Cambridge IGCSE · Biology 0610 · Notes

Plant nutrition

Read online at **pastopic.com/cambridge/biology-0610/notes/plant-nutrition**

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Read first: **Movement into and out of cells**, **Enzymes**

What you need to know

Plant nutrition is one of the most tested topics in IGCSE Biology: it appears on every paper, as one-mark multiple-choice questions and as whole structured questions about a leaf or an experiment. The parts marked **Extended only** are tested on Papers 2 and 4 only. By the end of this topic you should be able to:

1. **Describe photosynthesis**: the process in which plants make (synthesise) carbohydrates from raw materials, using energy from light.
2. **State the word equation**: carbon dioxide + water → glucose + oxygen, in the presence of light and chlorophyll.
3. **State that chlorophyll** is a green pigment found in chloroplasts.
4. **State what chlorophyll does**: it transfers energy from light into energy in chemicals, which is used to make carbohydrates.
5. **Outline what happens to the carbohydrates made**: starch as an energy store, cellulose to build cell walls, glucose used in respiration to release energy, sucrose transported in the phloem, and nectar to attract insects for pollination.
6. **Explain why plants need** nitrate ions (to make amino acids) and magnesium ions (to make chlorophyll).
7. **Investigate the need for chlorophyll, light and carbon dioxide** for photosynthesis, with suitable controls.
8. **Investigate and describe** how light intensity, carbon dioxide concentration and temperature affect the rate of photosynthesis.
9. **Investigate and describe** how light and dark affect gas exchange in an aquatic plant, using hydrogencarbonate indicator solution.
10. **State that most leaves are thin and have a large surface area**, and explain why these help photosynthesis.
11. **Identify the parts of a leaf** of a dicotyledonous plant in diagrams and photographs: chloroplasts, cuticle, guard cells and stomata, upper and lower epidermis, palisade mesophyll, spongy mesophyll, air spaces, vascular bundles, xylem and phloem.
12. **Explain how each of those parts** helps the leaf to photosynthesise.
13. **Extended only:** state the balanced chemical equation: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.
14. **Extended only:** identify and explain the limiting factors of photosynthesis in different conditions.

Understand it

What photosynthesis is

Animals must eat food. Plants make their own. **Photosynthesis** is the process in which a plant uses **energy from light** to build **carbohydrates** (first glucose) from two simple raw materials: **carbon dioxide** from the air and **water** from the soil. Oxygen is made as a waste product.

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$$

- **Carbon dioxide** enters the leaf from the air by **diffusion**, through the stomata.
- **Water** is absorbed from the soil by root hair cells and carried up to the leaf in the **xylem**.
- **Glucose** stays in the plant and is used or turned into other substances (see below).
- **Oxygen** is not needed for photosynthesis. Some is used in the plant's own respiration; the rest **diffuses out of the leaf through the stomata**.

Extended only. The balanced chemical equation is

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

Count the atoms to check it: both sides have 6 carbon, 12 hydrogen and 18 oxygen atoms. So **six** molecules of carbon dioxide make **one** molecule of glucose, and six molecules of oxygen are released.

Chlorophyll and chloroplasts

Photosynthesis happens inside **chloroplasts**, small structures in the cytoplasm of green plant cells. Chloroplasts contain **chlorophyll**, a **green pigment**. Chlorophyll **absorbs (traps) light**, and **transfers energy from light into energy in chemicals**: the energy ends up stored in the glucose made. Without chlorophyll there is no photosynthesis, which is why the white parts of a variegated (green-and-white) leaf make no starch.

Keep the three words apart: the **chloroplast** is the structure (where), **chlorophyll** is the pigment inside it (what traps light), and **photosynthesis** is the process.

What the plant does with the carbohydrate

Glucose is the first carbohydrate made, and the plant turns it into what it needs:

Carbohydrate	Use in the plant
Glucose	used in **respiration** to release energy
Starch	the **energy store** (made from glucose; insoluble, so it stays where it is stored)
Cellulose	builds **cell walls**
Sucrose	the form **transported in the phloem** to other parts of the plant

Carbohydrate	Use in the plant
Nectar (a sugary liquid)	**attracts insects** for pollination

Glucose, together with nitrate ions, is also used to make amino acids and so proteins (next section). Because starch is made from the glucose of photosynthesis, **testing a leaf for starch** is the usual way of showing that it has photosynthesised.

Mineral ions: magnesium and nitrate

Plants take mineral ions from the **soil**, through their root hair cells. Two matter here:

- **Magnesium ions** are needed to **make chlorophyll**. A plant short of magnesium makes less chlorophyll, so its leaves turn **yellow** (often between the veins). With less chlorophyll it absorbs less light, photosynthesises less and grows less.
- **Nitrate ions** are needed to **make amino acids**, which are joined to make **proteins** (including enzymes) for growth. A plant short of nitrate grows poorly.

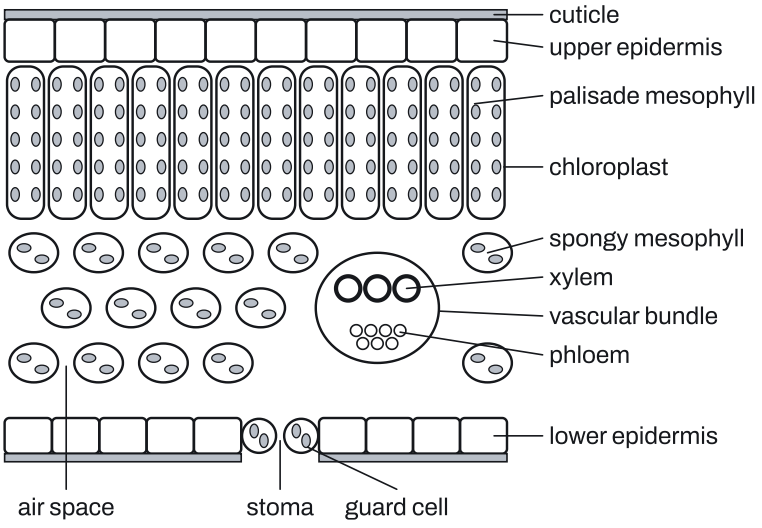
Magnesium makes chlorophyll, not chloroplasts, and not glucose. Nitrate makes amino acids and proteins, not carbohydrates.

Leaf structure

Most leaves are **thin** and have a **large surface area**.

- A **large surface area** absorbs **more light**, and has more stomata for carbon dioxide to diffuse in.
- A **thin** leaf means a **short diffusion distance** for carbon dioxide to reach every cell, and light reaches all the cells inside.

Inside, a leaf is built in layers:



Structure	What it is like	How it helps photosynthesis
Cuticle	thin waxy layer on the epidermis, not made of cells	waterproof, so it cuts water loss; transparent, so light passes through
Upper epidermis	one layer of thin cells with no chloroplasts	transparent, so light reaches the palisade layer; protects the leaf
Palisade mesophyll	tall cells, closely packed, near the upper surface, with **many chloroplasts**	absorbs most of the light: the **main site** of photosynthesis
Spongy mesophyll	rounded, irregular, **loosely packed** cells with fewer chloroplasts	the gaps between them are the air spaces; the cells also photosynthesise
Air spaces	gaps between the spongy cells, linked to the stomata	let carbon dioxide **diffuse** to the mesophyll cells (and oxygen out); give a large surface for gas exchange
Stomata	pores, mostly in the **lower** epidermis	let carbon dioxide in and oxygen (and water vapour) out
Guard cells	a pair of cells around each stoma; they have chloroplasts	change shape to **open and close** the stoma, controlling gas exchange and water loss
Vascular bundle	a vein: xylem and phloem together	brings in water, takes away sugar, supports the leaf
Xylem	tubes of dead cells, towards the upper side of the bundle	brings **water** (a raw material) and mineral ions to the leaf
Phloem	living cells, towards the lower side of the bundle	carries **sucrose** (and amino acids) away from the leaf
Chloroplasts	in palisade, spongy and guard cells, not in epidermal cells	contain chlorophyll, which absorbs light

The path of carbon dioxide into a leaf: air → **stoma** → **air spaces** → dissolves in the water on a mesophyll cell's surface → diffuses through the cell wall and membrane → **chloroplast**. It moves by **diffusion**, down its concentration gradient, because photosynthesis keeps using it up inside the leaf.

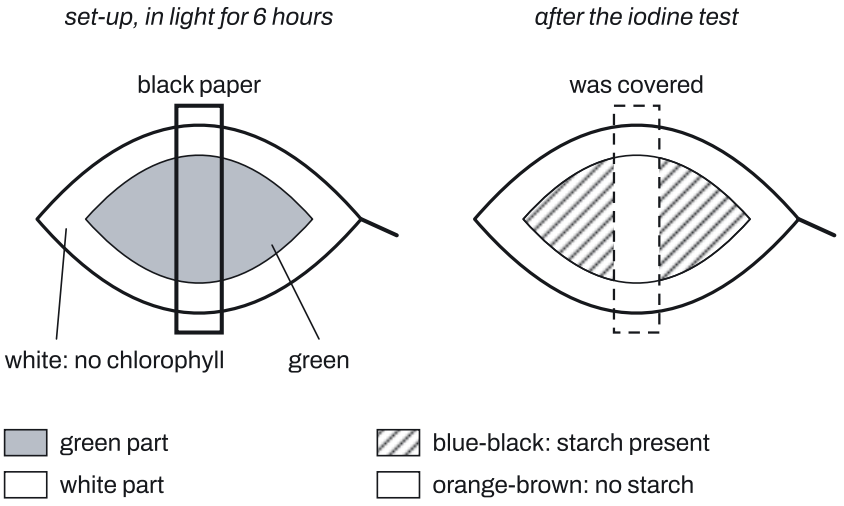
Showing what photosynthesis needs

Every one of these experiments uses the **starch test** on a leaf.

1. **Destarch the plant**: keep it in the dark for about 48 hours. With no light it can't photosynthesise, and it uses up its stored starch in respiration. Now any starch found later must have been made **during** the experiment.
2. Set up the experiment (below), then leave the plant in the light for several hours.
3. **Boil the leaf in water** for a minute: this kills the cells and breaks down their membranes, so iodine can get in.

4. **Put it in hot ethanol** (in a water-bath, because ethanol is flammable): this removes the **chlorophyll**, so the colour change is easy to see. The leaf goes white and brittle.
5. **Rinse in water** to soften it, spread it on a white tile and add **iodine solution**.
6. **Blue-black** = starch present (it photosynthesised). **Stays orange-brown (yellow-brown)** = no starch.

Needs	How to test it	The control
Chlorophyll	use a **variegated** leaf (green and white parts)	the green parts: only they turn blue-black
Light	cover part of a leaf with black paper or foil	the uncovered part: only it turns blue-black
Carbon dioxide	enclose a leaf or plant with **soda lime** or potassium hydroxide solution, which absorb carbon dioxide	an identical set-up without the absorber (or with water instead): only this leaf turns blue-black



Only the parts that had **chlorophyll**, **light** and **carbon dioxide** make starch.

Measuring the rate of photosynthesis

An aquatic plant such as pondweed gives off bubbles of **oxygen** from its cut stem as it photosynthesises. Count the bubbles per minute (or collect the gas and measure its volume): more bubbles per minute means a faster rate.

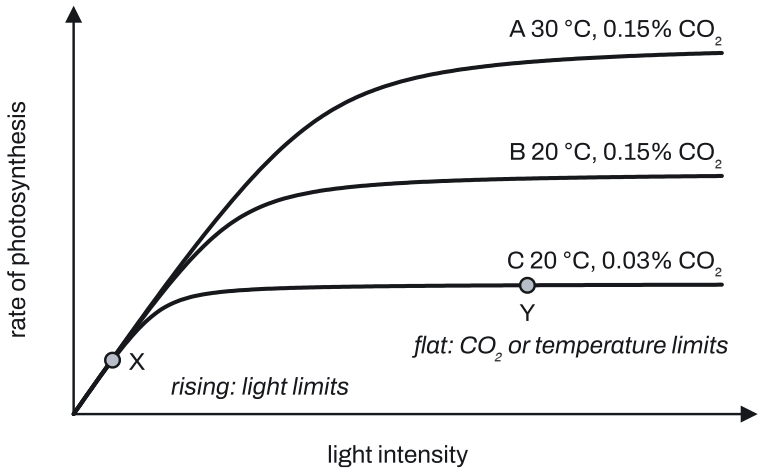
- **Light intensity**: move a lamp to different distances from the plant. The **closer** the lamp, the **brighter** the light, the more bubbles. Do it in a dark room so the lamp is the only light.
- **Carbon dioxide**: add different amounts of **sodium hydrogencarbonate** to the water; it releases carbon dioxide.
- **Temperature**: stand the tube in water-baths at different temperatures.
- **Keep the other factors the same**: the same plant (or the same length of the same species), the same lamp distance, the same temperature, the same carbon dioxide, the same time to adjust (leave it a few minutes at each new condition before counting), and repeat for a mean.

The usual results:

- **More light → faster**, but the rate levels off at high light intensity.
- **More carbon dioxide → faster**, and it too levels off.
- **Temperature**: photosynthesis is controlled by **enzymes**, so the rate rises to an **optimum** temperature and then falls as the enzymes are **denatured** (see Enzymes).

Limiting factors (Extended only)

A **limiting factor** is something in the environment in such short supply that it holds back the rate of a process. For photosynthesis the limiting factors are **light intensity**, **carbon dioxide concentration** and **temperature**. At any moment, the rate is set by whichever one is in shortest supply; increasing that one speeds photosynthesis up, and increasing the others does nothing.



How to read a graph like this:

- **Where a curve is rising**, the factor on the x-axis is limiting. At X, more light gives a faster rate, so **light intensity** is the limiting factor. All three curves share this rise, so extra carbon dioxide or warmth makes no difference there.
- **Where a curve is flat**, the x-axis factor is **no longer** limiting: more light does nothing. **Something else** is limiting, and you find it by comparing curves. Compare two curves that differ in **one** factor only: if raising that factor gives a higher plateau, it was limiting the lower curve. On this graph, C (0.03% carbon dioxide) levels off far below B (0.15%, same temperature), so at Y **carbon dioxide** is limiting.
- A flat line means the rate is **constant**, not that photosynthesis has stopped.
- Water and oxygen are **not** limiting factors in these questions.

Why temperature matters. The reactions of photosynthesis are catalysed by enzymes. Up to the optimum, a higher temperature gives the enzyme and substrate molecules more **kinetic energy**, so there are more frequent **effective collisions** and more enzyme–substrate complexes: the rate rises. Above the optimum the enzymes are **denatured** and the rate falls.

Glasshouses use this. A grower can remove limiting factors to get more photosynthesis, so more carbohydrate for growth and a higher **yield**: extra **carbon dioxide** (from gas cylinders or burning a fuel such as paraffin), extra **lighting** in dull weather or at night, and **heating** in cold weather. There is no point adding more of a factor that isn't limiting, and too much heat wastes money, can denature enzymes and makes plants lose water faster (they then close their stomata, cutting off carbon dioxide).

Gas exchange in light and dark

Plants **respire all the time**, day and night, releasing carbon dioxide. They **photosynthesise only in the light**, taking in carbon dioxide.

Condition	What happens	Net carbon dioxide
Bright light	photosynthesis faster than respiration	taken **in** (oxygen given out)
Dim light	both at the same rate	no net change
Dark	respiration only	given **out** (oxygen taken in)

Over 24 hours, photosynthesis rises from dawn, peaks around midday and is zero at night; respiration carries on at a steady rate all the time.

Hydrogencarbonate indicator solution shows the carbon dioxide concentration of the water around an aquatic plant or the air around a leaf. Carbon dioxide is acidic, so more carbon dioxide lowers the pH:

Carbon dioxide	More than in air	Same as air (start)	Less than in air
Colour	**yellow**	**red** (orange-red)	**purple** (magenta)

Put pondweed in tubes of red indicator and seal them:

- **In the light**: the plant photosynthesises faster than it respires, removes carbon dioxide, and the indicator turns **purple**.
- **In the dark** (tube wrapped in foil): only respiration, carbon dioxide rises, and the indicator turns **yellow**.
- **Control**: a tube with no plant stays **red**, showing the plant causes the change. Use the same volume of indicator, the same temperature and the same time.

A related set-up: a leaf in a sealed tube with a chemical that **absorbs carbon dioxide** and a drop of coloured liquid in a narrow tube leading out. **In the dark**, the leaf respires: it takes in oxygen, and the carbon dioxide it releases is absorbed, so the volume of gas falls and the drop moves **towards the leaf**. The movement is caused by **respiration**.

Key facts and formulas

There is no formula list in the IGCSE Biology exam. Everything below must be learnt.

Formula	Status
carbon dioxide + water → glucose + oxygen (light and chlorophyll above the arrow)	Learn it
Extended: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$	Learn it
Photosynthesis: plants make carbohydrates from raw materials using energy from light	Learn it
Chlorophyll: green pigment in chloroplasts; transfers energy from light into energy in chemicals	Learn it
Magnesium ions → chlorophyll; nitrate ions → amino acids → proteins	Learn it
Glucose → respiration; starch → store; cellulose → cell walls; sucrose → phloem transport; nectar → attract insects	Learn it
Iodine: blue-black = starch; orange-brown = no starch	Learn it
Hydrogencarbonate indicator: yellow = more CO_2, red = air level, purple = less CO_2	Learn it
Extended: limiting factors are light intensity, CO_2 concentration and temperature	Learn it
$\text{percentage change} = \frac{\text{new} - \text{original}}{\text{original}} \times 100$	Learn it
$\text{rate} = \frac{\text{number of bubbles}}{\text{time}}$	Learn it

How to do it

In the questions we have tagged for this topic (179 questions, 2021–2025, on Papers 1–4), the types came up this often. 35 of the 179 questions mix types, so the counts add up to more than 179.

Question type	Questions
Identify leaf tissues and cells (label, name, locate)	52
State raw materials, products, site and the role of chlorophyll	34
Magnesium and nitrate ions: uses and deficiency	27
Starch test on leaves (destarch, variegated leaf, cover, iodine)	24
Explain how leaf structure is adapted for photosynthesis	20
Write the photosynthesis equation (word or balanced symbol)	18

Question type	Questions
Identify limiting factors from graphs and data	18
Describe, explain and predict rate-investigation results	16
Gas exchange in light and dark (hydrogencarbonate indicator)	16
Uses of the carbohydrates made	13
Calculate from photosynthesis data	5
Glasshouse crop production	3

Most are one-mark multiple choice on Papers 1 and 2. On Papers 3 and 4 plant nutrition usually comes as a whole question built around a leaf diagram or a pondweed experiment.

1. Identify leaf tissues and cells (52 questions)

1. **Find the top of the leaf**: the cuticle and upper epidermis are on the side with the tall palisade cells.
2. **Work down the layers**: cuticle → upper epidermis → palisade mesophyll → spongy mesophyll (with the vascular bundle) → lower epidermis → cuticle.
3. **Recognise each cell by its shape**: palisade = tall, packed, full of chloroplasts; spongy = rounded with gaps; epidermis = flat, no chloroplasts; guard cells = a bean-shaped pair around a pore.
4. **In a vascular bundle**: xylem is the larger, thick-walled tubes (upper side); phloem is the smaller cells (lower side).

Variations you will meet:

- **"Which layer has the most chloroplasts?" or "does most photosynthesis?"** Palisade mesophyll.
- **"Which cells photosynthesise?"** Palisade, spongy **and guard cells**; not epidermal cells, and the cuticle isn't cells at all.
- **"Which cell controls gas exchange?"** or "the entry of carbon dioxide": the guard cell.
- **"Name the two tissues in a vascular bundle"**: xylem and phloem (2 marks, either order).
- **"How many guard cells?"** Count the pores and double it: two guard cells per stoma.
- **Surface view photographs**: the lower epidermis seen from below shows pairs of guard cells with pores between them among the jigsaw-shaped epidermal cells.
- **Draw a label line**: rule it so it ends exactly on the structure, with the name at the end.
- **Leaves of water plants** (Paper 4, from the Adaptive features topic): a very thin cuticle and stomata only on the upper surface, because the lower surface touches the water.

2. State raw materials, products, site and chlorophyll's role (34 questions)

1. **Raw materials**: carbon dioxide and water. **Products**: glucose and oxygen. **Energy source**: light.
2. **Site**: the **chloroplast**. **Pigment**: **chlorophyll**.

3. **Role of chlorophyll** (up to 4 marks): it is the green pigment in chloroplasts **(1)**; it absorbs (traps) light **(1)**; it transfers energy from light into energy in chemicals **(1)**; this energy is used to make carbohydrates such as glucose **(1)**.

Variations you will meet:

- **"Which process requires chlorophyll?"** Photosynthesis, which is plant **nutrition**.
- **"Which gas leaves through the stomata as a product?"** Oxygen. Carbon dioxide is taken in.
- **"In which process is oxygen a waste product?"** Photosynthesis.
- **"Which process produces carbon dioxide in plants?"** Respiration.
- **"Which processes transfer energy from light into chemicals?"** Photosynthesis only, not respiration.
- **Fill-in sentences** such as "carbon dioxide is a **raw** material"; "the lamp was kept at the same distance so the light **intensity** stayed the same".

3. Magnesium and nitrate ions (27 questions)

1. **Magnesium ions → chlorophyll.** Without them: less chlorophyll, **yellow leaves** (between the veins), less light absorbed, less photosynthesis.
2. **Nitrate ions → amino acids → proteins** (and so enzymes, growth).
3. Both come from the **soil** and are absorbed by **root hair cells**.

Variations you will meet:

- **"Explain why a plant needs nitrate"** (Paper 4, 2–3 marks): to make amino acids **(1)**, which are joined to make proteins **(1)**, needed for growth or to make enzymes **(1)**.
- **A graph of crop protein against nitrate fertiliser**: more nitrate, more protein, up to a point.
- **Linked chains** (Extended, harder): nitrate ions are taken up by active transport, which needs energy from respiration. If the soil is waterlogged (little oxygen) or the plant has little glucose, there is less aerobic respiration, less energy, less nitrate absorbed, fewer amino acids and less protein.
- **"Which substance contains magnesium?"** Chlorophyll (not cellulose or glucose).

4. Starch test on leaves (24 questions)

1. **Predict** which parts turn blue-black: only parts that had **chlorophyll** (green), **light** (uncovered) and **carbon dioxide**. Everything else stays orange-brown.
2. **Explain each step** of the method if asked: destarch in the dark (starch used up in respiration); boil (kill cells, let iodine in); hot ethanol (remove chlorophyll so the colour shows); iodine (tests for starch).
3. **Explain a result**: "The white part stayed orange-brown because it has no chlorophyll **(1)**, so it can't absorb light / photosynthesise **(1)**, so no glucose or starch was made **(1)**."

Variations you will meet:

- **Why iodine shows photosynthesis happened**: glucose made in photosynthesis is turned into starch, and iodine turns blue-black with starch.

- **A plant kept without carbon dioxide** (soda lime): every part stays orange-brown, even the green parts.
- **Two leaves, one covered and one not**: in multiple choice, find the part that had all three needs.
- **Carbohydrate elements** may be asked alongside: carbon, hydrogen and oxygen.

5. Explain leaf adaptations for photosynthesis (20 questions)

1. Name the **feature** and give its **reason** as a pair; each pair scores. "Thin, **so** carbon dioxide has a short distance to diffuse" beats "thin".
2. Use the table in "Understand it". The favourites:
   - **large surface area** → absorbs more light;
   - **thin** → short diffusion distance for gases; light reaches all cells;
   - **palisade**: near the top, closely packed, many chloroplasts → absorbs most light;
   - **spongy**: loosely packed, irregular cells, air spaces → carbon dioxide diffuses to the cells; large surface for gas exchange;
   - **stomata and guard cells** → open to let carbon dioxide in, close to reduce water loss;
   - **transparent cuticle and epidermis** → let light through;
   - **xylem** → brings water; **phloem** → takes sucrose away.

Variations you will meet:

- **"Describe the pathway of carbon dioxide into a leaf"** (Paper 4): diffuses through the stoma → air spaces → dissolves in the moisture on a mesophyll cell → diffuses into the cell and its chloroplasts.
- **"How is the palisade cell adapted?"** Many chloroplasts, tall shape, near the upper surface, packed tightly. Don't answer about the whole leaf when asked about one cell.
- **"Describe how guard cells adapt the leaf"**: they change shape, opening or closing the stoma, which lets carbon dioxide in for photosynthesis and controls water loss.
- **Statements about palisade and spongy layers** in multiple choice: both have chloroplasts; palisade cells are packed tightly; the spongy layer has air spaces and is near the stomata.

6. Write the photosynthesis equation (18 questions)

1. **Word equation** (Core, 2 marks): carbon dioxide + water **(1)** → glucose + oxygen **(1)**. "Light" and "chlorophyll" above the arrow are fine; don't put them on either side.
2. **Balanced symbol equation** (Extended, 2 marks): correct formulae CO_2, H_2O, $C_6H_{12}O_6$, O_2 **(1)**; balanced with 6, 6, 1, 6 **(1)**.

Variations you will meet:

- **"$C_6H_{12}O_6$ is one product; state the formula of the other"**: O_2.
- **Multiple choice**: check the numbers are 6, 6, 1, 6 and that oxygen (not water) is the product.
- **"How many carbon dioxide molecules make one glucose?"** Six.

7. Identify limiting factors (18 questions, Extended)

1. **On the rising part** of a curve: the factor on the x-axis is limiting.
2. **On the flat part**: something else is limiting. Look at the key: if a curve with more carbon dioxide levels off higher, carbon dioxide was limiting the lower one; if a warmer curve is higher, temperature was limiting.
3. **If nothing on the graph tells you**, name the other two factors (for a light graph: carbon dioxide concentration or temperature).

Variations you will meet:

- **"Describe and explain the shape of the lines"** (Paper 4, up to 6 marks): the rate increases as light intensity increases **(1)**, so light is limiting at first **(1)**; the line then levels off / becomes constant **(1)**, so light is no longer limiting **(1)**; name what is limiting on the plateau with the evidence from the other lines **(1)**; light provides the energy for photosynthesis **(1)**. Use the words **limiting factor**.
- **"State the term for something in short supply that restricts a process"**: limiting factor.
- **"Why was carbon dioxide supplied in excess?"** So it isn't a limiting factor, and only the factor being tested affects the rate.
- **Temperature graphs**: kinetic energy and collisions up to the optimum; enzymes denatured above it.
- **Multiple choice with graphs of all three factors**: pick the point on a rising part to say "X is limiting there".

8. Describe, explain and predict rate-investigation results (16 questions)

1. **Describe** (what happens): the trend **(1)**; any change in the trend, such as "each increase in distance gives a smaller decrease" or "levels off at 0.4" **(1)**; a data quote with numbers **and units (1)**.
2. **Explain** (why): the bubbles are **oxygen**, a product of photosynthesis **(1)**; light (or carbon dioxide) is needed for photosynthesis **(1)**; the greater the lamp distance, the lower the light intensity **(1)**; so less photosynthesis, fewer bubbles.
3. **Variables**: say what was changed, what was measured (bubbles per minute) and what was kept the same (lamp distance, temperature, carbon dioxide, plant, time).

Variations you will meet:

- **"Why is the oxygen collected less than the oxygen made?"** Some is used by the plant's own **respiration** (and some dissolves in the water).
- **"Why is carbon dioxide used in photosynthesis faster than the leaf takes it in?"** Respiration in the leaf's own cells releases carbon dioxide, which is used in photosynthesis too, so the uptake from the air is less than the total used.
- **Temperature data**: rises to an optimum, then falls because enzymes are denatured.
- **"Suggest a table of results"**: columns with the variable changed first, headings with units.
- **Predict a line** for a colder or lower carbon dioxide condition: same start, lower plateau.

9. Gas exchange in light and dark (16 questions)

1. **Recall the colours**: more carbon dioxide → **yellow**; air level → **red** (orange-red); less → **purple**.
2. **Decide which process wins**: light → photosynthesis faster than respiration → carbon dioxide falls → purple. Dark → respiration only → carbon dioxide rises → yellow.
3. **Tubes with animals** (a snail, maggots): animals only respire, so carbon dioxide rises, light or dark.

Variations you will meet:

- **Explain with pH** (Paper 4): carbon dioxide is acidic, so less carbon dioxide means a higher pH (purple), and more means a lower pH (yellow).
- **Dim light**: photosynthesis and respiration are equal, so the indicator stays red.
- **"Which tube has the least carbon dioxide after an hour?"** The one with a plant in the light and nothing else that respires.
- **Graphs over 24 hours**: photosynthesis is a hump in daylight only; respiration is steady all day and night.
- **An ink drop moving towards a leaf in the dark** with a carbon dioxide absorber: oxygen used in **respiration**.

10. Uses of the carbohydrates made (13 questions)

Glucose → **respiration**; starch → **energy store**; cellulose → **cell walls**; sucrose → **transport in the phloem**; nectar → **attract insects** for pollination.

Variations you will meet:

- **"Draw lines" matching substance to use**: draw exactly the number asked.
- **"Outline how the carbohydrates are used"** (Paper 4, up to 4 marks): give four different uses, each linked to its carbohydrate; glucose with nitrate ions to make amino acids is also accepted.
- **Trick rows** in multiple choice: "cellulose for energy storage" and "starch to build cell walls" are both wrong.

11. Calculate from photosynthesis data (5 questions)

1. **Pick the right two values** from the table, taking care with the order (which is the original).
2. **Percentage change** $= \dfrac{\text{new} - \text{original}}{\text{original}} \times 100$; a negative answer is a decrease, so write it as a positive "percentage decrease".
3. **Round** as asked (whole number, 2 or 3 significant figures). Show the working: there are marks for choosing the values and for the calculation even if the rounding goes wrong.

Variations you will meet:

- **Rate from a count**: 75 bubbles in 3 minutes is $75 \div 3 = 25$ bubbles per minute.
- **A difference read from a graph**: read both y-values carefully and subtract; give units.

- **Leaf area from squared paper**: count the squares the leaf covers; with 1 cm squares, 40 squares is 40 cm^2 (the unit is cm^2, not cm).

12. Glasshouse crop production (3 questions, Extended)

1. **Why add carbon dioxide (or light, or heat)?** It removes a **limiting factor (1)** → more photosynthesis **(1)** → more glucose, so more growth and a higher yield **(1)**.
2. **How to add carbon dioxide**: burn a fuel such as paraffin or gas, or release it from cylinders.
3. **Too much heat**: enzymes may be denatured; more water is lost by transpiration, so the plants may wilt or close their stomata, which lets in less carbon dioxide.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) State the word equation for photosynthesis. **[2]**

(b) State the name of the cell structure where photosynthesis happens, and of the pigment it contains. **[2]**

(c) Describe the role of this pigment in photosynthesis. **[3]**

(d) A plant is grown in soil with too few magnesium ions. Suggest and explain how its leaves look. **[2]**

(e) State two uses in the plant of the glucose made in photosynthesis. **[2]**

(f) **Extended:** Write the balanced chemical equation for photosynthesis, and state how many oxygen molecules are released when the plant makes 2 molecules of glucose. **[3]**

(a) carbon dioxide + water **B1** → glucose + oxygen **B1**.

(b) Chloroplast **B1**; chlorophyll **B1**.

(c) Chlorophyll absorbs light **B1**; it transfers energy from light into energy in chemicals **B1**; used to make glucose (carbohydrates) **B1**.

(d) Yellow leaves **B1**, because magnesium is needed to make chlorophyll, so less chlorophyll is made **B1**.

(e) Any two: used in respiration to release energy; turned into starch as an energy store; turned into cellulose for cell walls; turned into sucrose to be transported in the phloem; used to make nectar **B1 B1**.

(f) $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$: formulae **B1**, balancing **B1**. Each glucose comes with 6 oxygen molecules, so 2 glucose release $2 \times 6 = 12$ oxygen molecules **B1**.

Example 2

A student put a piece of pondweed in water and placed a lamp at different distances from it, in a dark room. At each distance she waited 2 minutes, then counted the bubbles given off.

Distance of lamp / cm	**10**	**20**	**30**	**40**	**50**
Bubbles per minute	48	30	18	11	7

(a) At 20 cm she counted 90 bubbles in 3 minutes. Show that this gives the value in the table. **[1]**

(b) Calculate the percentage decrease in the number of bubbles per minute when the lamp was moved from 20 cm to 40 cm. Give your answer as a whole number. **[3]**

(c) Describe and explain the results. **[4]**

(d) State two variables she should keep the same. **[2]**

(a) $90 \div 3 = 30$ bubbles per minute. **B1**

(b) Values chosen: 30 and 11 **M1**. $\frac{30 - 11}{30} \times 100 = 63.33\ldots$ **M1**. $= 63\%$ (whole number) **A1**.

(c) Any four:

- Describe: as the distance increases, the number of bubbles decreases **B1**; each 10 cm step gives a smaller decrease (18, then 12, 7, 4 fewer bubbles) **B1**; a data quote with units, such as 48 bubbles per minute at 10 cm and 7 bubbles per minute at 50 cm **B1**.
- Explain: the bubbles are oxygen, made in photosynthesis **B1**; the further away the lamp, the lower the light intensity **B1**; light provides the energy for photosynthesis, so less light means less photosynthesis **B1**.

(d) Any two: temperature of the water; carbon dioxide concentration (amount of hydrogencarbonate); the same piece or size of pondweed; the time for counting; the same lamp **B1 B1**.

Example 3

A plant with variegated leaves was kept in a dark cupboard for 48 hours. One leaf then had a strip of black paper clipped across it, and the plant was put in bright light for 6 hours. The leaf was then tested for starch.

(a) Explain why the plant was first kept in the dark. **[2]**

(b) Before adding iodine, the leaf was boiled in water and then placed in hot ethanol. Explain why it was put in ethanol. **[1]**

(c) Predict the colour, after adding iodine, of: the green part under the paper; the white part not under the paper; the green part not under the paper. Explain the result for the green part under the paper. **[5]**

(d) Pondweed was placed in two sealed tubes of red hydrogencarbonate indicator. Tube P was in the light and tube Q was covered in foil. Predict and explain the colour of each tube after 3 hours. **[4]**

(a) To remove (destarch) the starch already in the leaves **B1**: in the dark the starch is used up in respiration, so any starch found later was made during the experiment **B1**.

(b) To remove the chlorophyll, so the colour change with iodine can be seen **B1**.

(c) Green, covered: orange-brown **B1**. White, uncovered: orange-brown **B1**. Green, uncovered: blue-black **B1**. The covered part got no light **B1**, so it could not photosynthesise, so no glucose (and so no starch) was made **B1**. (The white part has no chlorophyll, which is why it makes no starch either.)

(d) P turns purple **B1**: in the light, photosynthesis is faster than respiration, so carbon dioxide is taken out of the water **B1**. Q turns yellow **B1**: in the dark there is only respiration, so carbon dioxide is added to the water **B1**.

Example 4

Extended. The rate of photosynthesis of a crop plant was measured at 20 °C at different light intensities, in two carbon dioxide concentrations.

Light intensity / arbitrary units	0	1	2	3	4	5	6
Rate at 0.04% CO_2 / arbitrary units	0	8	14	16	16	16	16
Rate at 0.10% CO_2 / arbitrary units	0	8	16	23	28	30	30

(a) State the limiting factor at a light intensity of 1 arbitrary unit. Explain how the data show this. **[2]**

(b) State the limiting factor at 0.04% carbon dioxide between light intensities 3 and 6. Explain how the data show this. **[2]**

(c) Calculate the percentage increase in the highest rate when the carbon dioxide concentration was raised from 0.04% to 0.10%. Give your answer to 2 significant figures. **[2]**

(d) A grower keeps the crop in a glasshouse at 0.10% carbon dioxide and light intensity 6. Suggest how the grower could increase the rate further, and explain why it would work. **[3]**

(a) Light intensity **B1**. Both rates are the same (8) at 1 unit, so extra carbon dioxide makes no difference there; only more light would increase the rate **B1**.

(b) Carbon dioxide concentration **B1**. More light gives no increase (the rate stays at 16), but with more carbon dioxide the rate is higher (30), so carbon dioxide was in short supply **B1**.

(c) $\dfrac{30 - 16}{16} \times 100 = 87.5$ **M1**; $= 88\%$ (2 s.f.) **A1**.

(d) Raise the temperature (towards the optimum) or raise the carbon dioxide concentration further **B1**: the rate has levelled off (30 at 5 and 6), so light is no longer limiting, and carbon dioxide or temperature must be **B1**; the table can't tell which, so either answer with its reason scores: more carbon dioxide supplies more raw material, while warmer means more kinetic energy and more effective collisions, so the enzyme-controlled reactions go faster **B1**. (Not too hot, or the enzymes are denatured.)

Common mistakes

- **Writing "chlorophyll" when asked for a cell structure**, or "chloroplast" when asked for a pigment. Chloroplast = structure; chlorophyll = pigment. Examiner reports mention this swap again and again.
- **Saying magnesium makes chloroplasts.** Magnesium ions are needed to make **chlorophyll**.
- **Not knowing magnesium at all.** Very few Core candidates remember it: learn "magnesium → chlorophyll, nitrate → amino acids".
- **Getting the equation back to front** or adding extra substances, such as oxygen as a raw material or light as a reactant. Light and chlorophyll go above the arrow only.
- **Saying carbon dioxide leaves the leaf** in daylight. In the light, carbon dioxide diffuses **in** and **oxygen** diffuses **out** through the stomata.
- **Saying chlorophyll turns light into chemicals** or "makes energy". Energy is never made: chlorophyll **transfers energy** from light into energy in chemicals.
- **Forgetting the hydrogencarbonate colours** or writing "hydrogencarbonate" without "indicator". Yellow = more carbon dioxide; purple = less.
- **Using one limiting factor for the whole graph.** On a light graph, light limits the rising part; carbon dioxide or temperature limits the plateau. Use the words "limiting factor" in the answer.
- **Saying photosynthesis "stops" where a graph levels off.** A flat line means the rate is constant.
- **Explaining temperature with transpiration or humidity** instead of enzymes. Temperature affects the rate of photosynthesis through the kinetic energy of molecules and, above the optimum, denatured enzymes.
- **Describing without data, or data without units.** "Describe the results" needs a figure with its units.
- **Mixing up leaf and cell adaptations.** If asked about the palisade cell, give features of the cell (many chloroplasts, tall, near the surface), not of the whole leaf.
- **Calling the cuticle a tissue** or saying it photosynthesises. It is a waxy layer, not cells.

How to get the marks

- **Name structures exactly**: "palisade mesophyll", "spongy mesophyll", "guard cell", "lower epidermis", "xylem", "phloem". "Mesophyll" alone, or "stoma" for a guard cell, is not enough.
- **Pair every feature with its reason** in adaptation answers: "air spaces, so carbon dioxide can diffuse to the mesophyll cells".
- **"State"** needs a word or short phrase. Don't add a second answer: a wrong extra answer can cancel a right one.

- **"Describe" a set of results**: the trend, any change in the trend, and at least one data quote with units. Don't explain unless asked.
- **"Explain" results**: link the factor to photosynthesis (light gives the energy; carbon dioxide is a raw material), say the bubbles are oxygen, and on Paper 4 use "limiting factor".
- **Calculations**: write the values you chose, the working, then round exactly as asked. Marks are given for each step.
- **Experiments**: name the control and say what it shows ("the tube with no plant shows the plant caused the colour change"); name variables to keep the same.
- **"Suggest"** means apply what you know to something new, such as a water plant or a glasshouse; any sensible biological reason scores.
- **Draw lines / tick boxes**: exactly as many as the question says.

Quick check

1. Name the two raw materials and the two products of photosynthesis.
2. Name the mineral ion a plant needs to make chlorophyll, and describe what the leaves look like when the plant is short of it.
3. Pondweed gave off 36 bubbles in 3 minutes. The lamp was moved closer and it then gave off 60 bubbles in 3 minutes. (a) Calculate the rate, in bubbles per minute, at each distance. (b) Calculate the percentage increase in rate, to the nearest whole number.
4. A sealed tube of red hydrogencarbonate indicator contains pondweed and is kept in the dark for 2 hours. Predict the final colour and explain it.
5. **Extended:** (a) How many carbon dioxide molecules are used to make 3 molecules of glucose? (b) A graph of the rate of photosynthesis against carbon dioxide concentration levels off at high carbon dioxide. Name two factors that could be limiting the rate there.

Answers

1. Raw materials: carbon dioxide and water. Products: glucose and oxygen.
2. Magnesium. The leaves turn yellow (between the veins), because less chlorophyll is made.
3. (a) $36 \div 3 = 12$ bubbles per minute, then $60 \div 3 = 20$ bubbles per minute. (b) $\frac{20 - 12}{12} \times 100 = 66.7$, so a 67% increase.
4. Yellow. In the dark there is no photosynthesis, only respiration, which releases carbon dioxide, so the carbon dioxide concentration rises.
5. (a) $3 \times 6 = 18$ molecules. (b) Light intensity and temperature.

Past questions to try

- **0610/32/O/N/23 Q2**: a starch test on a variegated leaf, with a no-carbon-dioxide prediction and carbohydrate uses.
- **0610/41/M/J/23 Q4**: describing and explaining limiting factors on a light-intensity graph, and how carbohydrates are used (Extended).
- **0610/42/M/J/24 Q4**: hydrogencarbonate indicator in light and dark explained with pH, and limiting factors (Extended).
- **0610/43/M/J/22 Q5**: carbon dioxide enrichment and lighting in glasshouses (Extended).