

Organisms (Form and function) revision notes

How the form of whole organisms suits their function. Gas exchange in mammals and leaves, and transport in blood and in xylem.

For IB Diploma Biology SL undefined. **HL only** is additional higher level content, for HL students only.

1 Gas exchange Spec B3.1

Gas exchange and exchange surfaces Spec B3.1.1, B3.1.2, B3.1.3

Every organism must take in oxygen for aerobic respiration and remove carbon dioxide, and photosynthesising organisms do the reverse in the light. **Gas exchange** happens by **diffusion**, so it depends on surface area, distance and the concentration gradient.

Why size makes it harder

- As an organism gets bigger, its volume rises faster than its surface area, so the **surface area-to-volume ratio** decreases. There is less surface for each unit of respiring tissue.
- The distance from the centre of the organism to its exterior also increases, and diffusion is only fast over very short distances.
- Small organisms (for example a unicellular organism or a flatworm) can exchange gases across their whole body surface. Large, active organisms need a specialised gas-exchange surface and a transport system to carry gases to and from every cell.

Properties of gas-exchange surfaces

The four properties of gas-exchange surfaces

Property	Why it helps
Permeable	Oxygen and carbon dioxide can pass through the cells and membranes freely.
Thin tissue layer	A short diffusion distance makes diffusion fast.
Moist	Gases dissolve in the film of water before they diffuse across the surface.
Large surface area	More gas can diffuse across at the same time.

Keeping concentration gradients steep in animals

- Dense networks of blood vessels** (capillaries) lie right next to the exchange surface.
- Continuous blood flow** carries oxygenated blood away and brings deoxygenated blood with a high carbon dioxide concentration, so the gradient never levels out.
- Ventilation** replaces the medium next to the surface: air is pumped in and out of lungs, and water is pumped over the gills of fish.

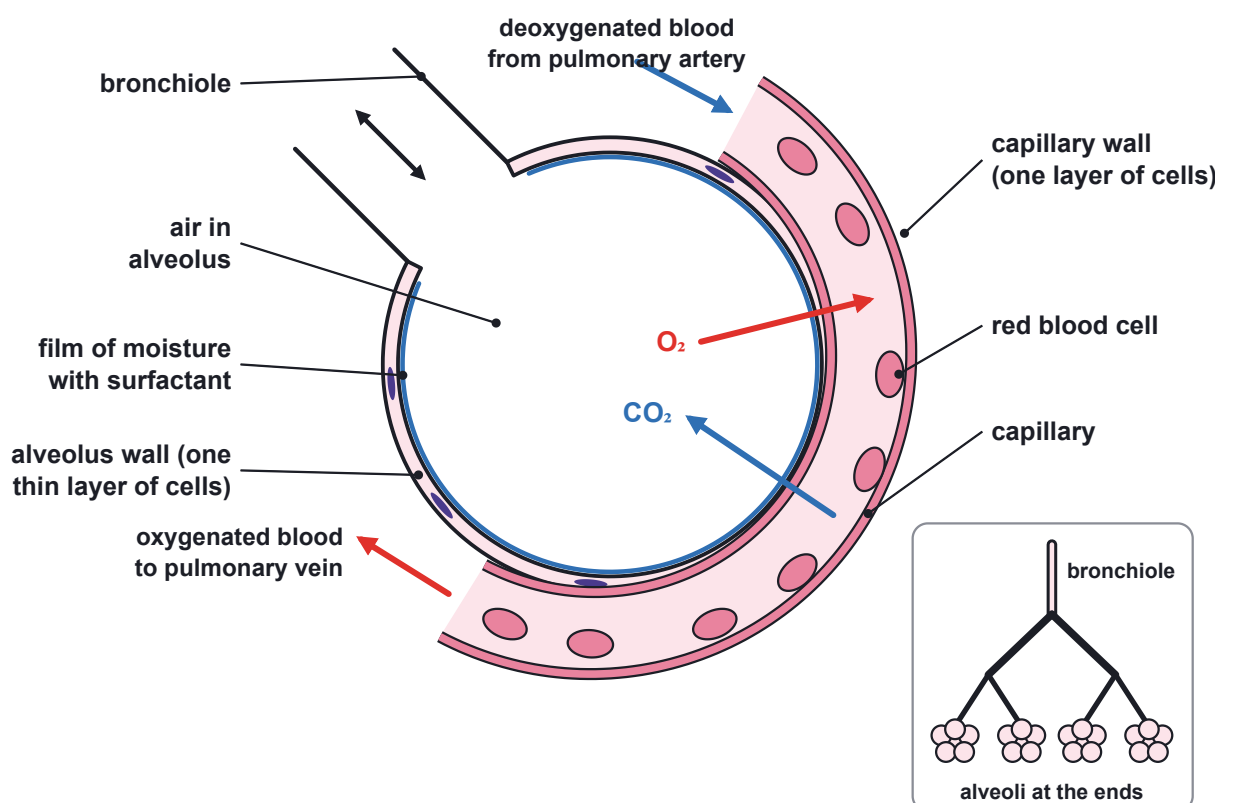
Exam tip: Linking question: how do multicellular organisms solve the problem of access to materials for all their cells? A good answer pairs a large exchange surface with a transport system that delivers to every cell.

Adaptations of mammalian lungs Spec B3.1.4

Air enters through the trachea, which divides into two bronchi, one to each lung. Each bronchus divides again and again into a **branched network of bronchioles**, which end in clusters of tiny air sacs called **alveoli**.

Adaptations of the alveolar lungs for gas exchange	
Adaptation	How it helps gas exchange
Branched network of bronchioles	Carries air to and from hundreds of millions of alveoli spread through the whole lung.
High surface area	The very large number of small alveoli gives a huge total surface for diffusion.
Extensive capillary beds	Each alveolus is covered in capillaries, so blood flows close to every part of the surface and keeps the gradient steep.
Thin walls	The alveolus wall and the capillary wall are each one layer of very thin, flattened cells, so the diffusion distance is short.
Surfactant	A fluid secreted by cells in the alveolus wall reduces the surface tension of the water lining, so the alveoli do not stick together and collapse when air is breathed out.
Moist lining	Oxygen dissolves in the film of moisture before it diffuses into the blood.

Oxygen diffuses from the air in the alveolus into the blood, and carbon dioxide diffuses from the blood into the alveolus. Ventilation and continuous blood flow keep both gradients steep.



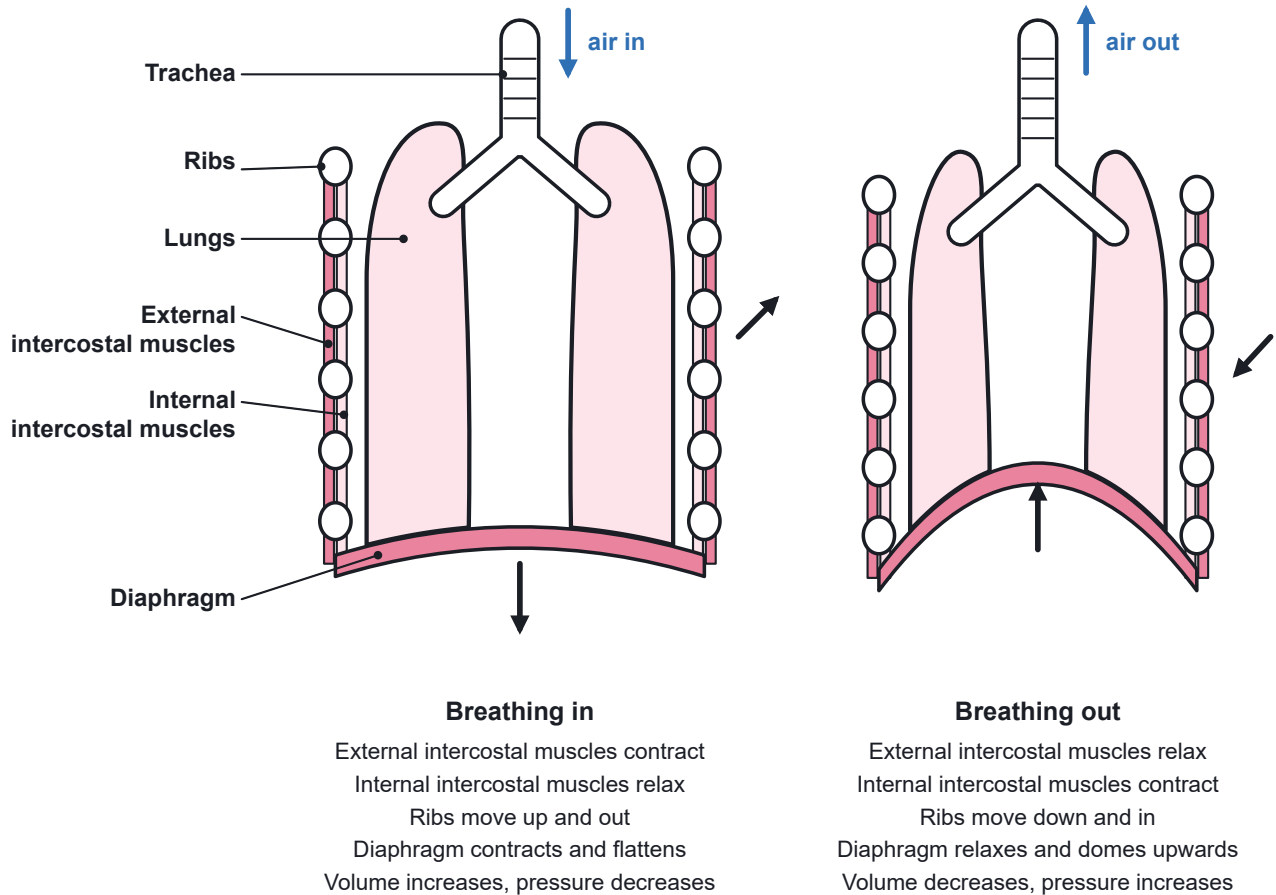
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Gas exchange in an alveolus: **two thin layers of cells** separate the air from the blood, and blood flow keeps the gradients steep.

Common mistake: Surfactant does not help gases dissolve or diffuse. Its job is to lower surface tension so the alveoli stay open.

Ventilation and lung volumes Spec B3.1.5, B3.1.6

Air always flows from higher to lower pressure. Muscles change the **volume of the thorax**, which changes the pressure inside it (pressure and volume are inversely related).



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Inspiration and expiration change the volume of the thorax. The breathing-out panel shows forced expiration: in quiet expiration the internal intercostal muscles stay relaxed. The abdominal muscles (not drawn) also contract in forced expiration.

Muscle actions during ventilation		
Structure	Inspiration (breathing in)	Expiration (breathing out)
Diaphragm	Contracts and flattens, moving down	Relaxes and is pushed back up into a dome (by elastic recoil and the abdominal organs; in forced expiration also by the abdominal muscles)
External intercostal muscles	Contract, pulling the ribcage up and out	Relax
Internal intercostal muscles	Relax	Relaxed in quiet expiration; contract in forced expiration, pulling the ribcage down and in
Abdominal muscles	Relax, so abdominal organs can be pushed down	Relaxed in quiet expiration; contract in forced expiration, pushing abdominal organs and the diaphragm up
Ribs	Move up and out	Move down and in (by gravity and elastic recoil in quiet expiration; pulled by the internal intercostals in forced expiration)
Thorax volume and pressure	Volume increases, pressure falls below atmospheric, air flows in	Volume decreases, pressure rises above atmospheric, air flows out

Quiet expiration (breathing out at rest) is mainly passive: the diaphragm and external intercostal muscles relax, and the stretched lungs and chest wall recoil elastically, so thorax volume falls. **Forced expiration** (during exercise, coughing, or when measuring vital capacity or expiratory reserve) is active: the internal intercostal muscles and the abdominal muscles contract, so more air is pushed out, faster.

Common mistake: Do not say the internal intercostal muscles contract in every breath out. They contract only in forced expiration; quiet expiration relies on muscle relaxation and elastic recoil.

Lung volumes

Tidal volume	The volume of air breathed in or out in one normal breath.
Inspiratory reserve volume	The extra volume of air that can be breathed in by force after a normal inspiration.
Expiratory reserve volume	The extra volume of air that can be breathed out by force after a normal expiration.
Vital capacity	The largest volume of air that can be breathed out after the deepest possible breath in: tidal volume + inspiratory reserve + expiratory reserve.

Some air always stays in the lungs (the residual volume), so a spirometer cannot measure it and vital capacity is less than total lung volume.

Practical skill: Measure lung volumes with a digital spirometer, or by breathing out through a tube into an upturned, water-filled, calibrated bottle and reading the volume of water displaced. Repeat each measurement three times and use the mean.

Reading a spirometer trace

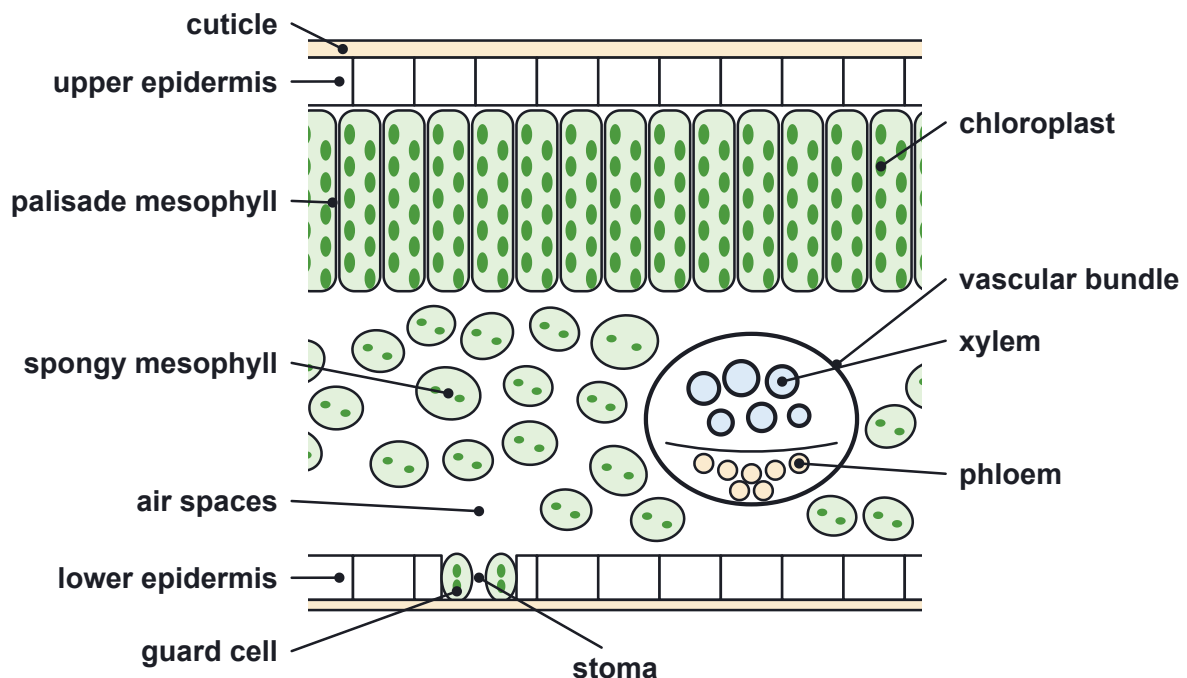
On a spirometer trace, a normal breath goes from 2.3 dm³ to 2.8 dm³. The deepest breath in reaches 5.8 dm³ and the deepest breath out falls to 1.2 dm³. Find the tidal volume, inspiratory reserve, expiratory reserve and vital capacity. (Practice data.)

1. Tidal volume = $2.8 - 2.3 = 0.5 \text{ dm}^3$
2. Inspiratory reserve = $5.8 - 2.8 = 3.0 \text{ dm}^3$
3. Expiratory reserve = $2.3 - 1.2 = 1.1 \text{ dm}^3$
4. Vital capacity = $5.8 - 1.2 = 4.6 \text{ dm}^3$ (check: $0.5 + 3.0 + 1.1 = 4.6 \text{ dm}^3$)

Answer: TV 0.5 dm³, IRV 3.0 dm³, ERV 1.1 dm³, VC 4.6 dm³

Gas exchange in leaves Spec B3.1.7, B3.1.8

In the light a leaf takes in carbon dioxide for photosynthesis and releases oxygen. The challenge is to let gases in and out without losing too much water.



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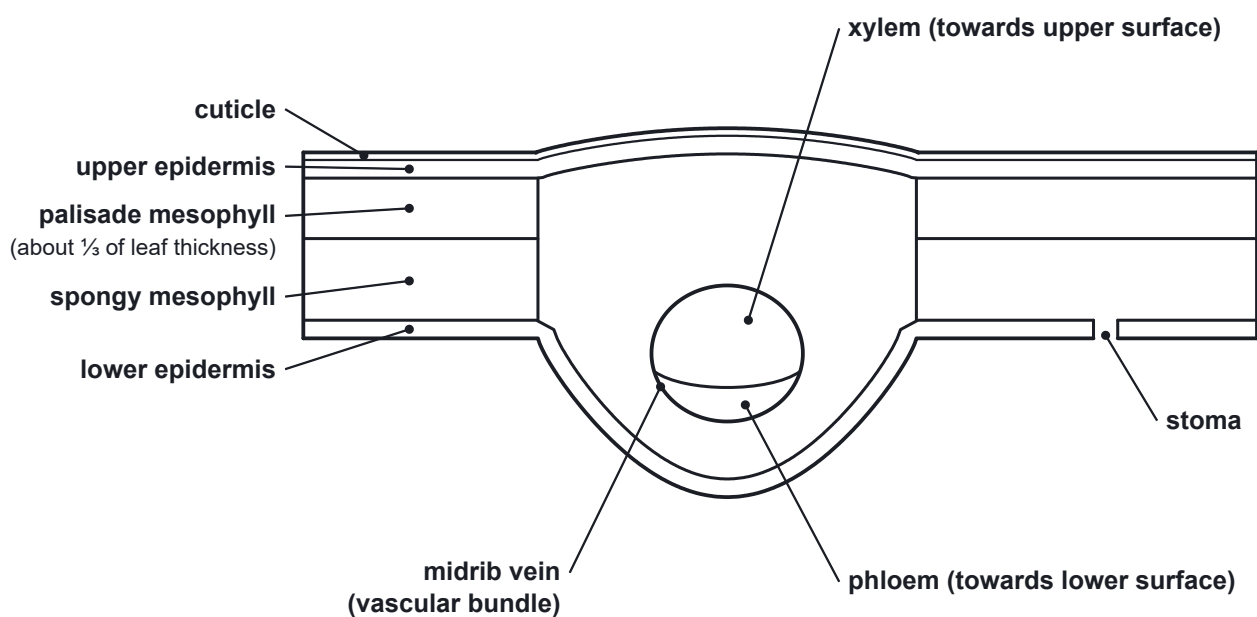
Tissues of a dicotyledonous leaf, drawn with cells. A plan diagram shows the same tissues as outlines only.

Adaptations of a leaf for gas exchange

Structure	Adaptation
Waxy cuticle	Waterproof layer on the epidermis that reduces water loss by evaporation.
Epidermis	A single, tightly packed layer of cells that secretes the cuticle and protects the leaf; it is transparent, so light reaches the mesophyll.
Stomatal guard cells	Pairs of guard cells open the stoma between them to let CO ₂ in and O ₂ out, and close it to reduce water loss.
Air spaces	Connect the stomata with the mesophyll so gases diffuse quickly through the leaf.
Spongy mesophyll	Loosely packed cells with moist walls give a large surface area for gas exchange.
Veins	Xylem brings water to replace the water lost; phloem carries away the sugars made in photosynthesis.

Plan diagram of a leaf

A **plan diagram** shows the distribution of tissues as areas outlined by single lines, with no individual cells drawn. Draw it large, use a sharp pencil, no shading, and label with ruled lines that do not cross.



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Plan diagram of a dicotyledonous leaf: tissues as outlines only. In the vein, **xylem is towards the upper surface**.

Exam tip: In the vein, xylem is towards the upper surface and phloem towards the lower surface. Examiners check this in leaf plan diagrams.

Transpiration and stomatal density Spec B3.1.9, B3.1.10

Water evaporates from the moist walls of mesophyll cells into the air spaces, then water vapour diffuses out through open stomata. Because stomata must be open for CO₂ to enter, **transpiration is a consequence of gas exchange**.

Factors affecting the rate of transpiration

Factor	Effect on rate	Reason
Light intensity	Increases	Stomata open in the light for photosynthesis.
Temperature	Increases	More evaporation from cell walls and faster diffusion of water vapour.
Humidity	Decreases	Moist air outside lowers the water vapour concentration gradient.
Wind speed	Increases	Moving air removes water vapour from around the stomata, keeping the gradient steep.
Soil water availability	Decreases if water is short	Guard cells lose turgor and stomata close.

The rate of transpiration can be estimated with a potometer, which measures water uptake by a cut shoot.

Stomatal density

$$\text{stomatal density} = \text{number of stomata} \div \text{area of field of view (mm}^2\text{)}$$

Practical skill: To make a leaf cast, paint clear nail varnish on the lower epidermis, let it dry, lift it off with clear tape and stick it to a slide. Count stomata at high power in several fields of view, or count them on a micrograph with a known scale.

Calculating stomatal density

At high power the field of view has a diameter of 0.40 mm. Counts of stomata in five fields of view are 24, 27, 22, 26 and 26. Calculate the mean stomatal density. (Practice data.)

1. Mean count = $(24 + 27 + 22 + 26 + 26) \div 5 = 125 \div 5 = 25$
2. Radius = $0.40 \div 2 = 0.20 \text{ mm}$
3. Area = $\pi r^2 = 3.14 \times 0.20^2 = 0.126 \text{ mm}^2$
4. Density = $25 \div 0.126 = 198.4$

Answer: about 200 stomata per mm^2 ($2.0 \times 10^2 \text{ mm}^{-2}$)

Maths skill: Repeated counts vary because biological material is variable. Replicate counts and a mean increase the reliability of the data; the range or standard deviation shows the spread.

Quick check

1. What happens to the surface area-to-volume ratio as an organism grows larger?
2. What is the function of surfactant in the alveoli?
3. Which three volumes add up to the vital capacity?
4. Why does increased humidity reduce the rate of transpiration?

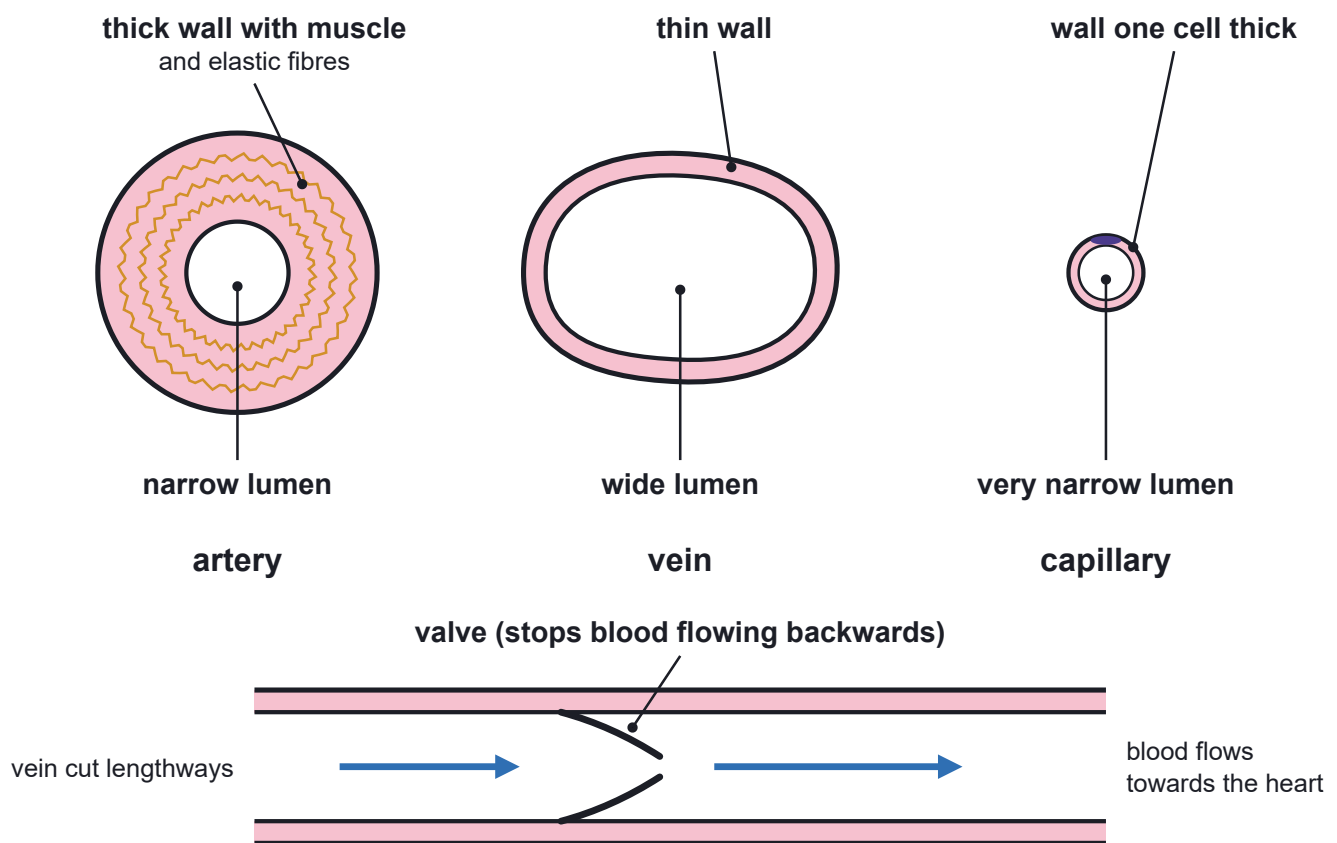
Adaptations of capillaries

Arterioles divide into networks of **capillaries** called capillary beds, which pass close to every active cell. Capillaries rejoin to form venules. All exchange between blood and tissues happens in capillaries.

Adaptations of capillaries	
Adaptation	How it helps exchange
Branching into dense networks	Gives a large total surface area and brings blood close to every cell.
Narrow diameter (about the width of a red blood cell)	Large surface area relative to volume; red blood cells pass close to the wall.
Thin wall: one layer of flattened endothelium cells on a basement membrane	Short diffusion distance.
Fenestrations (pores) in some capillaries	Allow faster exchange of fluid and solutes where exchange needs to be particularly rapid, for example in the glomerulus of the kidney and in the villi of the small intestine.
Slow blood flow	More time for exchange.

Common mistake: Write 'the capillary wall is one cell thick', not 'the capillary has a cell wall'. Animal cells have no cell walls.

Structure and adaptations of arteries and veins Spec B3.2.2, B3.2.3, B3.2.5



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Arteries have thick walls and narrow lumens; veins have thin walls, wide lumens and valves.

Arteries and veins compared		
Feature	Artery	Vein
Wall thickness relative to lumen	Thick wall, narrow lumen	Thin wall, wide lumen
Tunica media (smooth muscle and elastic fibres)	Thick layer	Thin layer
Shape in a micrograph	Round, with a folded inner lining	Often flattened or irregular
Valves	None along their length	Present
Blood pressure	High, pulsing	Low, steady

Practical skill: To identify a vessel in a micrograph, compare the thickness of the wall with the diameter of the lumen. In an artery the wall is thick relative to a narrow, round lumen; in a vein the wall is much thinner than the width of its wide, often flattened lumen.

Adaptations of arteries

- Elastic fibres** stretch when the ventricles pump blood in, then recoil between beats. The recoil pushes blood on and keeps the pressure up, so flow is less pulsing further from the heart.
- A thick layer of **smooth muscle** can contract to narrow the lumen, helping to maintain blood pressure.

- The thick wall, with a tough outer layer of collagen fibres, withstands high pressure without bursting.
- The narrow lumen helps maintain high pressure.

Adaptations of veins

- Pressure in veins is too low to push blood back to the heart unaided.
- Pocket **valves** close if blood starts to flow backwards, so blood moves only towards the heart.
- The thin, **flexible wall** is compressed when nearby skeletal muscles contract, squeezing blood towards the heart.
- A wide lumen offers little resistance to flow.

Pulse rates and occlusion of the coronary arteries Spec B3.2.4, B3.2.6

Measuring pulse rate

Each heartbeat sends a surge of blood along the arteries, felt as a **pulse**. The pulse rate equals the heart rate.

Practical skill: Press two fingertips (not the thumb, which has its own pulse) on the radial artery on the inside of the wrist or the carotid artery in the neck. Count beats for 30 s and multiply by 2, repeat and find the mean. Compare the result with a digital heart rate monitor or pulse oximeter.

Pulse rate

A student counts 19 beats in 15 seconds. Calculate the pulse rate. (Practice data.)

1. Beats per minute = $19 \times (60 \div 15)$
2. = $19 \times 4 = 76$

Answer: 76 beats per minute

Occlusion of the coronary arteries

The **coronary arteries** branch from the aorta and supply cardiac muscle with oxygen and glucose.

1. Fatty deposits (atheroma or plaque) build up in the wall of a coronary artery, under the endothelium: atherosclerosis.
2. The lumen narrows and the wall hardens, so blood flow is reduced.
3. If a plaque ruptures, a blood clot (thrombus) can form and block the artery completely: **occlusion**.
4. Cardiac muscle beyond the blockage gets too little oxygen for aerobic respiration, causing chest pain (angina) or, if severe, a heart attack (myocardial infarction), when part of the heart muscle dies.

Risk factors include a diet high in saturated fat, high blood cholesterol, smoking, high blood pressure, obesity, lack of exercise, increasing age, male sex and family history.

Exam tip: A correlation coefficient (r) from -1 to +1 measures how strongly two variables are correlated. Even a strong correlation, such as between saturated fat intake and coronary heart disease, does not prove that one causes the other; a low r or no correlation can be evidence against a hypothesis.

Water transport in xylem Spec B3.2.7, B3.2.8

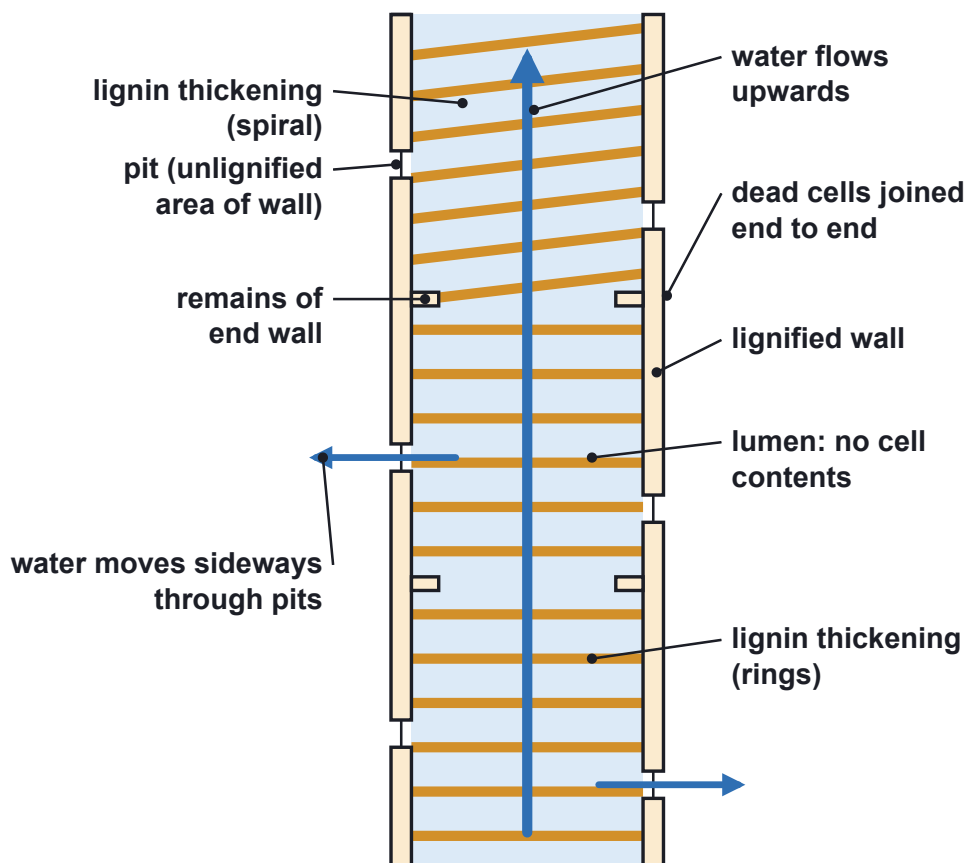
1. Water evaporates from the cell walls of spongy mesophyll cells and diffuses out of the leaf through stomata (transpiration).
2. Water is drawn out of the xylem vessels in the leaf veins and through the cell walls to replace it, by **capillary action** (adhesion of water to cellulose).
3. This generates **tension** (a negative pressure potential) in the xylem.
4. The tension pulls water up the xylem from the roots.

5. **Cohesion** between water molecules, due to hydrogen bonding, keeps the column of water continuous so it does not break.

This is the cohesion-tension mechanism. It is passive: the energy comes from evaporation, driven by heat from the sun, not from ATP.

Adaptations of xylem vessels

Xylem vessel adaptations	
Feature	Function
No cell contents (dead cells, no cytoplasm or nucleus)	Unimpeded flow of water.
Incomplete or absent end walls	Cells form a continuous tube, so water flows without obstruction.
Lignified walls (thickened in rings, spirals or networks)	Withstand the tension without collapsing inwards.
Pits (unlignified areas of wall)	Allow water to enter and leave the vessel, and pass between neighbouring vessels.



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A xylem vessel: a continuous tube of dead cells with **lignified walls** that resist tension, and pits for lateral movement of water.

Exam tip: Linking question: how do pressure differences contribute to the movement of materials?
Xylem uses negative pressure (tension); blood and phloem sap use positive pressure.

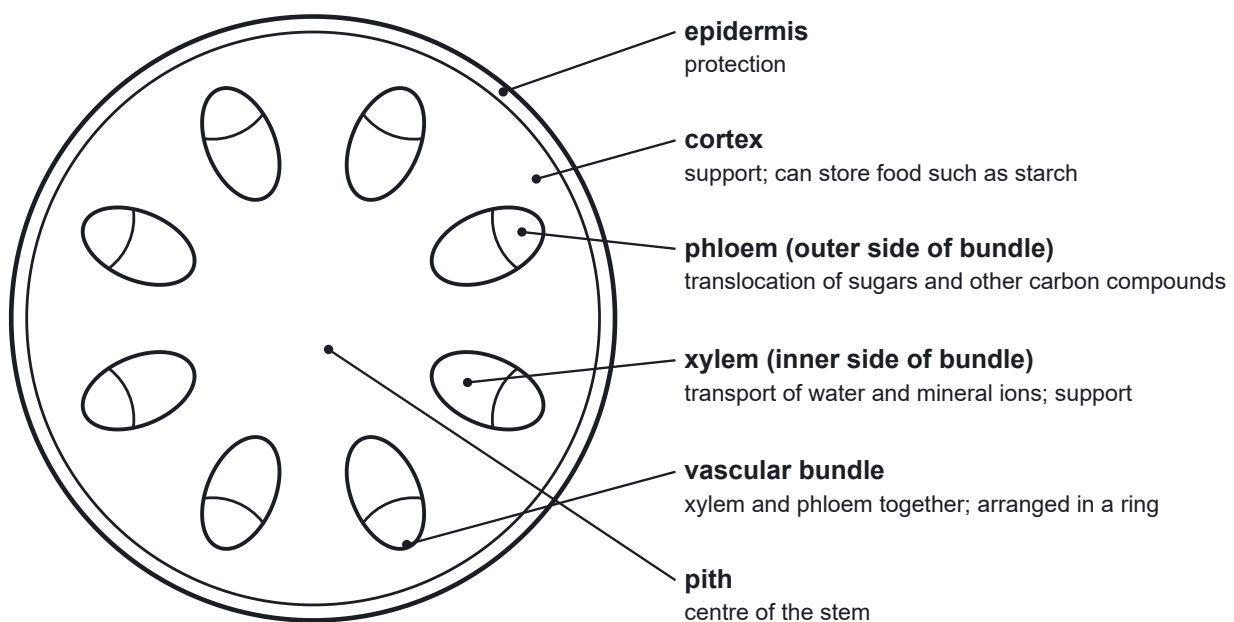
Tissues in dicotyledonous stems and roots Spec B3.2.9, B3.2.10

Functions of tissues in stems and roots

Tissue	Main function
Epidermis	Protective outer layer; in roots it bears root hairs that absorb water and mineral ions.
Cortex	Packing and support tissue between epidermis and vascular tissue; can store food such as starch; in roots water crosses it to reach the xylem.
Xylem	Transports water and mineral ions from roots to leaves; lignified walls give support.
Phloem	Transports sap containing sugars and other carbon compounds by translocation.
Vascular bundle	A strand of xylem and phloem together.

Stem

- Vascular bundles are arranged in a **ring** near the outside of the stem.
- In each bundle, phloem is on the outside and xylem on the inside.
- Cortex lies between the epidermis and the ring of bundles; the centre of the stem is pith.

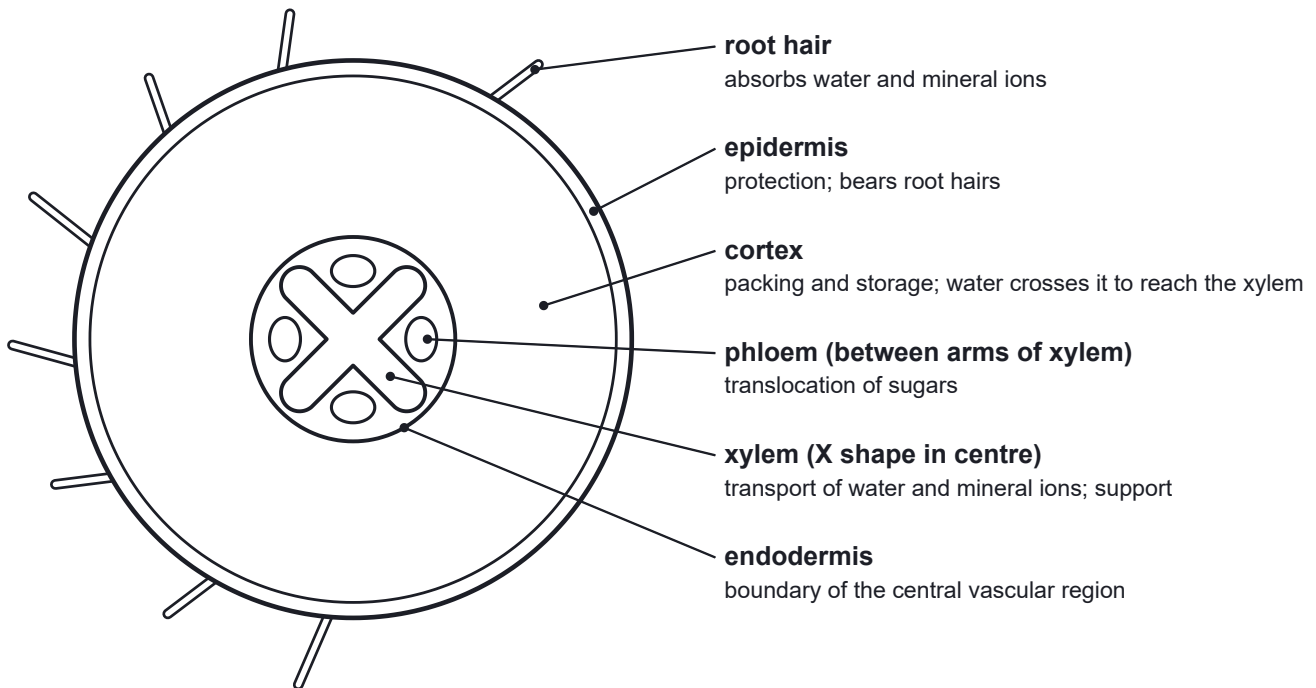


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Plan diagram of a dicotyledonous stem: vascular bundles in a **ring**, phloem outside and xylem inside each bundle.

Root

- Xylem and phloem form a **central vascular region**, not a ring: xylem in a star or X shape with phloem between its arms.
- The guide asks you to identify vascular bundles in the root too. In a root they are **radial**: the groups of xylem and phloem alternate on different radii inside one central vascular cylinder (the stele), instead of xylem and phloem sharing a bundle as in the stem.
- A wide cortex surrounds the vascular region, with the epidermis and root hairs on the outside.
- The central position of vascular tissue resists the pulling forces on a root.



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Plan diagram of a dicotyledonous root: xylem and phloem form a **central vascular region**, with phloem between the arms of the xylem.

Practical skill: Draw plan diagrams from micrographs: outline each tissue with a single clear line, keep proportions accurate, no cells and no shading. Label the tissues the guide lists (epidermis, cortex, vascular bundles, xylem and phloem; pith in the stem) and, for the stem, annotate each label with its main function.

Quick check

1. What are fenestrations in capillaries?
2. How do elastic fibres in artery walls help maintain blood pressure?
3. What causes tension in the xylem?
4. Where is xylem found in a dicotyledonous root?

Quick check answers

Gas exchange

- 1 . It decreases.
- 2 . It reduces surface tension so the alveoli do not stick together and collapse when air is breathed out.
- 3 . Tidal volume, inspiratory reserve volume and expiratory reserve volume.
- 4 . It reduces the concentration gradient of water vapour between the air spaces and the outside air.

Transport

- 1 . Pores in the capillary wall that allow particularly rapid exchange, for example in the kidney glomerulus.
- 2 . They stretch when blood is pumped in and recoil between beats, pushing blood on and keeping the pressure up.
- 3 . Loss of water by transpiration from leaf cell walls draws water out of the xylem by capillary action.
- 4 . In the centre, in a star or X shape, with phloem between its arms.