

Plant structures and their functions revision notes

Plants and algae make their own food by photosynthesis, and nearly every food chain depends on them. This topic covers how photosynthesis works and what limits it, and how water, mineral ions and sucrose move around a plant.

For Edexcel GCSE Combined Science 1SC0. **Higher tier** is only on the Higher paper.

1 Photosynthesis and limiting factors Spec 6.1-6.6

Photosynthetic organisms as producers Spec 6.1

Plants and algae carry out photosynthesis. They use light energy to make glucose from simple inorganic substances, so they do not need to eat other organisms.

This makes photosynthetic organisms the **main producers of food** and therefore of **biomass**. Biomass is the mass of living material. The glucose a plant makes is used to build new cells, so it becomes part of the plant's biomass.

Every food chain starts with a producer. Animals cannot make their own food, so they get their biomass, and the energy stored in it, by eating plants or algae, or by eating other animals that have eaten them.

Producer	An organism that makes its own food. Photosynthetic organisms (plants and algae) are the main producers of food and biomass.
Biomass	The mass of living material, which in a plant is made from the glucose it produces by photosynthesis.

Common mistake: Do not write that plants 'take in food' from the soil. Plants make their own food by photosynthesis. The roots take in water and mineral ions, not food.

The photosynthesis reaction Spec 6.2

Photosynthesis in plants and algae is an **endothermic reaction**. This means it takes in energy from the surroundings. The energy comes from **light**, which is absorbed by the green pigment chlorophyll in the chloroplasts.

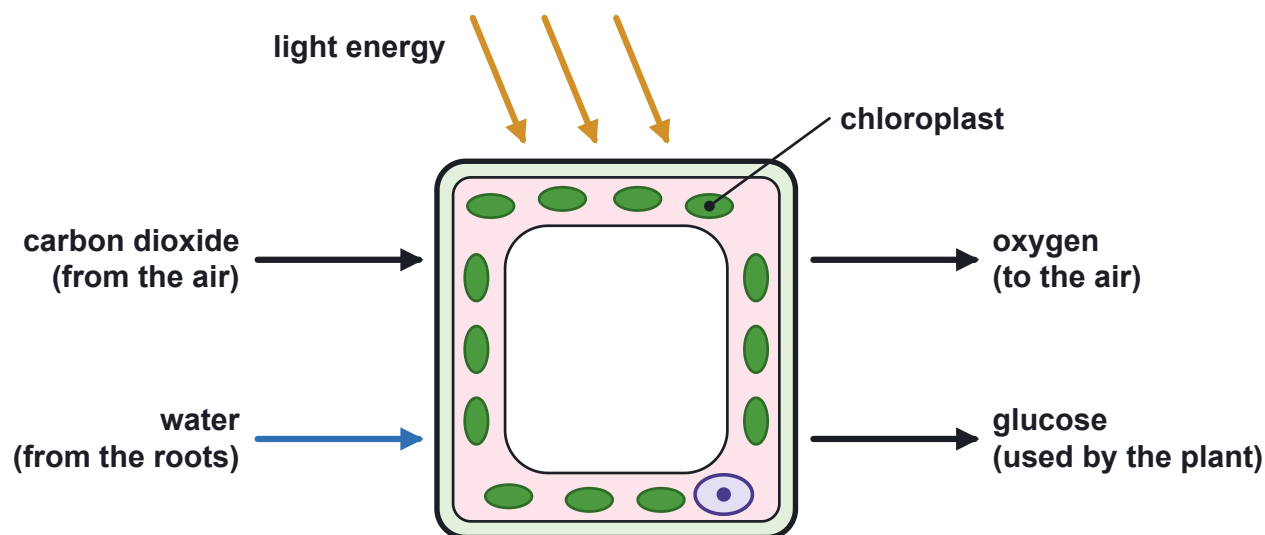
The light energy is used to react **carbon dioxide** and **water** to produce **glucose** and **oxygen**.

carbon dioxide + water → glucose + oxygen (in the presence of light)



Where the raw materials come from and where the products go

Substance	Reactant or product	Source or fate
Carbon dioxide	Reactant	Diffuses into the leaf from the air
Water	Reactant	Absorbed from the soil by the roots and carried to the leaf in the xylem
Glucose	Product	Used for respiration, or to build new plant material (biomass)
Oxygen	Product	Diffuses out of the leaf into the air



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Photosynthesis in a leaf cell: **light energy** is absorbed by chlorophyll in the chloroplasts.

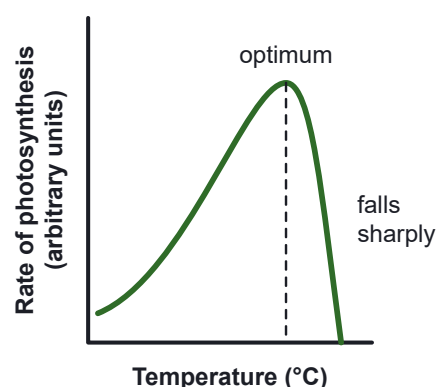
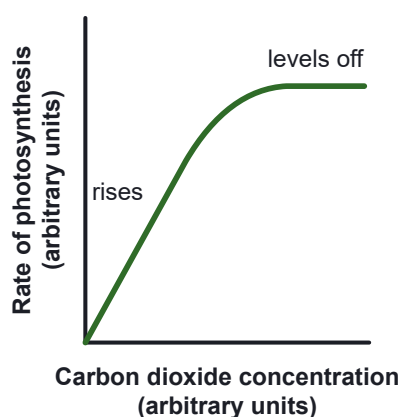
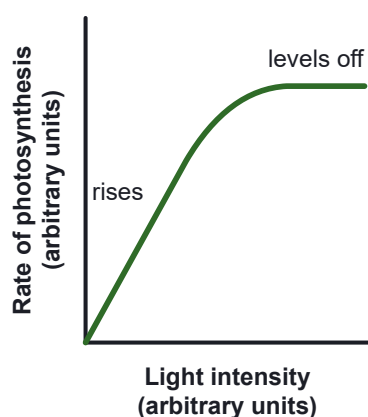
Exam tip: Light is the energy source, not a reactant, so it does not go in the word equation as a substance. Write 'in the presence of light' or put 'light energy' above the arrow.

Limiting factors Spec 6.3

A **limiting factor** is something that is in short supply, so it stops the rate of a process from going any faster. The rate of photosynthesis can be limited by **temperature**, **light intensity** and **carbon dioxide concentration**.

How each factor limits the rate of photosynthesis

Factor	Effect on rate	Why
Light intensity	Rate increases as light intensity increases, then levels off	Light provides the energy for the reaction. At low light, the amount of light limits the rate. At high light, another factor is limiting.
Carbon dioxide concentration	Rate increases as concentration increases, then levels off	Carbon dioxide is a reactant. At low concentration, there is not enough of it. At high concentration, another factor is limiting.
Temperature	Rate increases up to an optimum temperature, then falls sharply	Photosynthesis is controlled by enzymes. A higher temperature gives more collisions between enzymes and substrates. Above the optimum the enzymes are denatured, so the rate falls.



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Light intensity and carbon dioxide: the rate **rises, then levels off**. Temperature: the rate rises to an optimum, then **falls sharply**.

On a graph, the rate rises while the factor on the x-axis is the limiting factor. Where the line goes flat, that factor is no longer limiting and something else is. Reading a graph this way is a common exam question.

Maths skill: Plot the rate on the y-axis and the factor you changed on the x-axis. To describe a graph, state the trend, then quote data from it, for example the values where the line levels off.

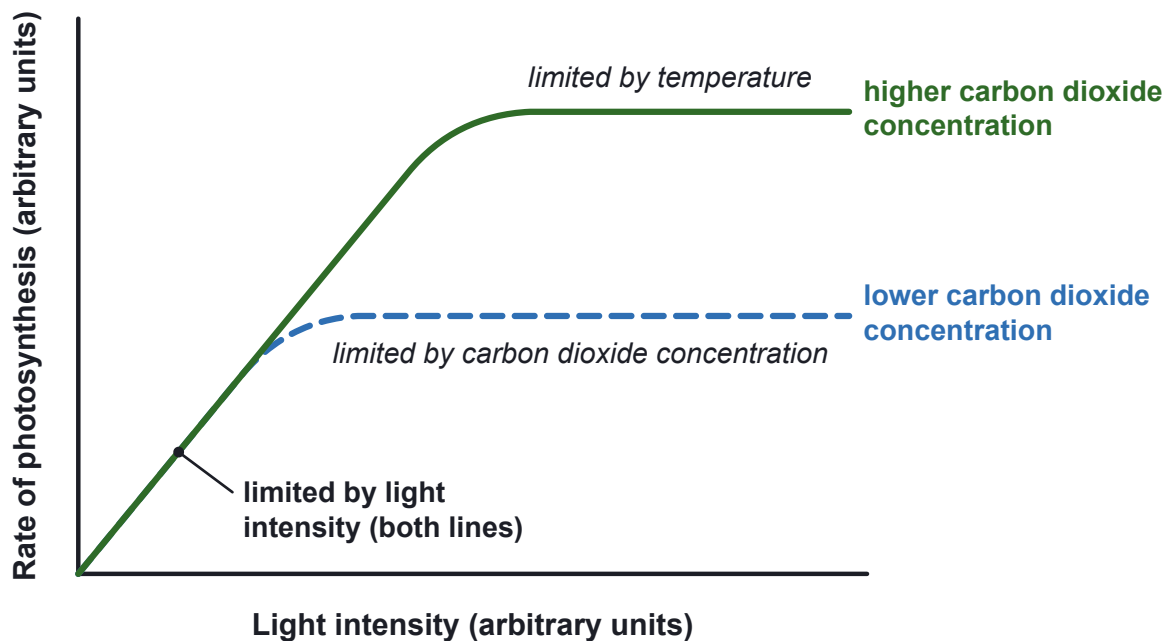
Common mistake: Do not write that the enzymes are 'killed' at high temperature. Enzymes are not alive. They are denatured, because their active site changes shape.

Interactions between limiting factors Spec 6.4 Higher tier

Temperature, light intensity and carbon dioxide concentration all act at the same time. At any moment, the rate of photosynthesis is limited by whichever factor is **in shortest supply**.

To explain a graph, find where the line levels off. At that point the factor on the x-axis is no longer limiting. Something else is, and it will be a factor that is not being increased.

- If a graph for light intensity has two lines, the line with a higher plateau has more of the other factor, for example a higher carbon dioxide concentration or a better temperature.
- The two lines are the same at low light intensity because light is the limiting factor for both.
- At the plateau, the lower line is limited by the factor that differs between the two conditions.
- If increasing one factor makes no difference to the rate, a different factor is limiting.



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Where each line levels off, light is no longer limiting. The **factor in shortest supply** sets the plateau.

Exam tip: Name the factor in your answer. 'Another factor is limiting' will not get the mark. Say which one and give the reason, for example 'carbon dioxide concentration is limiting because the rate rises when it is increased'.

Core practical: light intensity and photosynthesis Spec 6.5

You can investigate how **light intensity** affects the rate of photosynthesis using an aquatic plant such as pondweed. The light intensity is changed by moving a lamp to different distances from the plant.

1. Cut a piece of pondweed and place it in a boiling tube or beaker of water with a little sodium hydrogencarbonate, which supplies carbon dioxide. Place a heat shield (a clear container of water) between the lamp and the plant, or use an LED lamp, to keep the temperature constant.
2. Place a lamp a measured distance from the pondweed, for example 10 cm, using a ruler. Switch off or block other light sources.
3. Leave the pondweed for a couple of minutes to adjust to the new light level.
4. Count the number of bubbles of oxygen released from the cut end of the stem in one minute. (You can instead collect the gas and measure its volume.)
5. Repeat at different distances, for example 20, 30, 40 and 50 cm.
6. Repeat each distance at least three times and calculate a mean rate.

Variables		
Type	Variable	How it is controlled or measured
Independent	Light intensity	Changed by changing the distance between the lamp and the plant
Dependent	Rate of photosynthesis	Measured as the number of bubbles per minute, or the volume of gas collected per minute
Control	Temperature	Heat shield or water bath, and a lamp that gives out little heat
Control	Carbon dioxide concentration	Same amount of sodium hydrogencarbonate in the water each time
Control	The plant	Same piece of pondweed, with the same length of stem, for every distance

Typical results: the further the lamp is from the plant, the lower the light intensity, so fewer bubbles are released per minute. Plot the mean rate (y-axis) against the distance or light intensity (x-axis).

Higher tier

Because light intensity is inversely proportional to the square of the distance, plotting the rate against $1 \div \text{distance}^2$ should give a straight line while light is the limiting factor.

Counting bubbles is not very accurate because bubbles can be different sizes. Collecting the gas and measuring its volume gives better data.

Core practical: Safety: keep the mains lamp and its cable away from the water, and do not touch a hot lamp. Controlling temperature matters because a lamp placed close to the plant also warms the water, which would change the rate.

Exam tip: 'Light intensity' is the independent variable, not 'the distance'. Say that the distance is how you change the light intensity.

Light intensity, distance and the inverse square law Spec 6.6 Higher tier

When light is the limiting factor, the rate of photosynthesis is **directly proportional** to light intensity. If the light intensity doubles, the rate doubles.

The light intensity falls as the distance from the light source increases. So the rate of photosynthesis is **inversely proportional** to the distance from the light source. The exact relationship is the **inverse square law**: light intensity is proportional to $1 \div \text{distance}^2$, so the rate is too.

$$\text{light intensity} \propto 1 \div \text{distance}^2$$

- Double the distance: the intensity becomes $1 \div 2^2 = \text{one quarter}$.
- Treble the distance: the intensity becomes $1 \div 3^2 = \text{one ninth}$.
- Halve the distance: the intensity becomes $1 \div (\frac{1}{2})^2 = \text{four times as much}$.

Using the inverse square law

A pondweed 10 cm from a lamp releases 36 bubbles per minute. Light is the limiting factor. Predict the number of bubbles per minute when the lamp is moved to 30 cm.

1. The distance has increased by a factor of $30 \div 10 = 3$.
2. Light intensity is proportional to $1 \div \text{distance}^2$, so the intensity falls by a factor of $3^2 = 9$.
3. The rate is directly proportional to light intensity, so the rate also falls by a factor of 9.
4. New rate = $36 \div 9 = 4$ bubbles per minute.

Answer: 4 bubbles per minute

Maths skill: The rule only works while light is the limiting factor. Very close to the lamp, another factor such as carbon dioxide concentration or temperature takes over, and the rate stops increasing.

Quick check

1. Why are photosynthetic organisms called the main producers of biomass?
2. Why is photosynthesis described as endothermic?
3. Name the three limiting factors of photosynthesis.
4. In the light intensity core practical, how is the light intensity changed?

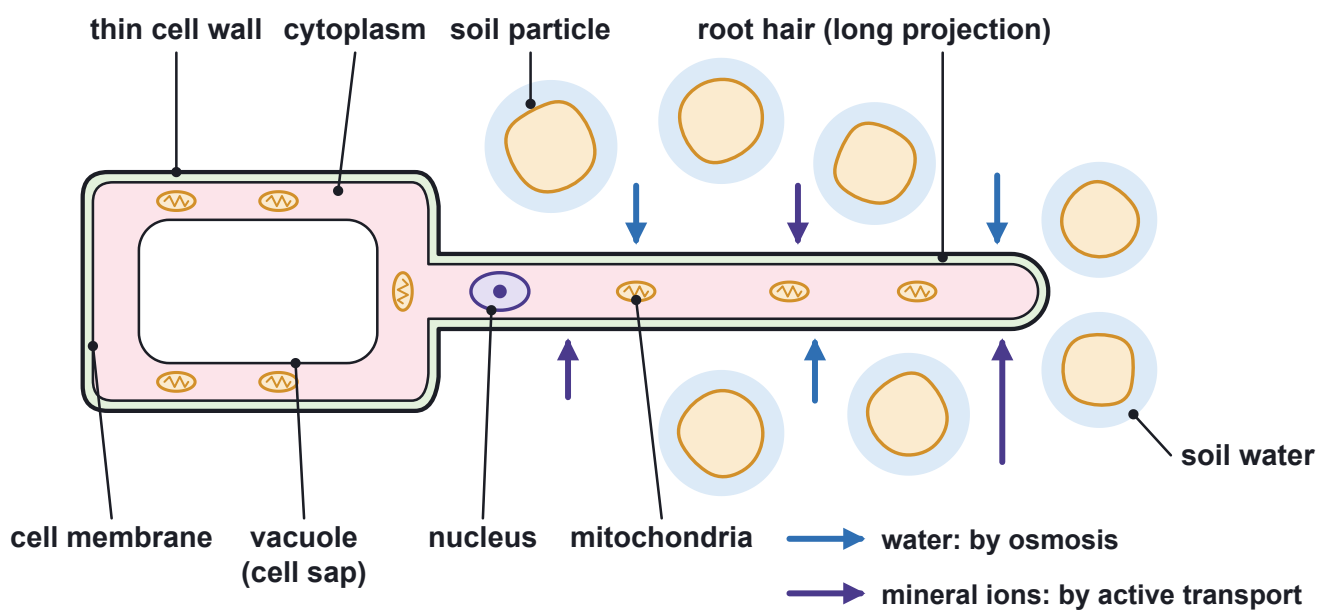
2 Transport in plants Spec 6.7-6.10

Root hair cells Spec 6.7

Root hair cells are found near the tips of roots. They take in **water** and **mineral ions** from the soil. Their structure is adapted for this job.

Adaptations of a root hair cell	
Adaptation	How it helps
A long, thin projection (the root hair)	Gives a large surface area for absorbing water and mineral ions
A thin cell wall	A short distance for water and mineral ions to cross
Many mitochondria	Release energy by respiration for the active transport of mineral ions into the cell
Cell sap more concentrated than the soil water	Water moves into the cell by osmosis

Mineral ions, such as nitrate ions, are usually at a lower concentration in the soil water than inside the cell. They are taken in by **active transport**, which needs energy from respiration.



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A root hair cell: water enters by **osmosis**; mineral ions enter by **active transport** using energy from the mitochondria.

Exam tip: For an 'explain' question, link each adaptation to a function: 'the root hair gives a large surface area, so more water can be absorbed'.

Xylem and phloem Spec 6.8

Xylem and phloem are the two transport tissues in a plant. They run together through the roots, stem and leaves.

Xylem

The xylem carries **water and mineral ions** from the roots to the rest of the plant. It is made of **lignified dead cells**.

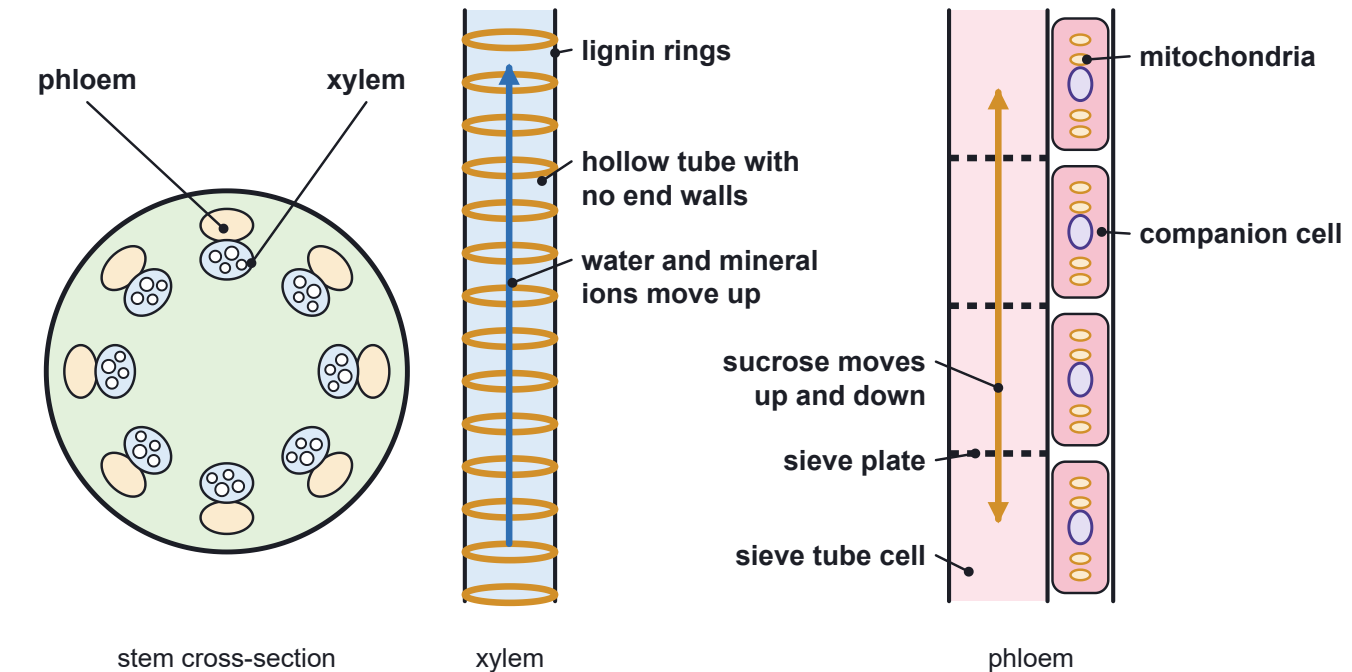
- The cells are dead, with no cytoplasm or nucleus, and the end walls between them have broken down, so they form a continuous hollow tube. Water can flow through easily.
- The walls are strengthened with lignin, which is strong and waterproof. This stops the tubes from collapsing and supports the plant.

Phloem

The phloem carries **sucrose** around the plant. It is made of **living cells** that use energy to transport sucrose.

- Sieve tube cells are joined end to end. The end walls have holes (sieve plates), so dissolved sucrose can pass from cell to cell.
- Companion cells are next to the sieve tube cells. They have many mitochondria to release the energy that is needed for the transport of sucrose.

Xylem and phloem compared		
	Xylem	Phloem
Substances carried	Water and mineral ions	Sucrose (dissolved in water)
Cells	Dead	Living
Cell walls	Thickened with lignin	Cellulose, with holes in the end walls (sieve plates)
Energy needed for transport	No	Yes



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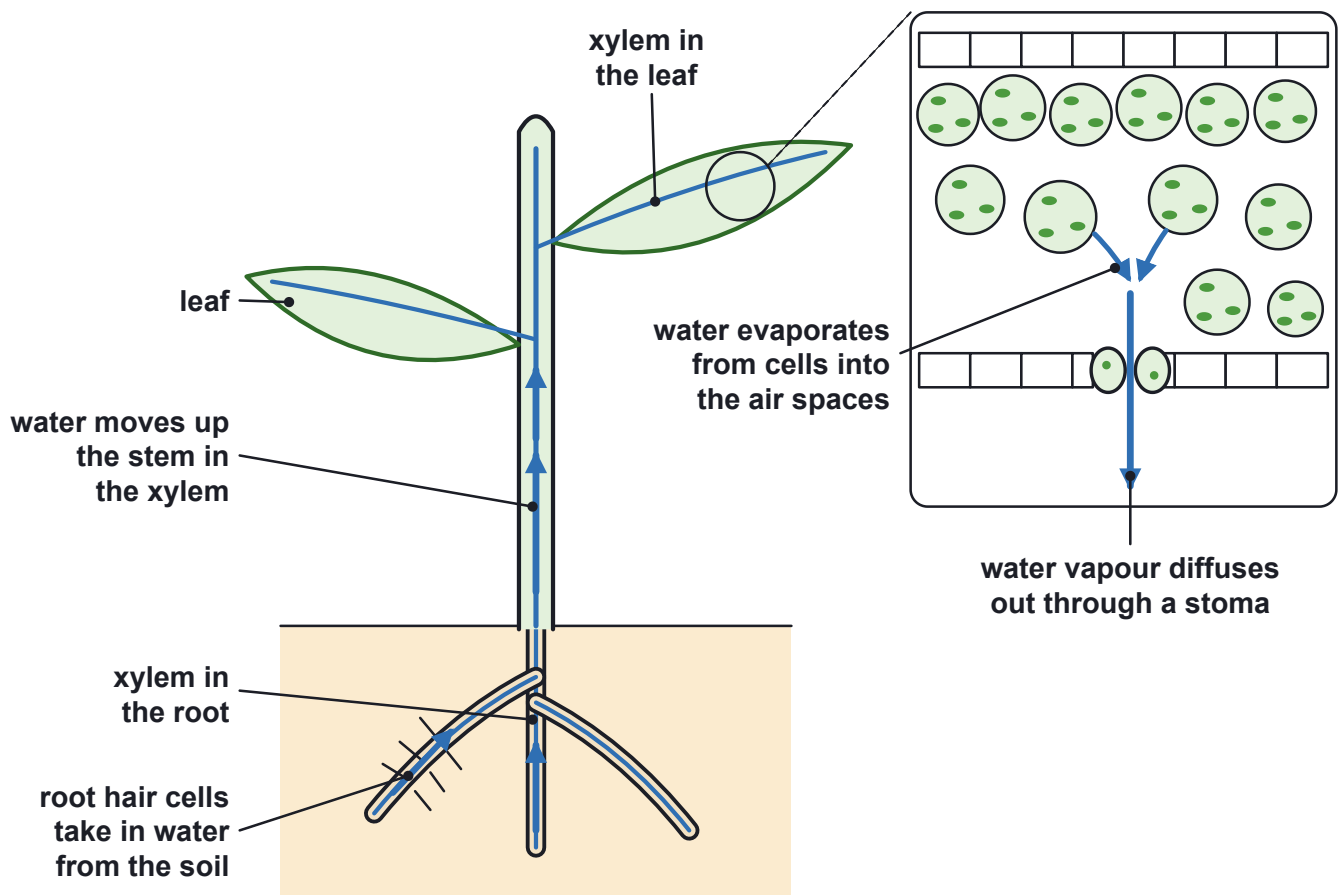
Xylem: **dead, hollow, lignified** tubes carrying water up. Phloem: **living** sieve tube cells and companion cells carrying sucrose both ways.

Common mistake: Do not mix the two up. Xylem = water and mineral ions, dead cells. Phloem = sucrose, living cells.

Transpiration and stomata Spec 6.9

Transpiration is the loss of water vapour from a plant, mainly through the stomata in the leaves. It pulls a continuous stream of water, called the **transpiration stream**, through the plant. This is how water and mineral ions are transported from the roots to the leaves.

1. Water is absorbed from the soil by the root hair cells.
2. Water and dissolved mineral ions move up through the xylem to the leaves.
3. Water evaporates from the surface of the cells inside the leaf, into the air spaces.
4. Water vapour diffuses out of the leaf through the stomata, into the air.



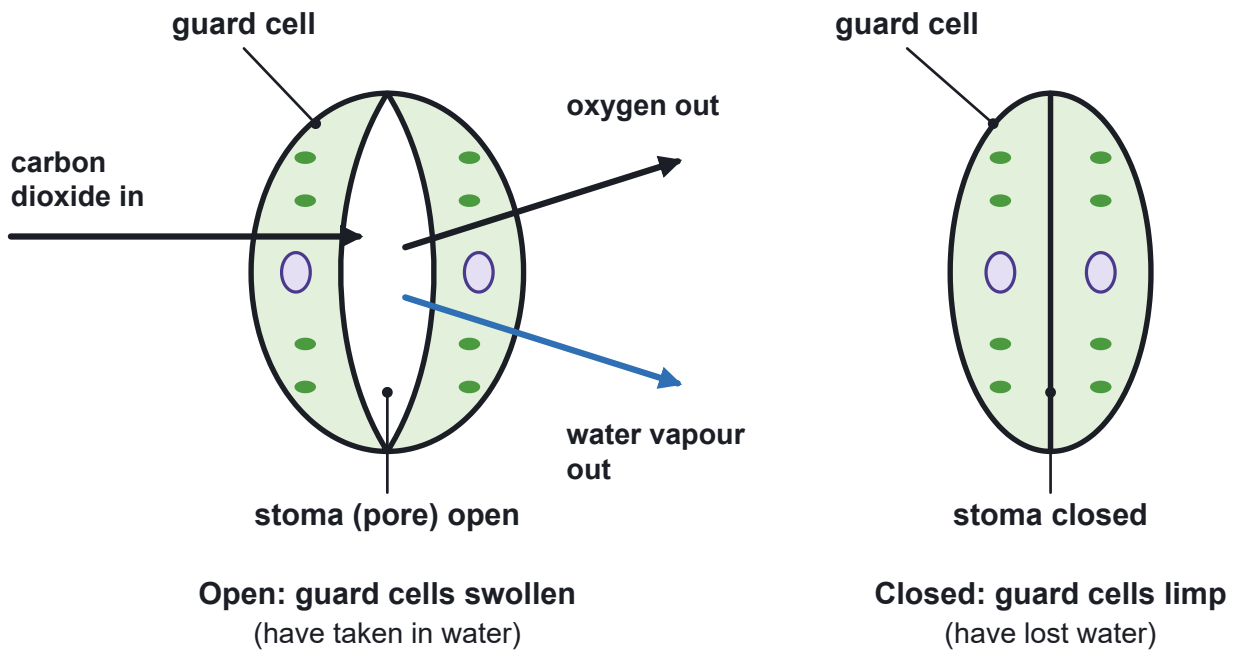
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The transpiration stream: water moves up the **xylem**, **evaporates** into the air spaces and **diffuses** out through the stomata.

Stomata

Stomata are tiny pores, found mainly on the underside of a leaf. Each stoma is surrounded by two **guard cells** which control whether the stoma is open or closed.

- Open stomata let carbon dioxide diffuse into the leaf for photosynthesis, and let oxygen and water vapour diffuse out.
- When the guard cells take in water they swell and the stoma opens.
- When the guard cells lose water they become limp and the stoma closes. This reduces the amount of water lost by transpiration, for example when the plant is short of water.



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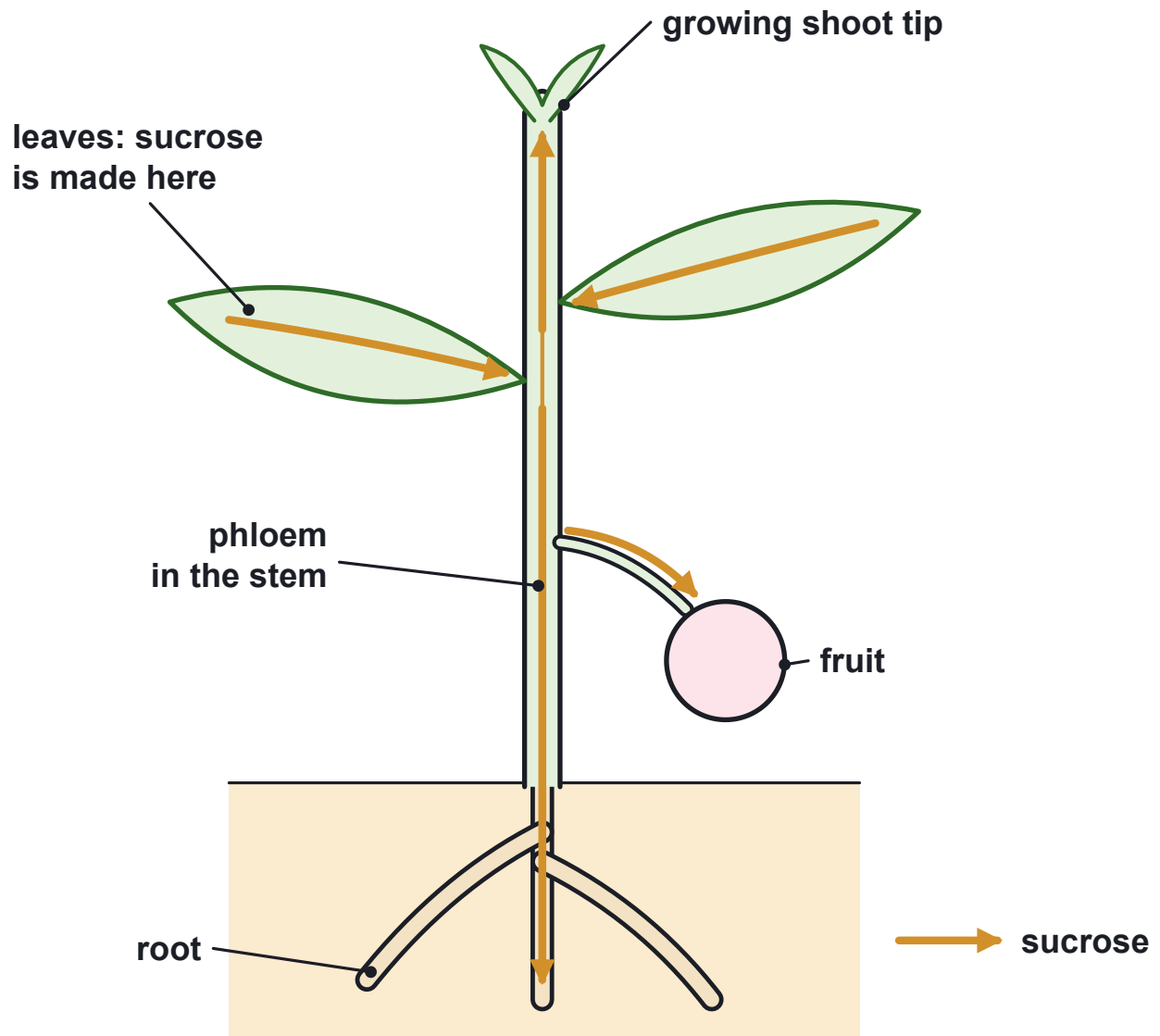
Guard cells that take in water swell and **open** the stoma; guard cells that lose water go limp and **close** it.

*Exam tip: Water is lost from the leaf by evaporation and then diffusion. Do not say that water 'escapes' or 'leaks'. Use the terms **evaporates** and **diffuses**.*

Translocation Spec 6.10

Translocation is the transport of **sucrose** around the plant. Sucrose is made from the glucose produced in photosynthesis, and it is carried dissolved in water in the **phloem**.

- Sucrose moves from the leaves, where it is made, to the parts of the plant that use it or store it, such as growing shoot tips, roots, flowers and fruits.
- It can move up and down the plant, depending on where it is needed.
- Translocation needs energy, which is released by respiration in the living cells of the phloem.



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Translocation: sucrose moves in the **phloem** from the leaves to where it is used or stored, **up and down** the plant.

Exam tip: Contrast it with transpiration: translocation moves sucrose in the phloem and uses energy. Transpiration moves water in the xylem and does not use energy from the plant's cells.

Quick check

1. Give two adaptations of a root hair cell.
2. Why is xylem made of lignified dead cells?
3. What is transpiration?
4. What is translocation?

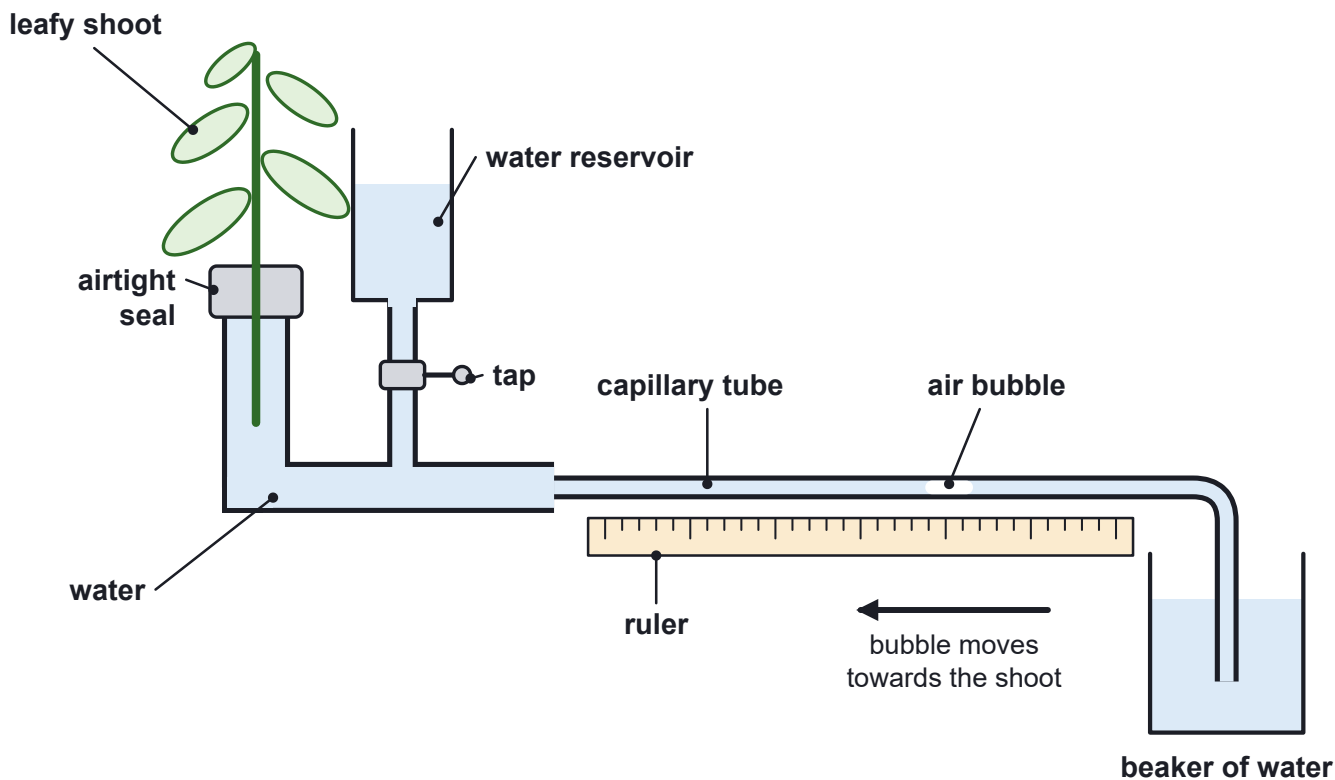
3 Leaves, water uptake and extreme environments Spec 6.11B-6.14B

Factors affecting water uptake Spec 6.12

The rate at which a plant takes up water depends on the rate of transpiration. When more water is lost from the leaves, more is pulled up through the xylem. Three environmental factors affect it.

Effect of environmental factors on water uptake		
Factor	Effect on water uptake	Explanation
Light intensity	Higher light intensity increases the rate	Stomata open in the light, so more water vapour can diffuse out of the leaf. Low light or darkness makes the stomata close.
Air movement	More air movement increases the rate	Moving air carries away water vapour from around the stomata. This keeps a steep concentration gradient, so water vapour diffuses out faster.
Temperature	Higher temperature increases the rate	Water evaporates from the cells faster, and water vapour particles move faster, so diffusion out of the leaf is faster.

A **potometer** is used to measure the rate of water uptake of a leafy shoot. As the shoot takes up water, an air bubble moves along a capillary tube. The distance moved in a set time is a measure of the rate. You can compare the rate in different conditions, for example with and without a fan, or in the light and in the shade.



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A potometer: the **distance the bubble moves** in a set time measures the rate of water uptake.

Common mistake: Say what happens and why. 'The rate goes up' is not enough. Add 'because the stomata are open' or 'because the water vapour is carried away, keeping a steep concentration gradient'.

Rate calculations for transpiration Spec 6.13

A rate tells you how much something changes in a unit of time. For water uptake or transpiration you can use the distance moved by a bubble in a potometer, the volume of water lost, or the change in mass of a plant.

$$\text{rate} = \text{change in quantity} \div \text{time taken}$$

$$\text{percentage change} = (\text{change in mass} \div \text{original mass}) \times 100$$

Rate of water uptake

In a potometer, an air bubble moved 31 mm, 28 mm and 34 mm in three repeats of 10 minutes each. Calculate the mean rate of water uptake in mm per minute.

1. Mean distance = $(31 + 28 + 34) \div 3 = 93 \div 3 = 31$ mm.
2. Rate = distance $\div$ time = $31 \div 10 = 3.1$ mm per minute.

Answer: 3.1 mm per minute

Percentage loss of mass

A leafy shoot had a mass of 25.0 g at the start of an investigation and 23.0 g at the end. Calculate the percentage loss of mass.

1. Loss of mass = $25.0 - 23.0 = 2.0$ g.
2. Percentage loss = $2.0 \div 25.0 \times 100 = 8\%$.

Answer: 8%

Maths skill: Always include the unit with a rate, for example mm per minute or cm³ per hour. Calculate a mean first if you are given repeats.

Quick check

1. What does a potometer measure?
2. Why does moving air increase the rate of transpiration?
3. A bubble in a potometer moves 24 mm in 8 minutes. What is the rate?
4. Why does a higher temperature increase the rate of water uptake?

Quick check answers

Photosynthesis and limiting factors

1. They make their own food (glucose) by photosynthesis, which builds biomass that other organisms feed on.
2. It takes in energy from the surroundings, in the form of light.
3. Temperature, light intensity and carbon dioxide concentration.
4. By changing the distance between the lamp and the pondweed.

Transport in plants

1. Any two of: a long, thin projection for a large surface area; many mitochondria for active transport; a thin cell wall.
2. Dead cells with no end walls form a continuous hollow tube for water, and lignin strengthens the walls.
3. The loss of water vapour from the leaves, which pulls water through the plant.
4. The transport of sucrose around the plant in the phloem.

Leaves, water uptake and extreme environments

1. The rate of water uptake of a leafy shoot.
2. It carries away water vapour, keeping a steep concentration gradient so water vapour diffuses out faster.
3. $24 \div 8 = 3$ mm per minute.
4. Water evaporates from the leaf cells faster and water vapour diffuses out faster, so more water is pulled up the xylem.