Cambridge IGCSE · Biology 0610 · Notes

Transport in plants

Read online at **pastopic.com/cambridge/biology-0610/notes/transport-in-plants**

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Read first: **Movement into and out of cells**, **Plant nutrition**

What you need to know

This topic comes up on every paper: one-mark multiple-choice questions on transpiration, xylem and phloem, and longer parts built around a section of a root, stem or leaf, or a transpiration experiment. Outcomes marked **Extended only** are tested on Papers 2 and 4 only. By the end of this topic you should be able to:

1. **State what xylem and phloem do**: xylem transports water and mineral ions, and supports the plant; phloem transports sucrose and amino acids.
2. **Find xylem and phloem** in diagrams and photographs of sections through the roots, stems and leaves of non-woody dicotyledonous plants.
3. **Extended only:** explain how the structure of a xylem vessel suits its job: thick walls containing lignin; no cell contents; cells joined end to end with no cross walls, making one long continuous tube.
4. **Identify root hair cells** in diagrams and photographs, and state what they do.
5. **State that root hairs have a large surface area**, which increases the uptake of water and mineral ions.
6. **Give the pathway of water** through the plant: root hair cells → root cortex cells → xylem → mesophyll cells.
7. **Show the pathway of water with a stain**: stand a plant or cut shoot in a coloured dye and look at sections of it.
8. **Describe transpiration** as the loss of water vapour from leaves.
9. **State how it happens**: water evaporates from the surfaces of the mesophyll cells into the air spaces, then diffuses out of the leaf through the stomata as water vapour.
10. **Investigate and describe** how temperature and wind speed change the rate of transpiration.
11. **Extended only:** explain how water vapour loss depends on the large internal surface area of the air spaces between mesophyll cells, and on the size and number of stomata.
12. **Extended only:** explain how water moves up the xylem: transpiration pull draws up a column of water molecules, held together by forces of attraction between them.
13. **Extended only:** explain how temperature, wind speed and humidity change the rate of transpiration.
14. **Extended only:** explain how and why wilting happens.
15. **Extended only:** describe translocation as the movement of sucrose and amino acids in the phloem from sources to sinks.
16. **Extended only:** describe sources (parts of a plant that release sucrose or amino acids) and sinks (parts that use or store them).
17. **Extended only:** explain why some parts of a plant can be a source at one time and a sink at another.

Osmosis and active transport are in Movement into and out of cells; leaf structure and photosynthesis are in Plant nutrition. This note uses both.

Understand it

Two transport tissues

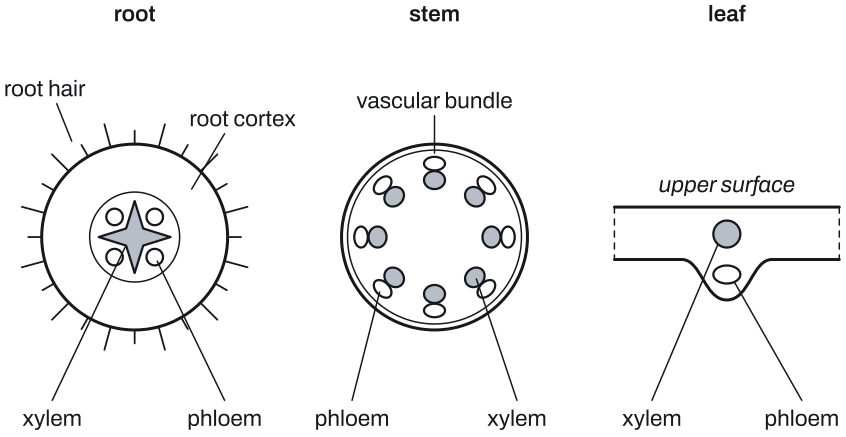
A plant needs water and mineral ions from the soil in every leaf, and it needs the sugar made in its leaves in every root, flower and fruit. Two tissues carry these, and they always run side by side in **vascular bundles** (the veins):

Tissue	Carries	Direction	Other job
Xylem	**water** and **mineral ions** (such as nitrate and magnesium ions)	up only: roots → stem → leaves	**supports** the stem and leaves
Phloem	**sucrose** and **amino acids**	up **and** down: from where they are made or stored to where they are needed	

Learn the pairs exactly. Phloem carries **sucrose**, not glucose or starch (starch is insoluble and cannot be moved). Xylem carries **mineral ions**, not sugar. Only xylem has the support job.

Where xylem and phloem are

The two tissues are arranged differently in each organ of a dicotyledonous plant, and you need to recognise all three:



- **Root**: xylem is in the **centre**, shaped like a star or a cross; phloem sits in the **gaps between the arms** of the star. Around them is the thick **root cortex**, and on the outside the epidermis with its **root hairs**.
- **Stem**: the vascular bundles form a **ring** near the outside. In each bundle, **phloem is on the outside** and **xylem is on the inside** (towards the centre).
- **Leaf**: xylem and phloem are in the veins. In a vein, **xylem is towards the upper surface** and **phloem towards the lower surface**.

A quick memory aid: in the stem and leaf, xylem is always on the side nearer the centre of the stem.

Seeing the water path with a stain. Stand a plant's roots (or a cut stem, such as celery) in water with a coloured dye for a few hours, then cut thin sections. The dye shows up only in the **xylem**, because that is where the water went: a star in the centre of the root, a ring of coloured spots in the stem, and the veins in the leaf. The dye travels faster in conditions that speed up transpiration (warm, dry, windy).

Extended: xylem vessels are built for their job

A xylem vessel is a long, hollow tube made of dead cells joined end to end.

Feature	Why it helps
Thick walls with lignin	lignin is strong and waterproof, so the vessels **support** the plant and don't collapse when water is pulled up
No cell contents (no cytoplasm, nucleus or vacuole)	nothing to get in the way, so water flows freely
Cells joined end to end with no cross walls	forms a **long continuous tube**, so an unbroken column of water can run from root to leaf

A xylem vessel has no mitochondria (it is dead) and no valves. Phloem is living tissue, which is why its features are different.

Water uptake: root hair cells

Water enters the plant through **root hair cells**, cells of the root epidermis that each grow one long, thin extension out into the soil.

- Their job is to **absorb water and mineral ions** from the soil. (They are underground, so they have **no chloroplasts**.)
- The long, thin shape gives a **large surface area**, so more water and mineral ions are taken up per second. A plant that loses its root hairs (for example when it is moved to a new pot) takes up less water and may wilt.
- Water enters by **osmosis**: the soil water is a dilute solution, and the cytoplasm and vacuole of the root hair cell are more concentrated, so water moves in through the partially permeable cell membrane.
- **Extended only:** mineral ions such as nitrate are usually more concentrated inside the root hair cell than in the soil, so they are taken in by **active transport**, which needs energy from **respiration**. That is why roots need oxygen and glucose (sent down in the phloem). Waterlogged soil has little oxygen, so less respiration, less active transport and fewer ions absorbed.

The pathway of water

Once inside, water crosses the root and travels up to the leaves in this order:

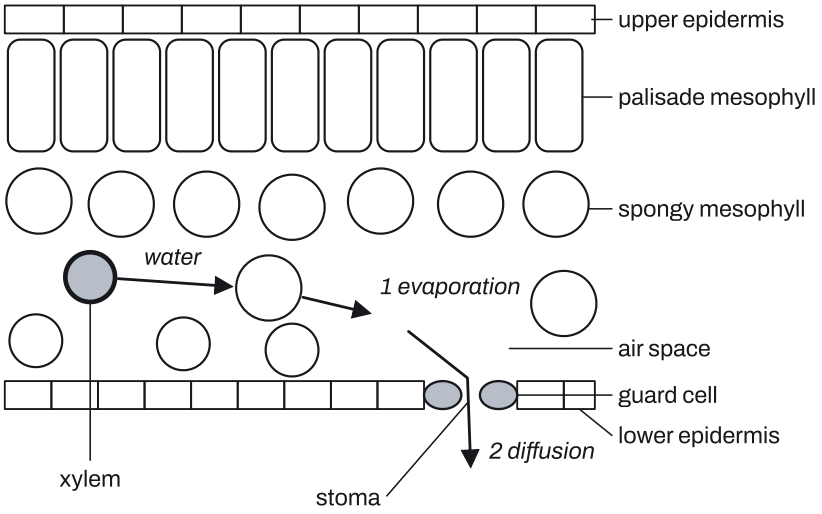
$$\text{soil} \rightarrow \textbf{root hair cell} \rightarrow \textbf{root cortex cells} \rightarrow \textbf{xylem} \rightarrow \textbf{mesophyll cells} \rightarrow \text{air spaces} \rightarrow \text{stomata} \rightarrow \text{air}$$

The four names in bold are the syllabus pathway. Water does **not** pass through the phloem. The xylem runs up the root, through the stem and into the veins of the leaf, where water leaves it and passes into the mesophyll cells.

Transpiration

Transpiration is the loss of water vapour from the leaves. It happens in two steps, and each step has its own process:

1. Water **evaporates** from the surfaces of the **mesophyll cells** (mostly the spongy mesophyll, which borders the air spaces) into the **air spaces**. Liquid water becomes water vapour.
2. The water vapour **diffuses** out of the leaf through the **stomata**, from the high concentration of water vapour inside the leaf to the lower concentration outside.



So "evaporation" belongs to the mesophyll cell surfaces and "diffusion" to the stomata; water does **not** evaporate straight out of the stomata, from the xylem or from the cuticle. Osmosis and active transport play no part in transpiration.

Water taken up by the roots is used for **photosynthesis**, keeps cells **turgid** so the plant is **supported**, carries mineral ions (it is the **solvent**), and cools the leaves as it evaporates. Most of it is lost by transpiration.

Extended: why leaves lose so much water

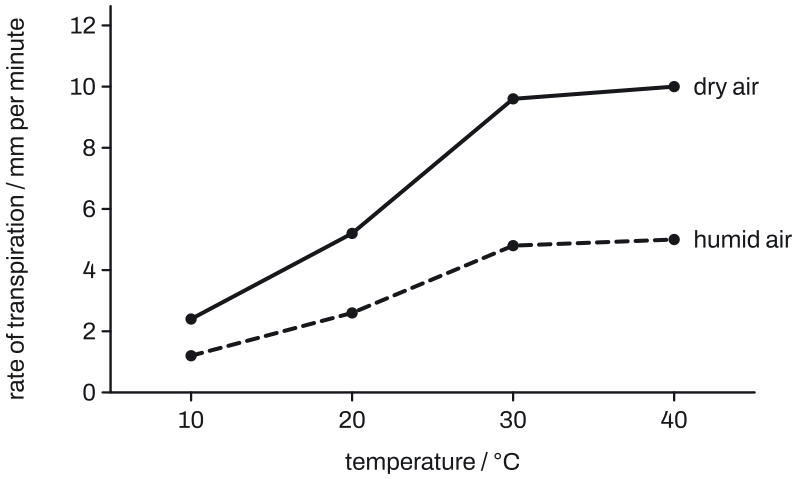
- The mesophyll cells are surrounded by **interconnecting air spaces**, giving a **very large internal surface area** of wet cell surface. Lots of water can evaporate at once.
- Water vapour can only get out through the **stomata**. The **more** stomata there are, and the **larger** (wider open) they are, the faster water vapour diffuses out. Most stomata are on the **lower** surface, so the lower surface loses more water than the upper surface, which also has a thicker waxy cuticle.
- Stomata are open in the light (for photosynthesis) and mostly close in the dark, so transpiration is much slower at night.

Extended: how water rises in the xylem

As water evaporates from the mesophyll cells and diffuses out of the leaf, water moves from the xylem in the leaf into the mesophyll cells to replace it. This creates a pull, the **transpiration pull**, on the water in the xylem. The water molecules are held together by **forces of attraction between water molecules**, so the whole **column of**

water in each xylem vessel is drawn up, like a chain, from the roots to the leaves. The xylem's lignified walls stop the vessels collapsing under this pull, and the lack of cross walls keeps the column unbroken.

What changes the rate of transpiration



Factor	Effect on transpiration	**Extended:** why
Higher temperature	faster	water molecules have more **kinetic energy**, so they **evaporate** from the mesophyll surfaces faster and **diffuse** out of the stomata faster
Higher wind speed	faster	wind blows water vapour away from the leaf surface, keeping the **concentration gradient** of water vapour between the air spaces and the air **steep**
Extended only: higher humidity (more water vapour in the air)	slower	the air outside already holds a lot of water vapour, so the **concentration gradient is smaller** and water vapour diffuses out more slowly; in air saturated with water vapour (100% humidity) there is almost no net loss

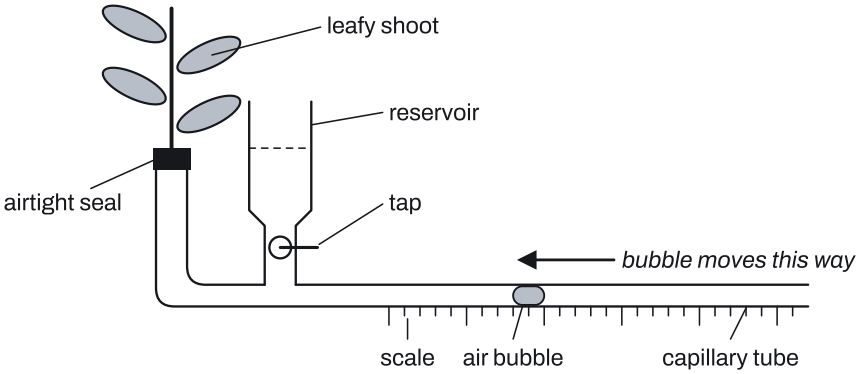
The fastest transpiration is on a **hot, dry (low humidity), windy** day; the slowest on a **cool, humid, still** day. At high temperatures or wind speeds the rate **levels off**: it cannot rise for ever, because the stomata are only so wide, and if water is lost faster than the roots can replace it the stomata close.

Measuring the rate of transpiration

The rate is measured from the water the plant **takes up** or the mass it **loses**:

- **Potometer (bubble method).** A leafy shoot is sealed into water-filled tubing that ends in a narrow capillary tube with a scale. As the shoot takes up water, an **air bubble** in the capillary tube moves **towards the shoot**. Rate $= \frac{\text{distance moved by the bubble}}{\text{time}}$, in mm per minute. The reservoir pushes the bubble back to the start between readings. (Strictly it measures water **uptake**, which is almost equal to water loss.)

- **Mass method.** Stand a potted plant (with the pot and soil sealed in a plastic bag) or a shoot in a flask of water (with a **layer of oil** on the water) on a balance. Rate $= \frac{\text{mass lost}}{\text{time}}$, in g per hour. The bag or oil stops water evaporating from the soil or the water surface, so only water lost from the leaves is measured.



Good practice: cut the shoot **under water** and fit it under water, so no air enters and blocks the xylem; make every joint airtight; let the shoot settle before timing; change only **one** factor (use a heater, a fan at different distances, or a clear plastic bag to raise humidity); repeat and find a mean.

Extended: wilting

A plant is held up partly by **turgor**: water in the vacuoles pushes each cell's contents against its cell wall, making the cells firm (**turgid**). When the plant **loses water by transpiration faster than it takes water up** (hot, dry, windy weather, or dry soil):

1. water moves **out** of the cells by **osmosis**;
2. the cells become **flaccid** and lose their **turgor pressure**;
3. the leaves and soft stems are no longer supported, so they droop: the plant **wilts**.

Wilting also closes the stomata and folds the leaves, which cuts water loss, but it slows photosynthesis because less carbon dioxide gets in. A cut shoot standing in water does not wilt, even in dry air, because it can take up as much water as it loses.

Extended: translocation, sources and sinks

Translocation is the movement of **sucrose and amino acids** in the **phloem**, from **sources** to **sinks**.

- A **source** is a part of the plant that **releases** sucrose or amino acids into the phloem. The main source is a **photosynthesising leaf**. A storage organ (a potato tuber, a bulb, a seed) is also a source when it breaks down its stored starch to sucrose and sends it out.
- A **sink** is a part that **uses or stores** sucrose or amino acids: growing shoot tips and young leaves, roots, flowers, developing fruits and seeds, and storage organs while they are being filled. Sinks use sucrose for **respiration** and **growth**, or turn it into **starch** to store.

Because sources and sinks can be above or below each other, phloem carries its contents **up and down** the plant (unlike xylem).

Why one part can be both. It depends on the time of year:

Part	Sink when …	Source when …
Potato tuber	summer: sucrose from the leaves is sent down and stored in it as starch	spring: its starch is broken down to sucrose and sent up to feed the new shoots before they have leaves
Bulb	late in the season: the leaves refill it	early in the season: it feeds the new shoots and leaves
Leaf	young and growing: it takes in sucrose	mature and photosynthesising: it sends sucrose out

Ringing (girdling) experiments. Removing a complete ring of bark from a stem removes the **phloem**, which lies just under the bark, but leaves the **xylem** in the middle. Sucrose coming down from the leaves (the source) cannot get past the ring, so it builds up **above** the ring (the stem swells there), and fruits on a ringed branch (sinks) get more sugar and grow **bigger**. Parts below the ring are starved of sucrose. The leaves above the ring still get **water and mineral ions**, because the xylem is intact, so they don't wilt. Supplying one leaf with carbon dioxide containing **radioactive carbon** and tracking where the radioactive sucrose goes shows the same thing: it travels in the phloem from that leaf to the sinks, both up and down.

Key facts and formulas

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

Formula	Status
Xylem: water and mineral ions, and support; phloem: sucrose and amino acids	Learn it
Root: xylem a central star, phloem between its arms; stem: bundles in a ring, phloem outside, xylem inside; leaf vein: xylem upper, phloem lower	Learn it
Root hair cells: absorb water (by osmosis) and mineral ions; large surface area	Learn it
Water pathway: root hair cells → root cortex cells → xylem → mesophyll cells	Learn it
Transpiration: loss of water vapour from leaves; evaporation from mesophyll surfaces into air spaces, then diffusion out through stomata	Learn it
Faster transpiration: higher temperature, higher wind speed; **Extended:** lower humidity	Learn it
Extended: xylem: thick lignified walls, no cell contents, no cross walls (continuous tube)	Learn it
Extended: transpiration pull draws up a column of water held together by attraction between water molecules	Learn it
Extended: wilting: water loss > water uptake → cells lose water by osmosis → flaccid, no turgor	Learn it

Formula	Status
Extended: translocation: sucrose and amino acids in phloem, source → sink	Learn it
Rate $= \frac{\text{distance moved by bubble (or mass lost)}}{\text{time}}$; percentage change $= \frac{\text{change}}{\text{original}} \times 100$	Learn it

How to do it

We tagged 175 questions for this topic (2021–2025, Papers 1–4; 140 different, since some multiple-choice questions appear on more than one paper). 29 of them mix types, so the counts add up to 247.

Question type	Questions
Define or describe transpiration	41
Predict or explain how temperature, humidity or wind change transpiration	36
Identify xylem or phloem in a section, or from a dye experiment	33
State the functions of xylem and phloem	26
Translocation: sources and sinks	22
Root hair cells: water and ion uptake	20
Order the water pathway from soil to leaf	18
Calculate from transpiration or translocation data	10
Relate xylem structure to its function	9
Describe results from a transpiration graph or table	9
Interpret ringing and radioactive-tracer experiments	8
Explain wilting	6
Explain how water moves up the xylem	3
State uses of water in a plant	3
Plan or explain a transpiration investigation	3

Most are one-mark multiple choice on Papers 1 and 2. On Papers 3 and 4 they are parts of a longer question, usually built on a section of a plant organ, a potometer or a table or graph of transpiration rates.

1. Define or describe transpiration (41 questions)

1. **The definition**: the loss of **water vapour** from the **leaves** (of a plant).
2. **The mechanism**, in order: water **evaporates** from the surfaces of the **mesophyll cells** into the **air spaces (1)**; water vapour **diffuses** out through the **stomata (1)**.

Variations you will meet:

- **Gap-fills**: the usual four blanks are mesophyll, air, stomata and diffusion. "Leaf cells", "plant cells" or "empty spaces" do not score; write **mesophyll cells** and **air spaces**.
- **"By which process is water vapour lost from the leaf / does water leave through the stomata?"** Diffusion. **"Which process moves water from the mesophyll surfaces into the air spaces?"** Evaporation. Examiners report many students choosing evaporation for the stomata step.
- **"From which cells does most water evaporate?"** The **spongy mesophyll** cells (they face the air spaces), not the palisade cells, guard cells or xylem.
- **A leaf diagram with letters**: the letter for evaporation is on a spongy mesophyll cell next to an air space; the letter for water vapour leaving is the stoma.
- **"Name the process"** of water vapour loss: transpiration.
- **A longer "describe transpiration"**: don't spend your answer on the root hairs and xylem; the marks are for evaporation from mesophyll surfaces and diffusion through stomata.

2. Predict or explain how temperature, humidity or wind change transpiration (36 questions)

1. **Say what happens** to the rate (faster or slower), and with data if you are given any.
2. **Extended: explain** with the right idea for the factor:
   - **temperature**: more **kinetic energy** → faster **evaporation** from mesophyll surfaces → faster **diffusion** of water vapour through the stomata;
   - **wind**: removes water vapour from around the leaf → keeps the **concentration gradient** steep → faster diffusion;
   - **humidity**: more water vapour in the air → **smaller concentration gradient** → slower diffusion (the reverse for low humidity).

Variations you will meet:

- **"Which conditions give the highest rate?"** Hot, dry (low humidity) and windy. Lowest: cool, humid and still. Read each column heading of the table carefully: "high humidity: no" means dry air.
- **Pick the graph**: rate rises (then levels off) with temperature and with wind speed; rate falls as humidity rises.
- **Draw a new line or bar**: higher temperature or lower humidity → above the original line; higher humidity or a plastic bag over the shoot → below it (a bag traps water vapour, raising the humidity).
- **Explain the levelling off**: the stomata are fully open (or close to save water), or the plant cannot take up water any faster.
- **Light and dark** (given in the data): stomata are open in the light and mostly closed in the dark, so transpiration is much slower in the dark.
- **Upper and lower surfaces** of a leaf: the lower surface loses more water because it has **more stomata** (and a thinner cuticle).
- **Extended: number and size of stomata, and air spaces**: more or wider stomata, or a larger internal surface area of air spaces, → more water lost.
- **A leaf feature that cuts water loss** (a rolled leaf, hairs, stomata sunk in pits, few stomata, a thick waxy cuticle): rolling, hairs and pits **trap moist air** near the stomata, which **reduces the concentration gradient** of water vapour, so less diffuses out; a thick waxy cuticle stops evaporation from the leaf surface.
- **A dye moving up a stem**: it moves fastest when transpiration is fastest, since the dye travels with the water.

3. Identify xylem or phloem in a section, or from a dye experiment (33 questions)

1. **Decide which organ** the section is from: a root has a central star of xylem and root hairs; a stem has a ring of bundles; a leaf is a thin strip with layers of mesophyll.
2. **Find the tissue**: root, xylem = the star, phloem = between its arms; stem, xylem = inner part of each bundle, phloem = outer part; leaf vein, xylem = upper side, phloem = lower side.
3. **Answer with a letter or a label line** that touches the tissue.

Variations you will meet:

- **Dye experiments**: the stained part is **xylem** (a star in the root, spots in a ring in the stem, the veins of a leaf).
- **"Which tissue carries amino acids / sucrose?"** on a diagram: find the phloem.
- **"Circle a vascular bundle"** on a leaf: the vein in the middle, not the mesophyll or a single cell.
- **Name the plant part and the tissue** together: check the organ first (a root is often mistaken for a stem).
- **A photomicrograph of plant tissue**: it is xylem, not a blood vessel; think plant.
- **Extended: sketch the root**: draw the xylem as a star (or cross) in the centre, the phloem in the gaps, and label a root hair on the outside.
- **Stem of a monocotyledon** (a grass or cereal): the bundles are **scattered** through the stem, not in a ring as in a dicotyledon.

4. State the functions of xylem and phloem (26 questions)

1. **Xylem** (2 functions for 2 marks): transport of **water and mineral ions**; **support**.
2. **Phloem**: transport of **sucrose** and **amino acids**.

Variations you will meet:

- **"Which statement describes a function of xylem?"** Transport of mineral ions, or support. Not amino acids, not carbon dioxide.
- **Tables of ticks**: amino acids → phloem; mineral ions → xylem; sucrose → phloem; water → xylem.
- **"Which molecules are carried in the phloem?"** Sucrose ("sugar"), not starch, glucose or cellulose.
- **"Which tissue supports the plant?"** Xylem (not phloem, not the epidermis).
- **Gap-fill on xylem**: transports water and **(mineral) ions**; a long continuous **tube** with walls containing **lignin**; water moves up by transpiration **pull**; a **column** of water molecules held together by **forces of attraction**.
- **Aphids** feed by pushing their mouthparts into the **phloem**, which is rich in sucrose and amino acids.

5. Translocation: sources and sinks (22 questions, Extended)

1. **Definition**: the movement of **sucrose and amino acids** in the **phloem** from **sources to sinks**.
2. **Classify each part**: does it **release** sucrose (source) or **use or store** it (sink) **at the time described**?
3. **"Explain why a part can be both"**: at one time it stores sucrose as starch (sink); at another it breaks the starch down and releases sucrose (source). Name the times and say what it is doing at each.

Variations you will meet:

- **Flowers, fruits, leaves of a growing plant**: flowers and fruits are sinks, leaves are sources.
- **Statements about sources and sinks**: roots can be sinks; mesophyll cells (palisade or spongy) are sources when photosynthesising. Sink cells receive **sucrose**, not glucose.
- **Tubers, bulbs and seeds**: sink while being filled, source while feeding new growth (**0610/23/O/N/25 Q14** tests this set of ideas).
- **A plant with no green leaves** growing on a host plant: it is a sink, feeding from the host's phloem.
- **"Which row is correct for translocation?"** Sucrose and amino acids, phloem, source to sink. Not xylem, not starch, not "sink to source".

6. Root hair cells: water and ion uptake (20 questions)

1. **Function**: absorption of **water** and **mineral ions**.
2. **Adaptation**: long and thin, giving a **large surface area** for osmosis (and active transport).
3. **Process**: water enters by **osmosis**; **Extended:** mineral ions by **active transport**, using energy from respiration.

Variations you will meet:

- **"Name the cell labelled C"**: root hair cell ("root cell" is not enough).
- **"Which substances move from the soil into a root hair cell?"** Water and mineral ions (not glucose, not carbon dioxide and oxygen as the answer to this).
- **"Where on a seedling is most water absorbed?"** The region just behind the root tip covered in root hairs.
- **"Effect of having no root hairs?"** Less water (and fewer ions) absorbed.
- **Extended: why roots need glucose and oxygen**: for respiration, which releases the energy for active transport of ions.

7. Order the water pathway from soil to leaf (18 questions)

1. Write the four in order: **root hair cells** → **root cortex cells** → **xylem** → **mesophyll cells**.
2. If more is asked, add: → evaporates into **air spaces** → diffuses out through the **stomata**.

Variations you will meet:

- **Multiple choice with the same four words in different orders**: look for root hair first and mesophyll last, with xylem in between cortex and mesophyll.
- **"Which part is Z?"** in root hair → cortex → Z → mesophyll: xylem.
- **Extended prose**: "Water enters the root hair cell by osmosis, moves through the root cortex cells to the xylem, up the stem in the xylem, into the mesophyll cells of the leaf, then evaporates and diffuses out through the stomata."
- **Draw arrows** for water into and out of a plant: in at the roots, out at the leaves.

8. Calculate from transpiration or translocation data (10 questions)

1. **Rate** $= \frac{\text{change}}{\text{time}}$: mass lost ÷ hours, or bubble distance ÷ minutes. Find the change first (initial – final mass).

2. **Percentage change** $= \dfrac{\text{new} - \text{original}}{\text{original}} \times 100$.
3. Give the **unit** (g per hour, mm per minute) and the accuracy asked for.

Variations you will meet:

- **Greased leaves**: grease blocks stomata on the surface it covers. Water lost through the **upper** surface = (loss with no grease) − (loss with the **upper** surface greased); for a daily rate, divide by the number of days (**0610/22/O/N/25 Q12**).
- **A rate over a longer time**: rate × time, converting units first (12 hours = 43 200 seconds for a rate in g per m² per s).
- **Translocation rate**: distance moved ÷ time, for example cm per hour.
- **Unit conversion**: 1 cm² = 100 mm², so stomata per mm² × 100 = stomata per cm².

9. Relate xylem structure to its function (9 questions, Extended)

Link each feature **to** its job, one mark each:

- thick walls with **lignin** → strong, so they **support** the plant and don't collapse;
- **no cell contents** → nothing blocks the flow of water;
- cells joined **end to end with no cross walls** → a **continuous tube** for an unbroken water column.

Variations you will meet:

- **"Which feature provides support?"** Lignin present (not "no cross walls").
- **"What strengthens xylem walls?"** Lignin (not glycogen, starch or glycerol).
- **Wrong options to reject**: thin walls, cross walls, many mitochondria. Write "no **end** walls / cross walls", not "no cell walls".

10. Describe results from a transpiration graph or table (9 questions)

1. **State the trend** in terms of the variables: "as temperature increases, the rate of transpiration increases, then levels off".
2. **Quote data** with units: a pair of readings, or a comparison (e.g. "from 6 to 18 mm per minute").
3. **Compare** two lines: which is higher, where they meet, where they change shape.

Variations you will meet:

- **Tick the correct conclusions**: check each claim against the numbers: "triples" means × 3; "increases by 17" means a difference of 17; check the maximum really is the largest value.
- **Describe how the rate changes**, not how the temperature changes.
- **Two surfaces or two conditions** on one graph: describe both and compare.

11. Interpret ringing and radioactive-tracer experiments (8 questions, Extended)

1. **Removing a ring of bark removes the phloem**, not the xylem.

2. **Sucrose from the leaves (source) can't pass the ring**, so it collects above it: the stem swells above the ring, and fruits on a ringed branch (sinks) get more sucrose and grow bigger.
3. **Water and mineral ions still reach the leaves**, because the xylem is intact.

Variations you will meet:

- **A table of fruit masses**: describe (ringed is heavier, with a comparison) then explain with source, sink, phloem and translocation.
- **Radioactive carbon dioxide** given to one leaf: radioactivity appears in the phloem, in sinks both above and below the leaf; after ringing, it can't get below the ring.

12. Explain wilting (6 questions, Extended)

1. Water **loss** (by transpiration) is **greater than** water **uptake**.
2. Water moves **out of the cells by osmosis**.
3. Cells become **flaccid**, losing **turgor pressure** against the cell walls.
4. So the leaves and stems lose **support** and droop.

Variations you will meet:

- **"Which row explains wilting?"** High loss at the leaf surface, low uptake in the roots, flaccid cells.
- **A seedling moved to new soil** wilts: its root hairs were damaged, so less water is taken up.
- **Stomata close** when water is short: less water lost, but less carbon dioxide in, so photosynthesis slows.

13. Explain how water moves up the xylem (3 questions, Extended)

Water evaporating from the leaves creates a **transpiration pull (1)**, which draws up a **column of water** in the xylem **(1)**; the water molecules are held together by **forces of attraction** between them **(1)**.

14. State uses of water in a plant (3 questions)

Any two of: **photosynthesis** (a raw material); **support**, by keeping cells turgid; **transport** of mineral ions (as a solvent); **cooling** the leaves as it evaporates.

15. Plan or explain a transpiration investigation (3 questions)

1. **What to measure**: mass (a balance) or bubble distance (a scale) at regular times (a timer); rate = change ÷ time.
2. **Explain each detail**: shoot **cut under water** so no air bubbles block the xylem; **oil layer** stops water evaporating from the water surface; **plastic bag over the pot** so only water lost from the leaves is measured.
3. **Control variables**: same plant or similar-sized shoots, same light, same time; change only the factor under test.

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

Core.

(a) State two functions of xylem. **[2]**

(b) Name two substances transported in the phloem. **[2]**

(c) Describe how water that has reached a leaf in the xylem is lost to the air. **[5]**

(d) State one feature of a root hair cell that increases the uptake of water, and the process by which water enters it. **[2]**

(a) Transport of water and mineral ions **B1**; support **B1**.

(b) Sucrose **B1**; amino acids **B1**.

(c) Water passes from the xylem into the mesophyll cells **B1**. It evaporates **B1** from the surfaces of the mesophyll cells into the air spaces **B1**. The water vapour then diffuses **B1** out of the leaf through the stomata **B1**.

(d) Large surface area (long, thin extension) **B1**; osmosis **B1**.

Example 2

A student used a potometer to measure water uptake by a leafy shoot at different temperatures. For each temperature she recorded how far the air bubble moved in 5 minutes.

Temperature / °C	**10**	**20**	**30**	**40**
Distance moved by bubble in 5 minutes / mm	12	26	48	50
Rate / mm per minute	2.4	5.2		10.0

(a) Calculate the rate at 30 °C. **[1]**

(b) Calculate the percentage increase in the rate from 10 °C to 30 °C. **[2]**

(c) Describe the results. **[3]**

(d) **Extended:** explain why the rate increases from 10 °C to 30 °C. **[3]**

(e) Predict the effect of placing a fan next to the shoot at 20 °C, and explain your prediction. **[2]**

(f) Explain why the shoot was cut under water before it was fitted into the potometer. **[1]**

(a) $\frac{48}{5} = 9.6$ mm per minute **B1**.

(b) $\frac{9.6 - 2.4}{2.4} \times 100$ **M1** $= 300\%$ **A1**.

(c) As temperature increases, the rate of transpiration increases **B1**, then levels off above 30 °C **B1**; for example, 2.4 mm per minute at 10 °C rising to 9.6 mm per minute at 30 °C, but only 10.0 mm per minute at 40 °C **B1**.

(d) Water molecules have more kinetic energy **B1**, so water evaporates faster from the surfaces of the mesophyll cells **B1**, and water vapour diffuses faster out through the stomata **B1**.

(e) The rate increases (the bubble moves further in 5 minutes) **B1**; wind removes water vapour from around the leaf, so the concentration gradient of water vapour stays steep (Extended) **B1**.

(f) So that no air gets into the xylem and blocks the flow of water **B1**.

Diagram 3 in "Understand it" plots these results.

Example 3

Extended. Two identical potted plants had their pots sealed in plastic bags and stood on balances at 25 °C for 6 hours, one in dry air and one in humid air.

Air	Mass at start / g	Mass after 6 hours / g
dry (low humidity)	250.0	241.6
humid (high humidity)	250.0	247.9

(a) Calculate the rate of water loss of each plant in g per hour, and how many times faster the plant in dry air lost water. **[3]**

(b) Explain the difference. **[3]**

(c) Explain how water moves up the xylem of these plants. **[3]**

(d) After several hours the plant in dry air began to wilt. Explain why. **[3]**

(a) Dry: $\frac{250.0 - 241.6}{6} = \frac{8.4}{6} = 1.4$ g per hour **B1**. Humid: $\frac{2.1}{6} = 0.35$ g per hour **B1**. $\frac{1.4}{0.35} = 4$ times faster **B1**.

(b) In humid air there is more water vapour outside the leaf **B1**, so the concentration gradient of water vapour between the air spaces and the air is smaller **B1**, and less water vapour diffuses out through the stomata **B1**.

(c) Water evaporating from the leaves creates a transpiration pull **B1**, drawing up a column of water in the xylem **B1**, whose molecules are held together by forces of attraction between them **B1**.

(d) It lost water by transpiration faster than its roots could take it up **B1**; water left its cells by osmosis, so they became flaccid (lost turgor) **B1**, and could no longer support the leaves **B1**.

Example 4

Extended. A grower removed a complete ring of bark (containing the phloem) from the base of some canes of a grape vine. Other canes were left untouched. When the grapes were ripe, the grower measured their sugar content.

Cane	Mean sugar content of the grapes / g per 100 g
ringed	21.3
not ringed	15.8

(a) Calculate the percentage increase in sugar content on ringed canes, to three significant figures. **[2]**

(b) Explain the results. Use the terms source and sink. **[4]**

(c) Explain why the leaves on the ringed canes did not wilt. **[2]**

(d) In a second experiment, radioactive sucrose in the phloem moved 45 cm in 90 minutes. Calculate the rate of translocation in cm per hour. **[1]**

(e) Explain why a potato tuber is a sink in summer but a source in spring. **[3]**

(a) $\frac{21.3 - 15.8}{15.8} \times 100$ **M1** $= 34.8\%$ **A1**.

(b) The leaves photosynthesise and are the source of sucrose **B1**. Sucrose is translocated in the phloem **B1**. On a ringed cane it cannot move past the ring to the rest of the vine **B1**, so more sucrose goes to the grapes, the sinks, where it is stored, so they contain more sugar **B1**.

(c) Only the phloem was removed; the xylem is intact **B1**, so water (and mineral ions) still reach the leaves **B1**.

(d) $\frac{45}{1.5} = 30$ cm per hour **B1**.

(e) In summer the leaves send sucrose to the tuber, which stores it as starch, so the tuber is a sink **B1**. In spring the tuber breaks its starch down to sucrose **B1** and releases it into the phloem to the growing shoots, which have no leaves to photosynthesise yet, so the tuber is a source **B1**.

Common mistakes

- **Saying water evaporates from the stomata or from the leaf surface.** It evaporates from the surfaces of the **mesophyll cells** into the air spaces; water vapour then **diffuses** out through the stomata. Examiners give no credit for "evaporation" unless it is from the mesophyll cells.
- **Choosing evaporation for the stomata step**, or osmosis for either step. Stomata: diffusion.
- **"Leaf cells" or "empty spaces"** for mesophyll cells and air spaces. Use the exact terms.
- **Forgetting that xylem supports the plant.** It is the second function, and it is often the missing mark.
- **Saying phloem carries glucose, starch or "food".** It carries **sucrose** and **amino acids**.
- **Putting phloem in the water pathway.** Water goes root hair → cortex → xylem → mesophyll.
- **Getting humidity backwards.** High humidity **slows** transpiration: the concentration gradient is smaller.

- **Explaining temperature with "the plant is hot"** instead of kinetic energy, faster evaporation and faster diffusion.
- **Describing the temperature instead of the rate** when asked to describe results. Say what happens to the rate of transpiration.
- **Writing "no cell walls"** for xylem. It has thick walls; it has **no cross walls** (end walls). Xylem has no valves.
- **Calling a xylem vessel in a photograph a blood vessel.** Read the stem: it is plant tissue.
- **Not knowing source and sink**, or saying the swelling above a ring is the bark sinking. Leaves are the source; sucrose collects above the ring because the phloem is gone.
- **Talking about water and mineral ions in a translocation answer.** Translocation is sucrose and amino acids in the phloem.
- **Leaving out units** in a rate calculation.

How to get the marks

- **"State"** or **"name"**: one word or short phrase: "xylem", "diffusion", "root hair cell".
- **Use the exact terms**: mesophyll cells, air spaces, stomata, evaporation, diffusion, osmosis, xylem, phloem, lignin, sucrose, amino acids, transpiration pull, turgor, flaccid, source, sink, translocation.
- **"Describe"** a graph or table: the trend, where it changes, and a data quote **with units**. **"Compare"** needs both sets mentioned in the same sentence ("lower than", "twice as fast").
- **"Explain"**: give the reason chain, one link per mark: factor → effect on evaporation or on the concentration gradient → effect on diffusion through the stomata. Use the mark total to judge how many links.
- **"Suggest"**: apply the ideas to a new plant or set-up; more than one answer may be accepted.
- **"Predict" or "draw a line"**: put it clearly above or below the original, and give the reason if asked.
- **Label lines** on a diagram must touch the tissue you name. Label exactly what is asked.
- **Calculations**: show the working, give the unit, and give the number of decimal places or significant figures asked for.
- **Tick or circle** only as many as asked; extra ticks cancel marks.

Quick check

1. Name the tissue that (a) carries sucrose, (b) carries mineral ions, (c) supports the stem.
2. Put these in the order water passes through them: mesophyll cells, root hair cells, xylem, root cortex cells.
3. Leaves on three similar shoots were treated and the water each shoot lost in 5 days was measured: no grease, 9.0 g; lower surfaces greased, 2.5 g; both surfaces greased, 0.2 g. Calculate the mean water loss per day through the lower surfaces, and state which surface has more stomata.
4. State the conditions of temperature, humidity and wind that give the fastest transpiration.
5. **Extended:** (a) Explain why a bulb is a source early in the growing season and a sink later. (b) Explain why xylem vessels have no cross walls.

Answers

1. (a) Phloem; (b) xylem; (c) xylem.
2. Root hair cells → root cortex cells → xylem → mesophyll cells.
3. $\frac{9.0 - 2.5}{5} = 1.3$ g per day through the lower surfaces. The lower surface has more stomata (it lost most of the water).
4. High temperature, low humidity (dry air) and high wind speed.
5. (a) Early on, the bulb breaks down its stored starch and releases sucrose to the growing shoots and leaves, so it is a source; later the photosynthesising leaves send sucrose to it, and it stores it, so it is a sink. (b) So the cells form a long continuous tube with nothing to block the flow, carrying an unbroken column of water.

Past questions to try

- **0610/33/O/N/25 Q3**: the transpiration gap-fill, a rate from a potometer and conclusions from a table (Core).
- **0610/43/O/N/25 Q3**: water pathway, a transpiration calculation, temperature and humidity explained, and wilting (Extended).
- **0610/42/O/N/25 Q2**: xylem and phloem in a root, and a ringing experiment on apple trees (Extended).
- **0610/43/M/J/23 Q2**: the transpiration pull, and wind speed in light and dark (Extended).