. Mean = (15 + 17) / 2 = 16 bubbles min^{-1} (p. 30).
Light intensity (from distance)	Light Intensity $\propto$ 1 / $(\text{distance})^2$ *(This specific formula is not in the text but is standard for IGCSE)*	arbitrary units	If the lamp is moved from 10 cm to 20 cm (doubling the distance), the light intensity drops to $(1/2)^2$ = 1/4 of its original value.

8) Required practicals / experiments

Investigation 1: To show chlorophyll is necessary for photosynthesis (p. 14)

- **Aim:** To prove that starch is only made in the parts of a leaf that contain chlorophyll.
- **Apparatus:** A variegated plant (e.g., geranium), apparatus for starch test.
- **Method:**
  i. Destarch the plant for 48 hours.
  ii. Expose the plant to bright light for several hours.
  iii. Remove a variegated leaf and draw a diagram showing the green and white areas.
  iv. Test the leaf for starch using the standard procedure.
- **Variables:**
  - **IV:** Presence/absence of chlorophyll.
  - **DV:** Presence/absence of starch (indicated by iodine).

    - **Controls:** The green part of the leaf acts as a control for the white (experimental) part. Both parts receive the same light, CO_2, and water.
- **Expected Results:** The areas that were green turn blue-black. The areas that were white stain yellow-brown (p. 14).

Investigation 2: To show light is necessary for photosynthesis (p. 15)

- **Aim:** To prove that light is required for a leaf to produce starch.
- **Apparatus:** A healthy potted plant, black card or aluminium foil, paper clips, apparatus for starch test.
- **Method:**
    i. Destarch the plant.
    ii. Cover part of a leaf with a stencil made of black card, ensuring no light can get through to that section.
    iii. Place the plant in bright light for 4-6 hours.
    iv. Remove the leaf and the cover, then test the entire leaf for starch.
- **Variables:**
    - **IV:** Presence/absence of light.
    - **DV:** Presence/absence of starch.
    - **Controls:** The uncovered part of the leaf acts as the control.
- **Expected Results:** The part of the leaf exposed to light turns blue-black. The part covered by the stencil remains yellow-brown (p. 16).

Investigation 3: To investigate the effect of light intensity on the rate of photosynthesis (p. 27-28)

- **Aim:** To measure how changing light intensity affects the rate of oxygen production by a pond plant.
- **Apparatus:** Canadian pondweed (e.g., *Elodea*), beaker, water with sodium hydrogencarbonate (to provide CO_2), lamp, ruler, stopwatch.
- **Method:**
    i. Place a piece of pondweed (cut stem upwards) in a beaker of water containing sodium hydrogencarbonate.
    ii. Place a lamp 10 cm from the beaker.
    iii. Allow the plant to adjust for a few minutes, then count the number of oxygen bubbles produced in one minute. Repeat twice more and calculate a mean.
    iv. Move the lamp to 20 cm, 30 cm, 40 cm, etc., and repeat the counts at each distance.
- **Variables:**
    - **IV:** Light intensity (changed by varying the distance of the lamp).

    - **DV:** Rate of photosynthesis (measured by bubbles of oxygen produced per minute).
    - **Controls:** CO_2 concentration (kept constant by sodium hydrogencarbonate), temperature.
- **Safety:** Handle mains electricity lamp with dry hands.
- **Sources of Error:** Bubbles may be different sizes; counting fast bubbles is difficult; heat from the lamp can affect the rate.
- **Improvements:** Collect the gas in a measuring cylinder to measure volume instead of counting bubbles; place a heat shield (beaker of water) between the lamp and the plant.
- **Expected Results:** As the distance of the lamp increases, light intensity decreases, and the rate of bubbling decreases (p. 29). A graph of rate vs. $1/d^2$ should show an initial increase followed by a plateau.

9) Data handling and graphing

- **Tables:** Used to record results from experiments, often with repeat readings to calculate a mean (p. 30). You must be able to calculate the mean and identify/exclude anomalous results before plotting.
- **Line Graphs:** These are used to show the relationship between a continuous independent variable (e.g., light intensity, temperature, CO_2 concentration) and a continuous dependent variable (rate of photosynthesis).
    - **Axes:** The independent variable (what you change, e.g., light intensity) goes on the x-axis. The dependent variable (what you measure, e.g., rate of photosynthesis) goes on the y-axis.
    - **Trends:** For limiting factor graphs (Figure 6.13, p. 25), look for two key parts:
        a. **A rising section:** Where the factor on the x-axis is the limiting factor. The line slopes upwards.
        b. **A plateau (flat section):** Where the factor on the x-axis is no longer limiting; something else is. The line is horizontal.
- **Exam Prompts:**
    - "Calculate the mean..."
    - "Plot a graph of these results..."
    - "Describe the trend shown in the graph..." (state the relationship between the variables).
    - "Explain the shape of the graph..." (use your knowledge of limiting factors).
    - "Identify the limiting factor at point X..."

10) Common misconceptions and exam tips

- **Misconception:** Plants only respire at night.
  - **Correct Understanding:** Plants respire **24 hours a day** to release energy for life processes. During the day, the rate of photosynthesis is usually much higher than respiration, so there is a net intake of CO_2 and output of O_2 (p. 20).
  - **Quick Tip:** Respiration = Always on. Photosynthesis = Only in light.
- **Misconception:** A plant's "food" comes from the soil.
  - **Correct Understanding:** Plants get water and mineral ions from the soil, but their food (glucose) is made in the leaves using CO_2 from the air (p. 2). The mass of a plant comes mostly from the air, not the soil.
  - **Quick Tip:** Soil provides the 'vitamins' (minerals), but the air provides the 'calories' (carbon for glucose).
- **Misconception:** Photosynthesis is the reverse of aerobic respiration.
  - **Correct Understanding:** While the overall equations look opposite, they are completely different metabolic pathways, using different enzymes and occurring in different organelles (chloroplasts vs. mitochondria).
  - **Quick Tip:** Think of them as two different factories: one builds sugar (photosynthesis), the other breaks it down (respiration).
- **Exam Tip:** When asked about leaf adaptations, link **structure to function**. Don't just list the parts. For example, "The palisade cells are packed with chloroplasts (structure) in order to maximise light absorption for photosynthesis (function)."

11) Exam-style practice

Multiple Choice Questions (MCQs)

1. What is the correct balanced chemical equation for photosynthesis?
   A) $C\_6H\_12O\_6 + 6O\_2$
   $rightarrow 6CO\_2 + 6H\_2O$
   B) $6CO\_2 + 6H\_2O$
   $rightarrow C\_6H\_12O\_6 + 6O\_2$
   C) $CO\_2 + H\_2O$
   $rightarrow C\_6H\_12O\_6 + O\_2$
   D) $6O\_2 + 6H\_2O$
   $rightarrow C\_6H\_12O\_6 + 6CO\_2$

> **Answer: B.** This is the correct balanced equation with 6 molecules of carbon dioxide and water producing one molecule of glucose and 6 molecules of oxygen (p. 3).

2. A plant is deficient in magnesium ions. Which symptom is it most likely to show?
   A) Stunted growth
   B) Wilting
   C) Yellowing leaves (chlorosis)
   D) Poor fruit development
   > **Answer: C.** Magnesium is needed to make chlorophyll. Without it, the leaves cannot become green and appear yellow (p. 8).

3. In an experiment to investigate the effect of a factor on photosynthesis, why is the plant destarched first?
   A) To remove the chlorophyll from the leaves.
   B) To ensure that any starch detected at the end was made during the experiment.
   C) To make the leaves more permeable to iodine.
   D) To increase the rate of photosynthesis.
   > **Answer: B.** Destarching ensures there is no starch in the leaf at the start, so its presence at the end is valid proof of photosynthesis (p. 12).

4. Which part of the leaf has the primary function of gas exchange?
   A) Palisade mesophyll
   B) Xylem
   C) Cuticle
   D) Stomata
   > **Answer: D.** Stomata are the pores that open and close to allow gases like CO_2 and O_2 to move in and out of the leaf (p. 37).

5. A graph shows the rate of photosynthesis plotted against light intensity. The line becomes horizontal at high light intensities. What is the best explanation for this?
   A) All the chlorophyll has been destroyed.
   B) The temperature has become too high.
   C) Another factor, such as CO_2 concentration, has become limiting.
   D) The plant has run out of water.
   > **Answer: C.** When the graph plateaus, it means increasing the factor on the x-axis (light) has no further effect because another factor is in short supply and is now limiting the rate (p. 23).

6. How is glucose from the leaves transported to the roots?
   A) As starch in the xylem
   B) As sucrose in the phloem

C) As glucose in the xylem
D) As starch in the phloem

> **Answer: B.** Glucose is converted to sucrose for transport in the phloem sieve tubes (p. 5).

7. What is the function of the waxy cuticle on a leaf?
A) To absorb water
B) To reduce water loss
C) To perform photosynthesis
D) To transport sugars

> **Answer: B.** The waxy layer is waterproof and reduces evaporation from the leaf surface (p. 37).

8. Nitrate ions are essential for plants to produce which biological molecule?
A) Starch
B) Cellulose
C) Proteins
D) Fats

> **Answer: C.** Nitrates provide the nitrogen needed to make amino acids, which are the monomers of proteins (p. 8).

9. Which cells in the leaf contain the most chloroplasts?
A) Upper epidermal cells
B) Guard cells
C) Spongy mesophyll cells
D) Palisade mesophyll cells

> **Answer: D.** Palisade cells are located at the top of the leaf to receive maximum sunlight and are packed with chloroplasts to be the main site of photosynthesis (p. 43).

10. In an experiment using pondweed and a lamp, how is the rate of photosynthesis measured?
A) By the change in colour of the leaves
B) By the increase in mass of the pondweed
C) By counting the bubbles of gas produced per minute
D) By measuring the amount of water absorbed

> **Answer: C.** The gas produced is oxygen, a product of photosynthesis, so the rate of bubbling is a proxy for the rate of reaction (p. 28).

Short-Answer Questions

1. **State two ways a plant uses the glucose it produces during photosynthesis.**

> - Used in respiration to release energy (1).

> - Converted to starch for storage (1).
> - *(Also correct: Converted to sucrose for transport; used to make cellulose for cell walls)* (p. 4-7).

2. **Explain why a leaf tested for starch is first placed in boiling water and then in hot ethanol.**

   > - **Boiling water:** To kill the leaf and denature enzymes, stopping any further chemical reactions (1).
   > - **Hot ethanol:** To remove the chlorophyll (which is soluble in ethanol) so that the colour change of the iodine can be seen (1) (p. 13-14).

3. **A farmer grows tomatoes in a glasshouse. Suggest two ways they could increase the rate of photosynthesis to improve their crop yield.**

   > - Increase the carbon dioxide concentration in the air (e.g., using a CO_2 generator) (1).
   > - Increase the light intensity (e.g., using artificial lights, especially in winter) or increase the temperature (e.g., using heaters) (1) (p. 24).

4. **Describe the function of the palisade mesophyll and the spongy mesophyll in a leaf.**

   > - **Palisade mesophyll:** Main site of photosynthesis due to its cells being packed with chloroplasts and positioned near the top of the leaf for maximum light absorption (1).
   > - **Spongy mesophyll:** Contains air spaces that allow for efficient diffusion of gases (CO_2 and O_2) to and from the palisade cells (1) (p. 42).

5. **Explain the term 'limiting factor' in the context of photosynthesis.**

   > A limiting factor is a factor (such as light, CO_2 or temperature) which is in the shortest supply (1) and therefore restricts or 'limits' the rate of photosynthesis, even if the other factors are at their optimum level (1) (p. 23).

Structured Questions

1. A student investigated the effect of carbon dioxide concentration on the rate of photosynthesis in pondweed.
(a) **State** the balanced chemical equation for photosynthesis. [2]
(b) The student measured the rate of photosynthesis by counting bubbles. **Suggest** one source of inaccuracy with this method and **suggest** an improvement. [2]
(c) **Describe and explain** what would happen to the rate of photosynthesis if the light intensity was significantly decreased during the experiment. [3]

> **Marking Points:**
> (a) $6CO\_2 + 6H\_2O$
> $rightarrowC\_6H\_12O\_6 + 6O\_2$ (1 for correct formulae, 1 for correct balancing) (p. 3).

> (b) **Inaccuracy:** Bubbles can be of different sizes, so counting them is not an accurate measure of volume (1). **Improvement:** Collect the gas produced in an inverted measuring cylinder over a set time period and measure its volume (1).
> (c) **Description:** The rate of photosynthesis would decrease (1). **Explanation:** Light provides the energy for photosynthesis (1). If light intensity is decreased, it would become the limiting factor, slowing down the overall rate even if CO_2 concentration is high (1) (p. 23).

2. The diagram shows a cross-section of a plant leaf.
(a) **Identify** the layers/cells labelled A (palisade mesophyll) and B (stoma). [2]
(b) **Explain** three ways in which the structure of the leaf is adapted for efficient photosynthesis. [3]
(c) **Describe** the role of the guard cells in controlling gas exchange. [3]

> **Marking Points:**
> (a) A = Palisade mesophyll (1); B = Stoma/Stomatal pore (1).
> (b) **Any three from:**
>
> - **Broad/Flat shape** for a large surface area to absorb sunlight (1).
> - **Thin** for a short diffusion path for carbon dioxide to reach the palisade cells (1).
> - **Palisade cells** are near the top and packed with chloroplasts to maximise light absorption (1).
> - **Air spaces** in the spongy mesophyll allow for easy diffusion of gases (1).
> - **Stomata** allow CO_2 to enter the leaf from the atmosphere (1) (p. 36, 42-45).
>   (c) In the light, guard cells take up water by osmosis and become turgid (1). Their unevenly thickened walls cause them to curve outwards, opening the stoma (1). This allows CO_2 to diffuse into the leaf for photosynthesis. In the dark, they lose water, become flaccid, and the stoma closes (1) (p. 39).

12) Quick revision checklist

- [ ] I can state the word equation for photosynthesis: carbon dioxide + water → glucose + oxygen.
- [ ] I can state the balanced chemical equation: $6CO\_2 + 6H\_2O$ $rightarrowC\_6H\_12O\_6 + 6O\_2$.
- [ ] I know that chlorophyll absorbs light energy and converts it to chemical energy.
- [ ] I can list the four main uses of glucose: respiration, storage as starch, transport as sucrose, and making cellulose.
- [ ] I know that nitrates are needed for making proteins and magnesium is needed for making chlorophyll.

- [ ] I can identify the main tissues in a leaf cross-section (cuticle, epidermis, palisade/spongy mesophyll, vascular bundle).
- [ ] I can link the structure of each leaf tissue to its function in photosynthesis.
- [ ] I can explain how guard cells open and close the stomata.
- [ ] I understand that light intensity, CO_2 concentration, and temperature can be limiting factors for photosynthesis.
- [ ] I can interpret graphs showing the effects of limiting factors.
- [ ] I can describe the method for testing a leaf for starch, including the reasons for each step.
- [ ] I can explain how to set up a controlled experiment to show the need for light, CO_2, or chlorophyll.

13) Flashcards (ready-to-use)

Question	Answer
What is photosynthesis?	The process where plants use light energy to make carbohydrates (glucose) from carbon dioxide and water. (p. 1)
What is the word equation for photosynthesis?	carbon dioxide + water $xrightarrowtextlight/chlorophyll$ glucose + oxygen (p. 3)
What is the function of chlorophyll?	To absorb light energy and convert it into chemical energy. (p. 2)
Why do plants need nitrate ions?	To make amino acids, which are used to build proteins. (p. 8)
Why do plants need magnesium ions?	To make chlorophyll. A lack of magnesium causes yellow leaves (chlorosis). (p. 8)
How do plants store excess glucose?	They convert it into insoluble starch. (p. 4)
How do plants transport sugar from leaves?	They convert glucose to sucrose, which is transported in the phloem. (p. 5)
Name the main photosynthetic tissue in a leaf.	The palisade mesophyll. (p. 42)

Question	Answer
What is the function of the leaf's spongy mesophyll layer?	The air spaces allow for easy diffusion of CO_2 to the photosynthesising cells. (p. 42)
What is a stoma?	A pore in the leaf epidermis that allows for gas exchange. (p. 37)
How do guard cells open the stoma?	They take in water, become turgid and curve outwards. (p. 39)
What is a limiting factor?	A factor in short supply (e.g., light) that restricts the rate of photosynthesis. (p. 23)
What are the three main limiting factors for photosynthesis?	Light intensity, carbon dioxide concentration, and temperature. (p. 23-24)
What is the test for starch?	Add iodine solution. A blue-black colour indicates starch is present. (p. 14)
Why is a leaf boiled in ethanol before testing for starch?	To remove the green chlorophyll, which would hide the iodine colour change. (p. 14)
What is the role of the xylem in a leaf?	To transport water and minerals to the leaf cells. (p. 42)
What is translocation?	The transport of sugars (as sucrose) in the phloem. (p. 43)

14) 60-second recap

Plant nutrition is all about photosynthesis, the process of converting carbon dioxide and water into glucose and oxygen using light energy trapped by chlorophyll. The balanced equation is $6CO\_2 + 6H\_2O rightarrowC\_6H\_12O\_6 + 6O\_2$. This glucose is vital: it's used for respiration, stored as starch, transported as sucrose, or built into cellulose. The leaf is perfectly adapted for this, with a large surface area, palisade cells packed with chloroplasts, and stomata for gas exchange. However, the rate of photosynthesis can be held back by limiting factors: a shortage of light, carbon dioxide, or a non-optimal temperature. Plants also need minerals from the soil, especially nitrates for proteins and magnesium for chlorophyll.

15) References to pages

- **Photosynthesis (process & equation):** 1, 2, 3, 4
- **Use of glucose (starch, sucrose, etc.):** 4, 5, 6, 7
- **Mineral requirements (nitrates, magnesium):** 8
- **Limiting factors (light, CO_2, temp):** 23, 24, 25
- **Leaf structure and adaptations:** 35, 36, 37, 39, 41, 42, 43, 45
- **Starch test procedure:** 12, 13, 14
- **Experiments (necessity of light, CO_2, chlorophyll):** 14, 15, 16, 17
- **Experiments (rate of photosynthesis):** 27, 28, 29, 30, 31, 33, 34
- **Gas exchange (stomata, mesophyll):** 20, 37, 39, 42

16) Excluded "Going further" sections (not summarized)

Section title	**Pages**
Sources of mineral elements and effects of their deficiency	p. 8
Total excluded:	**1**