

Structure and functions in living organisms

revision notes

This topic is about how living organisms are built and how they work. It starts with cells, the molecules and enzymes inside them and how substances move in and out. It then follows the life processes of flowering plants and humans: nutrition, respiration, gas exchange, transport, excretion, and co-ordination and response.

For Pearson Edexcel International GCSE Biology 4BI1 and Science (Double Award) 4SD0. **Biology only** is not in the Double Award and is only examined on Paper 2.

1 Cells and levels of organisation Spec 2.1-2.6B

Levels of organisation Spec 2.1

Living things are built up in levels. Each level is made from the one below it. The smallest level you need to know is the **organelle**.

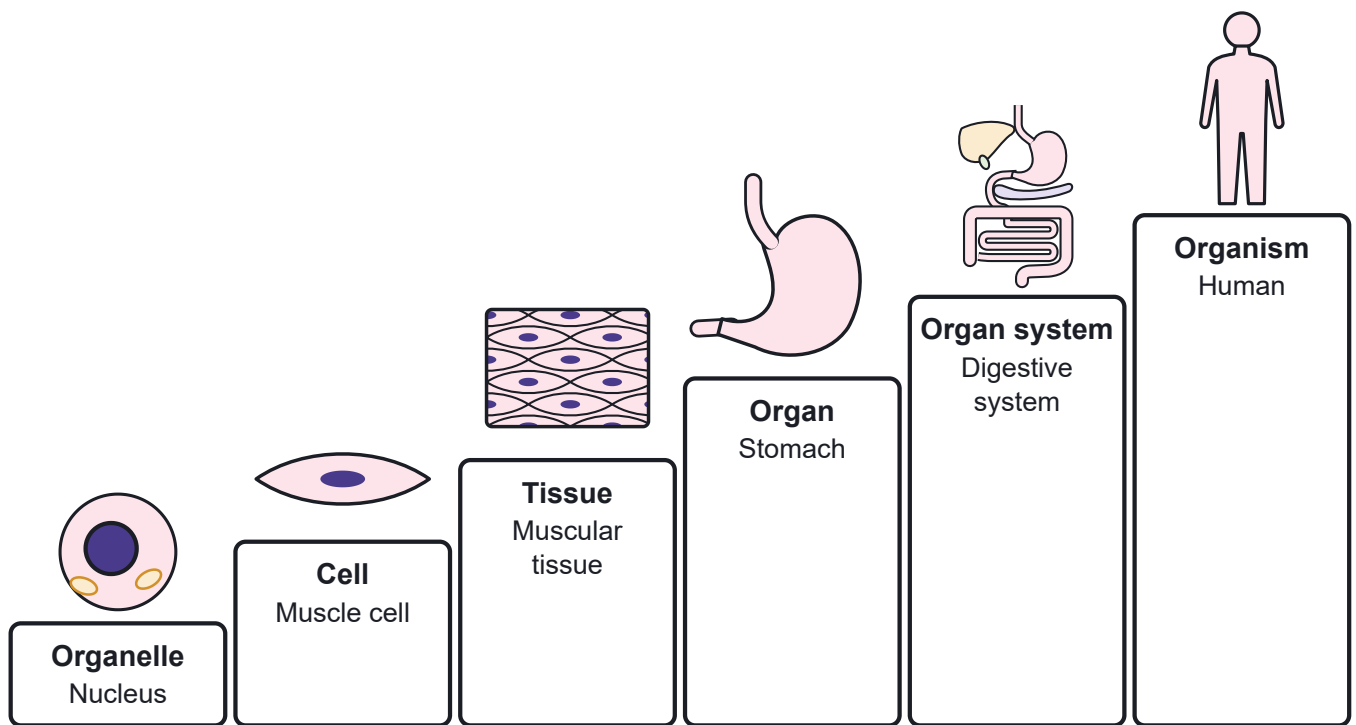
Organelle	A structure inside a cell that has a particular job, such as the nucleus or a mitochondrion.
Cell	The basic building block of all living organisms.
Tissue	A group of cells with a similar structure and function.
Organ	A group of different tissues that work together to perform a specific function.
Organ system	A group of organs that work together to carry out a major job in the body.

The stomach is a good example of an **organ**. It is made of several tissues that work together. Muscular tissue churns the food, glandular tissue makes digestive juices (enzymes and acid), and epithelial tissue covers the inside and outside surfaces.

The stomach is one of the organs in the **digestive system**. This is an **organ system**: several organs working together to digest and absorb food.

Levels of organisation		
Level	Animal example	Plant example
Organelle	A nucleus or a mitochondrion	A chloroplast
Cell	A muscle cell	A palisade mesophyll cell
Tissue	Muscular tissue	Palisade mesophyll
Organ	The stomach or the heart	A leaf
Organ system	The digestive system or the circulatory system	Roots, stem and leaves (transport system)
Organism	A human	A tree

Exam tip: An organ contains more than one tissue. To explain why something is an organ, say it is made of several tissues that work together to do a specific job.

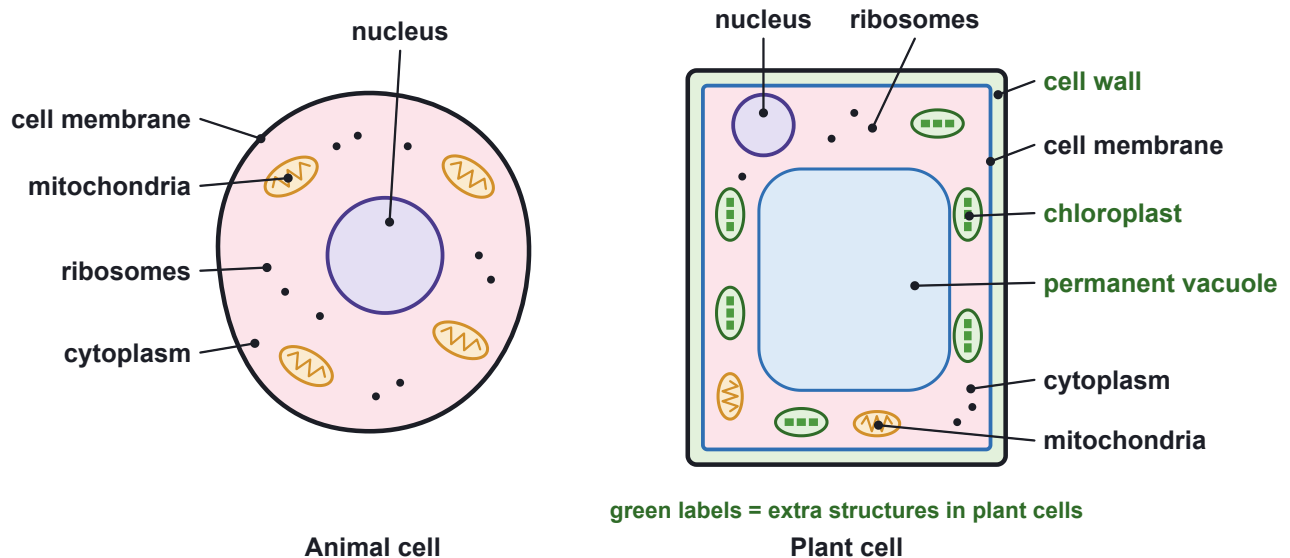


Levels of organisation: **organelle → cell → tissue → organ → organ system → organism**.

Animal and plant cell structure Spec 2.2, 2.3, 2.4

Most animal cells have a nucleus, cytoplasm, a cell membrane, mitochondria and ribosomes. Plant cells have all of these as well, and they often also have **chloroplasts**, a **vacuole** filled with cell sap and a **cell wall**.

Cell structures and their functions			
Structure	Function	Animal cell	Plant cell
Nucleus	Contains the genetic material (DNA) and controls the activities of the cell	Yes	Yes
Cytoplasm	Where most chemical reactions happen	Yes	Yes
Cell membrane	Controls the movement of substances into and out of the cell	Yes	Yes
Mitochondria	Where aerobic respiration takes place, releasing energy for the cell	Yes	Yes
Ribosomes	Where proteins are made (protein synthesis)	Yes	Yes
Cell wall	Made of cellulose; strengthens the cell and supports it	No	Yes
Chloroplasts	Contain chlorophyll, which absorbs light energy for photosynthesis	No	Yes (in cells exposed to light)
Vacuole	Filled with cell sap (a solution of sugars and salts); helps to keep the cell firm	No (or only small, temporary ones)	Yes (large, permanent)



Plant cells have the same structures as animal cells, plus a cell wall, chloroplasts and a large vacuole.

Similarities and differences

Comparing plant and animal cells		
	Animal cell	Plant cell
Similarities	Nucleus, cytoplasm, cell membrane, mitochondria, ribosomes	Nucleus, cytoplasm, cell membrane, mitochondria, ribosomes
Cell wall	Absent	Present, made of cellulose
Chloroplasts	Absent	Often present
Vacuole	Absent or small	Large vacuole with cell sap

Exam tip: When asked to explain how a structure is related to its function, name the structure, state what it does, then link that to the job of the cell. Chloroplasts absorb light for photosynthesis, so they are found in cells that make food.

Cell differentiation and specialised cells Spec 2.5B Biology only

Differentiation is the process by which a cell becomes specialised for a particular job. The cell gains the structures it needs to carry out its function. For example, a nerve cell has a long axon, and a root hair cell has a long projection that gives it a large surface area.

Differentiation is important in the development of specialised cells because a multicellular organism needs many different cell types doing different jobs. Specialised cells form tissues, which make up organs. Each type of **specialised cell** can then carry out its job efficiently.

Examples of specialised cells		
Cell	Special feature	How it helps
Root hair cell	Long projection from the cell	Large surface area for absorbing water and mineral ions
Nerve cell	Long axon	Carries electrical impulses over long distances
Red blood cell	No nucleus, and full of haemoglobin	No nucleus leaves more room for haemoglobin, which carries oxygen
Palisade mesophyll cell	Many chloroplasts	Absorbs a lot of light for photosynthesis

Exam tip: Link structure to function. 'The cell has become specialised' earns less than saying what structure it gained and what job that structure helps with.

Stem cells in medicine Spec 2.6B Biology only

Stem cells are cells that have not yet differentiated, so they can develop into different types of cell. They may be able to replace damaged or diseased cells. Possible uses include treating conditions such as diabetes and paralysis, and replacing damaged tissue.

Embryonic stem cells come from early embryos and can develop into almost any type of cell. **Adult stem cells**, for example from bone marrow, can develop into only a few types of cell.

Advantages and disadvantages of using stem cells in medicine	
Advantages	Disadvantages
Could treat conditions that are currently hard to treat, such as diabetes or paralysis.	Stem cells can divide out of control and form a tumour.
Could replace damaged cells with new healthy cells.	Viruses in donated stem cells could be passed to the patient and cause disease.
Could be used to grow replacement tissues.	The patient's immune system may reject cells from another person.
	Some people object to using embryos for ethical or religious reasons.

Exam tip: In a 'discuss' question, include at least one advantage and one disadvantage, and finish by weighing them up.

Quick check

- Put these in order, smallest first: organ, cell, organelle, tissue, organ system.
- What is the function of the mitochondria?
- Name three structures found in plant cells but not animal cells.
- Biology only What is differentiation?
- Biology only Give one disadvantage of using stem cells in medicine.

2 Biological molecules and enzymes Spec 2.7-2.14B

Carbohydrates, proteins and lipids Spec 2.7, 2.8

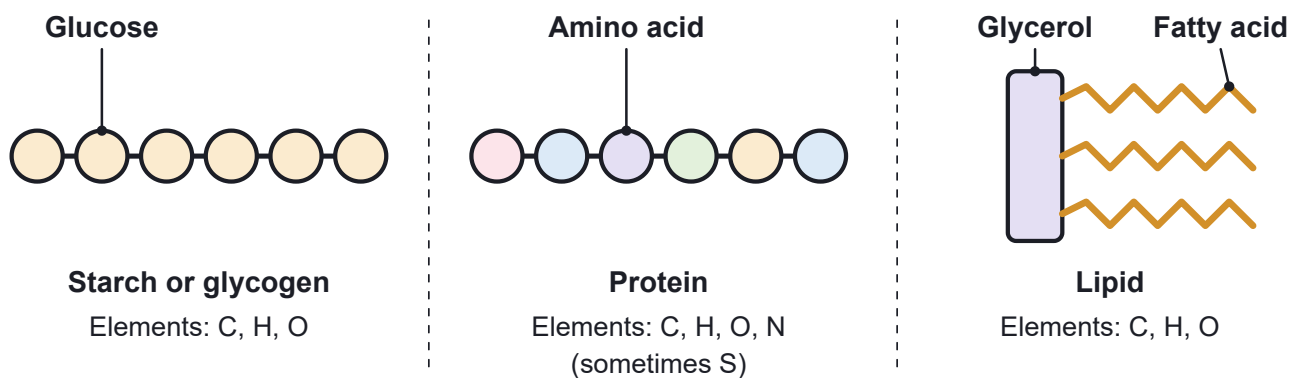
Carbohydrates, proteins and lipids (fats and oils) are the three main groups of **biological molecules**. They are all made from a small number of chemical elements.

Elements in biological molecules	
Biological molecule	Elements present
Carbohydrates	Carbon, hydrogen and oxygen (C, H, O)
Proteins	Carbon, hydrogen, oxygen and nitrogen (C, H, O, N), and sometimes sulfur (S)
Lipids (fats and oils)	Carbon, hydrogen and oxygen (C, H, O)

Carbohydrates, proteins and lipids are **large molecules** made up from smaller basic units. Many small units are joined together to make one large molecule.

Large molecules and their basic units	
Large molecule	Made from
Starch	Many simple sugars (glucose) joined together
Glycogen	Many simple sugars (glucose) joined together
Protein	Amino acids
Lipid	Fatty acids and glycerol (one glycerol and three fatty acids)

Starch is the storage carbohydrate in plants. Glycogen is the storage carbohydrate in animals. Both are made from glucose, which is a simple sugar.



Large molecules are built from smaller units: **glucose** → starch or glycogen, **amino acids** → protein, **glycerol + three fatty acids** → lipid.

Exam tip: A lipid is made from one glycerol and three fatty acids. Learn the numbers 1 and 3, and remember that, of the three groups, only proteins contain nitrogen.

Practical: food tests Spec 2.9

You can use chemical reagents to identify the main biological molecules in a food. If the food is a solid, crush it with a little water and use the liquid. For the fat test, shake the food with ethanol instead. Always wear eye protection.

Practical: A negative result means the reagent keeps its original colour. Learn the start colour as well as the positive result.

Food tests			
Food	Reagent	Method	Positive result
Glucose (a reducing sugar)	Benedict's solution	Add Benedict's solution and heat in a hot water bath for a few minutes	Blue to green, yellow, orange or brick-red , depending on the amount of sugar
Starch	Iodine solution	Add a few drops of iodine solution to the sample	Orange-brown to blue-black
Protein	Biuret reagent	Add biuret reagent to the sample and mix	Blue to purple (lilac)
Fat	Ethanol	Shake the sample with ethanol, then pour the mixture into water	A cloudy white emulsion forms

In a negative result, iodine stays orange-brown, Benedict's solution and biuret reagent stay blue, and the ethanol test stays clear. Ethanol is flammable, so keep it away from naked flames. Benedict's solution is heated in a water bath, not directly over a flame.

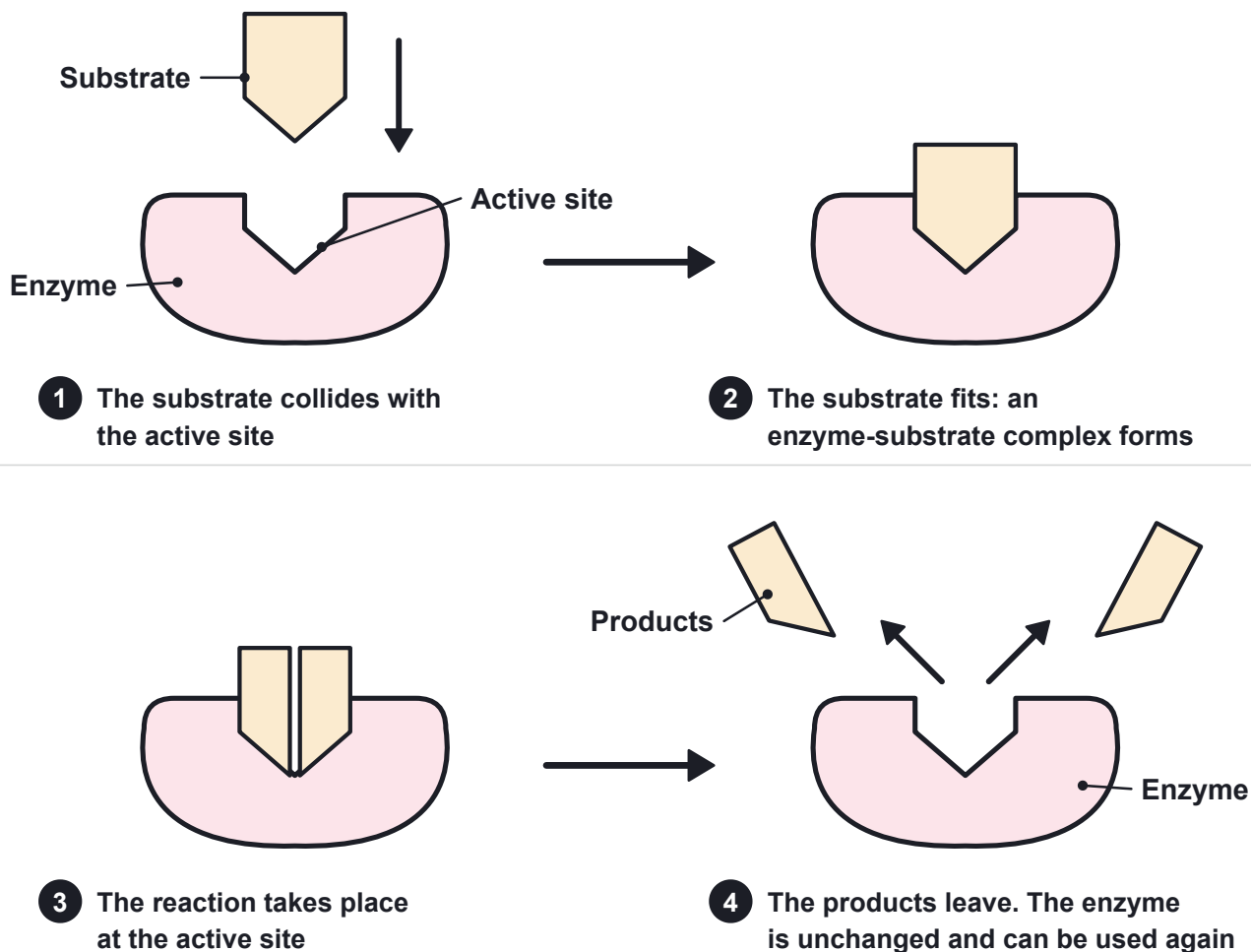
Enzymes as biological catalysts Spec 2.10

Metabolic reactions are the chemical reactions that happen in living cells. They are controlled by **enzymes**. Enzymes are proteins that act as **biological catalysts**. A catalyst speeds up a reaction without being used up. Each enzyme has a region called the **active site**, which has a particular shape.

The molecule an enzyme acts on is called the **substrate**. The substrate has a shape that is **complementary** to the active site, so it fits in, like a key in a lock. This is called the lock and key model.

1. The substrate collides with the active site of the enzyme.
2. The substrate fits into the active site, forming an enzyme-substrate complex.
3. The reaction takes place at the active site.
4. The product or products leave the active site and the enzyme is free to be used again.

Enzymes are **specific**. Only a substrate with a shape that fits the active site can bind to it, so each enzyme catalyses only one type of reaction.



The lock and key model. The substrate is complementary to the active site, and the enzyme is not used up.

*Exam tip: The mark scheme word is **complementary**. Say the shape of the substrate is complementary to the shape of the active site, not that they are 'the same'.*

Temperature, pH and enzyme activity Spec 2.11, 2.13

Temperature

As temperature increases, the particles move faster and have more kinetic energy. Enzyme and substrate collide more often, so the rate of reaction increases. The rate is highest at the **optimum temperature**, which is around 37 °C for many human enzymes.

Above the optimum temperature, the enzyme's structure is damaged and the shape of the active site changes. The substrate no longer fits, so the enzyme is **denatured** and the rate falls quickly towards zero. Denaturing is permanent.

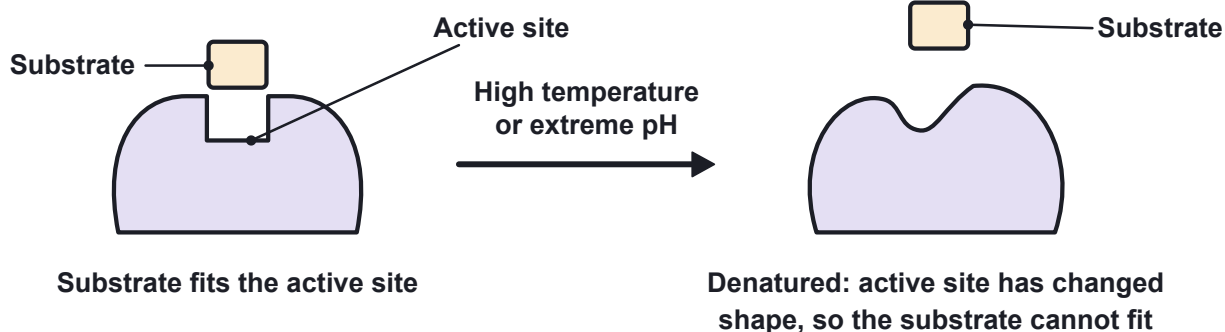
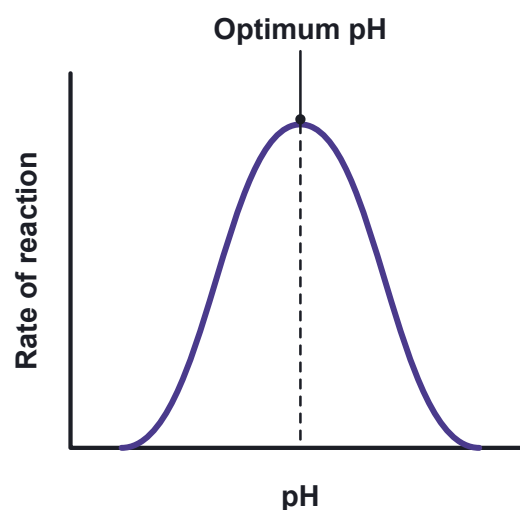
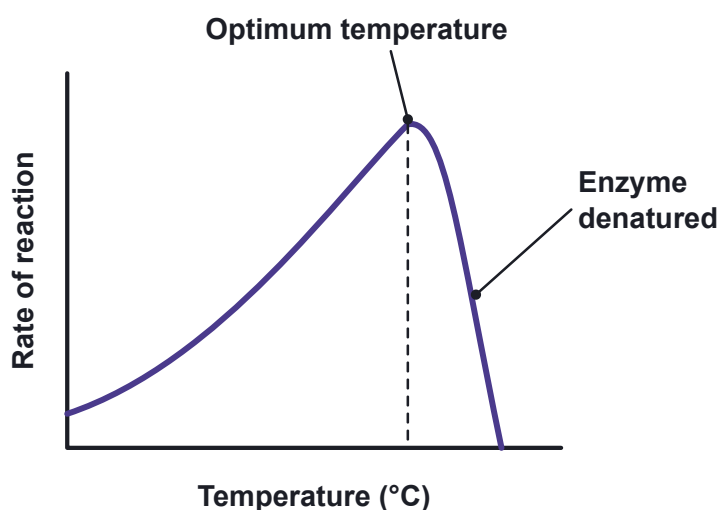
pH

Each enzyme has an **optimum pH** where it works fastest. If the pH is higher or lower than the optimum, the shape of the active site is altered, so the substrate fits less well and the rate decreases. At extreme pH the active site changes shape so much that the substrate cannot fit: the enzyme is denatured.

Different enzymes have different optimum pH values. For example, amylase in the mouth works best at about pH 7 (neutral), while pepsin, a protease in the acidic stomach, works best at about pH 2.

Summary of the effects on enzyme activity

Factor	Below the optimum	At the optimum	Above the optimum
Temperature	Rate increases as particles collide more often	Highest rate	Active site changes shape, enzyme denatured, rate falls
pH	Rate decreases as pH moves away from the optimum; denatured at extreme pH	Highest rate	Rate decreases as pH moves away from the optimum; denatured at extreme pH



Rate rises to the **optimum** then falls. Above the optimum temperature, or at extreme pH, the active site changes shape and the enzyme is **denatured**.

*Exam tip: When a graph falls after a peak, always give the reason: the active site has changed shape and the enzyme has been **denatured**. Do not say the enzyme has been 'killed'. Enzymes are not alive.*

Practical: temperature, pH and enzyme activity Spec 2.12, 2.14B

A common version of these investigations uses **amylase**, an enzyme that breaks down starch, and iodine solution to show when the starch has gone. Iodine stays orange-brown when there is no starch left.

Effect of temperature on enzyme activity

Practical: Independent variable: temperature; dependent variable: time for the starch to be broken down. Keep pH, volumes and concentrations the same each time.

1. Put drops of iodine solution into the wells of a spotting tile.

2. Set up water baths at different temperatures, for example 10, 20, 30, 40 and 50 °C.
3. Put starch solution and a buffer solution of one fixed pH in a test tube, and amylase solution in a second tube. Leave both in the water bath for a few minutes to reach the temperature.
4. Add the amylase to the starch and buffer, mix and start the stopwatch.
5. Every 30 seconds, use a dropping pipette to add a drop of the mixture to a well of iodine solution.
6. Record the time when the iodine stays orange-brown. This shows all the starch has been broken down.
7. Repeat at each temperature and calculate a mean time.

Typical results: the shortest time is at the **optimum temperature**. The time is longer at low temperatures because there are fewer collisions, and at high temperatures the enzyme is **denatured** so the starch may never be broken down. Calculate the rate as $1 \div \text{time}$ and plot it against temperature. Take care with hot water, and wear eye protection because iodine solution is an irritant.

Controlling variables

Variable	How it is controlled
pH	Add the same buffer solution to every tube
Volume and concentration of enzyme	Use the same amount of the same solution each time
Volume and concentration of starch	Use the same amount of the same solution each time

Biology only

Effect of pH on enzyme activity

Biology only

Practical: Independent variable: pH, using buffer solutions; dependent variable: time for the starch to be broken down. Keep temperature, volumes and concentrations the same each time.

Biology only

Use the same method, but keep the temperature fixed by putting all the tubes in one water bath (for example at 35 °C), and use buffer solutions of different pH values, such as pH 3, 5, 7, 9 and 11. Repeat each pH and calculate a mean.

Biology only

Typical results for the pH practical: the shortest time is at the optimum pH, where the enzyme works fastest. Times get longer at pH values further from the optimum. Plot the rate ($1 \div \text{time}$) against pH and draw a smooth curve through the points.

Quick check

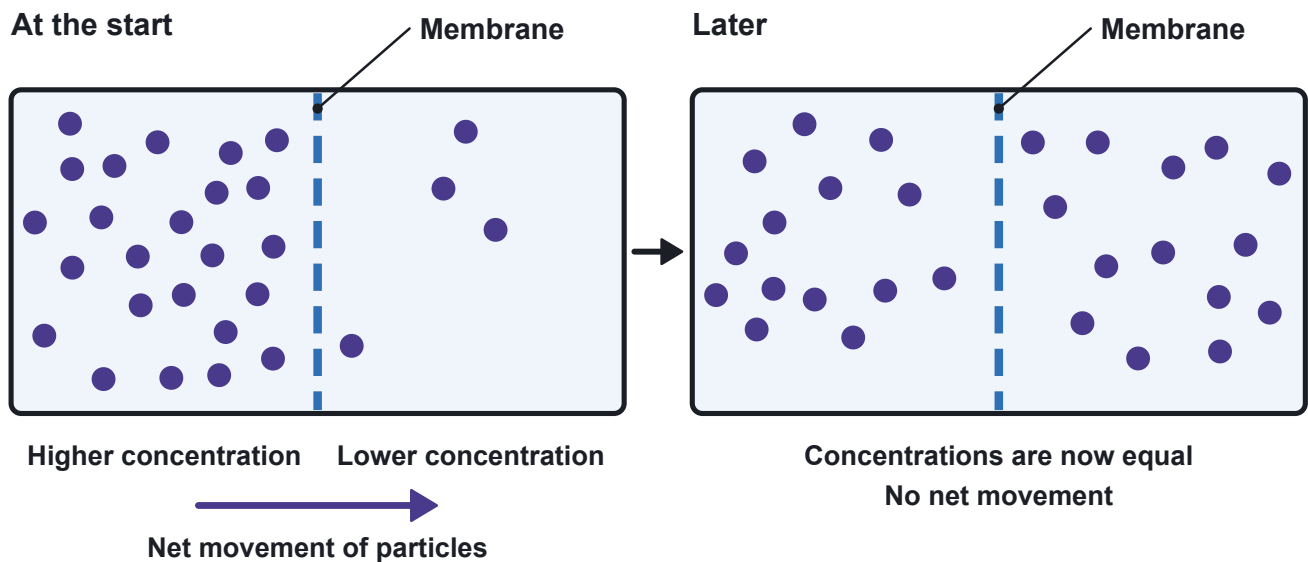
1. Which elements are present in proteins but not in carbohydrates or lipids?
2. What are the smaller units that make up a protein?
3. What colour does Benedict's solution turn with glucose when heated?
4. What is meant by a biological catalyst?
5. Why does a very high temperature stop an enzyme working?

3 Movement of substances into and out of cells Spec 2.15-2.17

Diffusion Spec 2.15

Diffusion is the net movement of particles from an area of higher concentration to an area of lower concentration. The particles move **down a concentration gradient**. It is a passive process, so it does not need energy from respiration.

Oxygen, carbon dioxide and dissolved substances such as glucose can diffuse into and out of cells through the cell membrane. For example, oxygen diffuses into a respiring cell because the concentration of oxygen is lower inside the cell, where it is being used up.



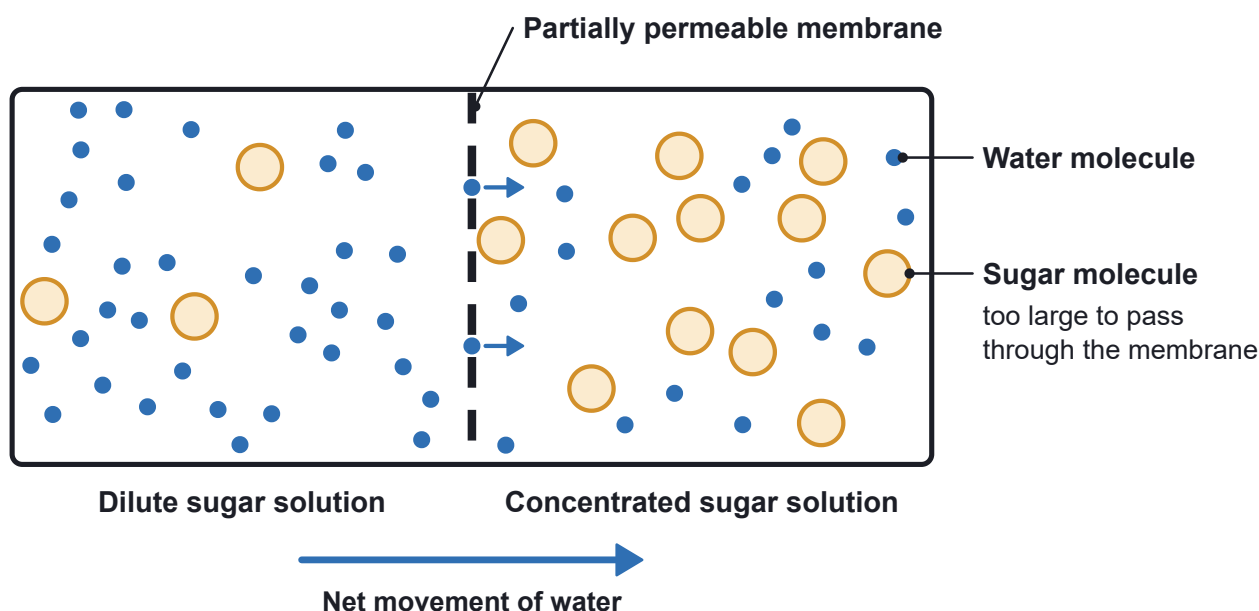
Diffusion: net movement of particles **down a concentration gradient** until the concentrations are equal.

*Exam tip: Always say **net** movement. Particles move in all directions, but more move down the gradient than up it.*

Osmosis Spec 2.15

Osmosis is the diffusion of water from a dilute solution to a more concentrated solution through a **partially permeable membrane**. A partially permeable membrane lets small molecules such as water through, but not larger molecules.

Osmosis is a passive process. It does not need energy from respiration. Cell membranes are partially permeable, so cells gain or lose water by osmosis when the solution around them is more dilute or more concentrated than the cytoplasm.



Osmosis: water moves from the dilute solution to the concentrated solution through a partially permeable membrane.

Common mistake: Osmosis is only about water. Do not write that 'particles' move by osmosis, and do not forget the partially permeable membrane.

Active transport Spec 2.15

Active transport is the movement of substances from a more dilute solution to a more concentrated solution, which is **against a concentration gradient**. It needs **energy from respiration**.

Active transport allows cells to take in substances they need even when they are in short supply outside the cell. For example, root hair cells take in mineral ions from the soil when the concentration of the ions is higher inside the cell than in the soil.

Three ways substances move into and out of cells			
	What moves	Direction	Energy from respiration?
Diffusion	Particles, such as oxygen and carbon dioxide	High to low concentration	No
Osmosis	Water only, through a partially permeable membrane	Dilute to concentrated solution	No
Active transport	Substances such as mineral ions	Low to high concentration, against the gradient	Yes

Factors affecting the rate of movement Spec 2.16

Four factors affect how fast substances move into and out of cells by diffusion and osmosis.

Factors affecting the rate of movement

Factor	Effect on the rate	Example
Surface area to volume ratio	A larger ratio means a faster rate for the size of the cell, because more surface is available for each unit of volume	Root hair cells have a long projection that gives a large surface area
Distance	A shorter distance means a faster rate	The wall of an alveolus is one cell thick
Temperature	A higher temperature means a faster rate, because particles have more kinetic energy and move faster	Diffusion is faster in a warm solution than in a cold one
Concentration gradient	A steeper gradient (a bigger difference in concentration) means a faster rate	Blood flow keeps the oxygen concentration lower in the blood than in the alveoli

Surface area to volume ratio

The **surface area : volume ratio** tells you how much surface an organism or cell has compared with its size. The bigger the object, the smaller this ratio becomes.

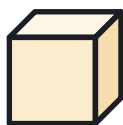
$$\text{surface area : volume ratio} = \text{surface area} \div \text{volume}$$

Surface area : volume ratio of a cube

A cube-shaped block of tissue has sides of 3 cm. Calculate its surface area : volume ratio.

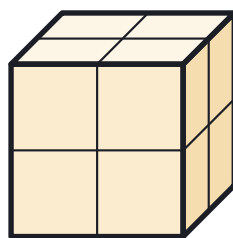
1. A cube has 6 faces. Area of one face = $3 \times 3 = 9 \text{ cm}^2$.
2. Surface area = $6 \times 9 = 54 \text{ cm}^2$.
3. Volume = $3 \times 3 \times 3 = 27 \text{ cm}^3$.
4. Ratio = 54 : 27. Divide both sides by 27.

Answer: 2 : 1



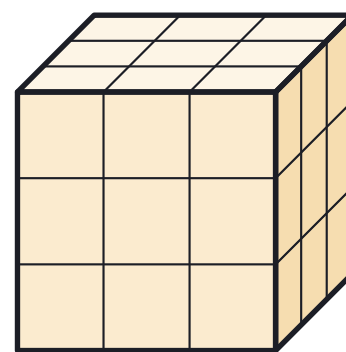
1 cm

surface area = 6 cm^2
 volume = 1 cm^3
 surface area : volume
 = 6 : 1



2 cm

surface area = 24 cm^2
 volume = 8 cm^3
 surface area : volume
 = 3 : 1



3 cm

surface area = 54 cm^2
 volume = 27 cm^3
 surface area : volume
 = 2 : 1

As the cube gets bigger, its **surface area : volume ratio gets smaller**.

- A single-celled organism has a **large surface area : volume ratio**. Substances only have a short distance to diffuse, so diffusion across the surface is fast enough.
- A multicellular organism has a **small surface area : volume ratio**. Many cells are deep inside the body, so the diffusion distance is long and diffusion across the body surface is too slow.

Common mistake: A thin membrane or wall gives a short diffusion distance. It does not give a larger surface area; these are two separate factors.

Practical: diffusion and osmosis Spec 2.17

You need to be able to investigate diffusion and osmosis using **living** systems (such as potato tissue) and **non-living** systems (such as Visking tubing and agar).

Living system: osmosis in potato cylinders

Practical: Independent variable: concentration of the solution; dependent variable: change in mass. Blot each cylinder dry before you weigh it, because surface water adds mass that is not from osmosis.

1. Use a cork borer to cut cylinders from one potato, and trim them to the same length.
2. Measure and record the mass of each cylinder.
3. Put each cylinder in a different concentration of sugar (or salt) solution, including pure water, using the same volume of solution each time.
4. Leave them for the same length of time at the same temperature.
5. Remove the cylinders, blot them dry with paper towel and measure their final mass.
6. Calculate the percentage change in mass for each cylinder and plot a graph of percentage change against concentration.

Result	Explanation
Mass increases	The solution is more dilute than the cell contents, so water moves into the potato by osmosis
Mass decreases	The solution is more concentrated than the cell contents, so water moves out of the potato by osmosis
No change in mass	The solution has the same concentration as the cell contents, so there is no net movement of water

$$\text{percentage change} = (\text{final mass} - \text{initial mass}) \div \text{initial mass} \times 100$$

Percentage change in mass

A potato cylinder has a mass of 3.00 g. After 30 minutes in a salt solution its mass is 2.55 g. Calculate the percentage change in mass.

1. change in mass = $2.55 - 3.00 = -0.45$ g
2. $-0.45 \div 3.00 = -0.15$
3. $-0.15 \times 100 = -15\%$

Answer: -15% (a loss of 15%)

Where the graph line crosses the x-axis (0% change), the concentration of the solution equals the concentration of the potato cell contents. Control the potato, the size of the cylinders, the volume of the solution, the time and the temperature. Cut on a tile away from your fingers, because cork borers and scalpels are sharp.

Non-living system: Visking tubing

Visking tubing is a partially permeable membrane with tiny pores. It lets small molecules such as water and glucose through, but not large molecules such as starch.

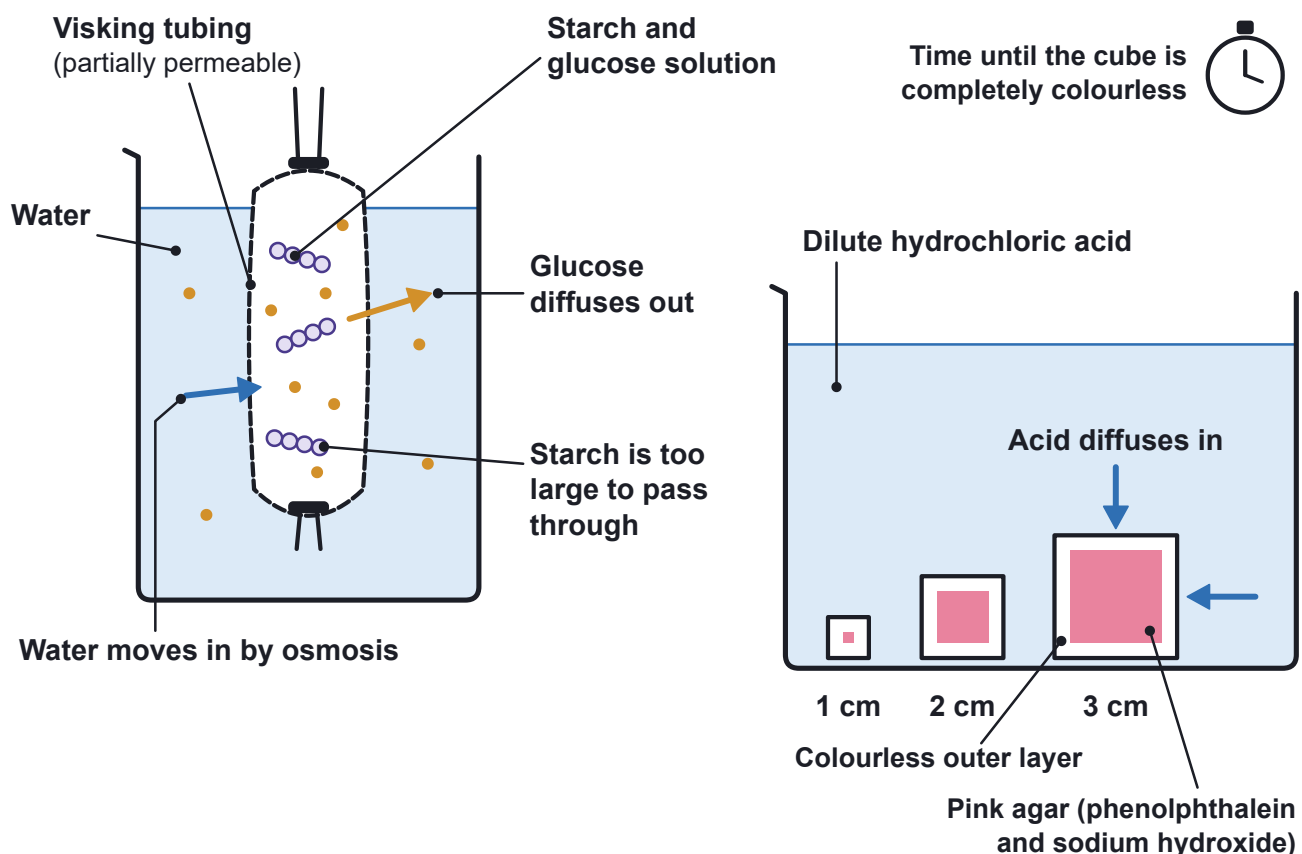
1. Tie one end of a length of soaked Visking tubing and fill it with a mixture of starch and glucose solution. Tie the other end.
2. Rinse the outside, then place the tube in a beaker of water.
3. After about 20 to 30 minutes, test the water in the beaker with Benedict's solution (for glucose) and with iodine solution (for starch).

Typical results: the water in the beaker gives a positive Benedict's test, so glucose has diffused out through the pores. It does not turn blue-black with iodine, so the starch molecules were too large to pass through. To show osmosis, fill the tube with a concentrated sugar solution and place it in water. The tube becomes firmer and gains mass as water moves in.

Non-living system: agar cubes

Agar jelly cubes can show diffusion and the effect of surface area to volume ratio. Make agar containing phenolphthalein indicator and a little dilute sodium hydroxide (an alkali), so it is pink. Cut cubes of different sizes, for example 1 cm, 2 cm and 3 cm. Place each cube in the same volume of dilute hydrochloric acid at the same temperature. As the acid diffuses in, it neutralises the alkali and the indicator turns colourless. Time how long each cube takes to become completely colourless.

Typical results: small cubes, with a larger surface area : volume ratio and a shorter distance to the centre, change colour all the way through sooner than large cubes. Wear eye protection when using acid and alkali.



Non-living models: **glucose** passes through the pores of Visking tubing but **starch** cannot; acid diffuses into small agar cubes faster than large ones.

Quick check

- 1 . Define diffusion.
- 2 . What is osmosis?
- 3 . Which of diffusion, osmosis and active transport needs energy from respiration?
- 4 . What happens to the surface area to volume ratio as an organism gets bigger?
- 5 . Why does a potato cylinder lose mass in a concentrated sugar solution?

4 Nutrition in flowering plants Spec 2.18-2.23

Photosynthesis and its equations Spec 2.18, 2.19

Photosynthesis is the process by which plants and algae make glucose. The energy comes from **light**, which is absorbed by the green pigment **chlorophyll** in the chloroplasts.

Photosynthesis is important because it converts **light energy to chemical energy**. The chemical energy is stored in the glucose that is made. Plants use this glucose for respiration and to build new plant material. Almost all food chains start with this stored energy.

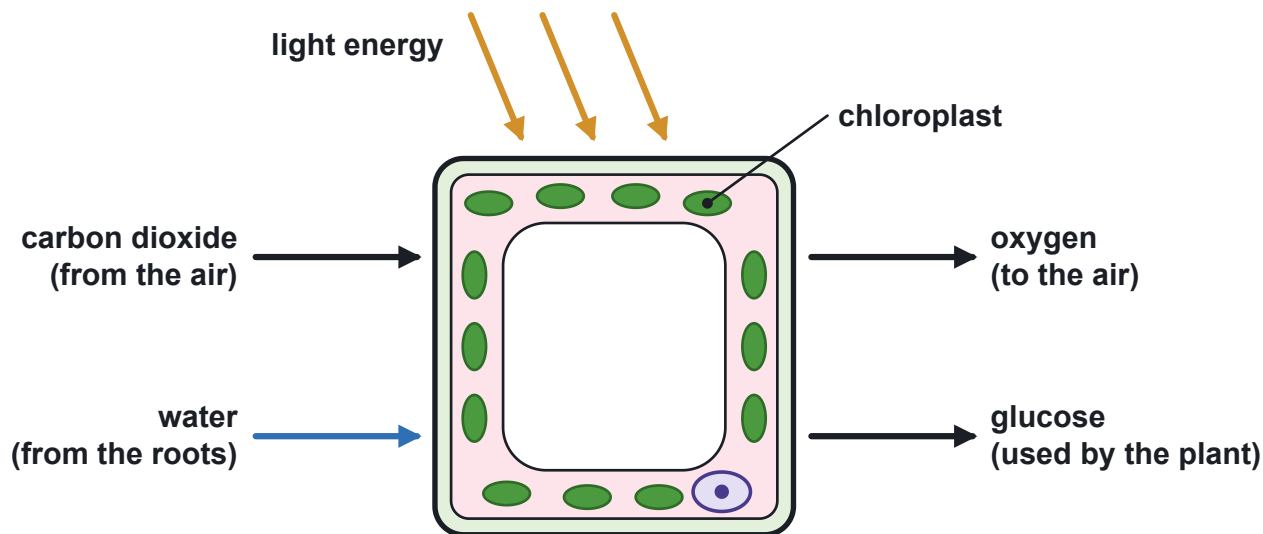
Light energy is used to react **carbon dioxide** and **water** to produce **glucose** and **oxygen**.

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

$6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ (in the presence of light and chlorophyll)

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



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

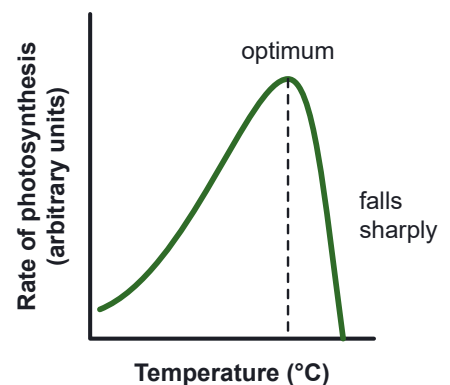
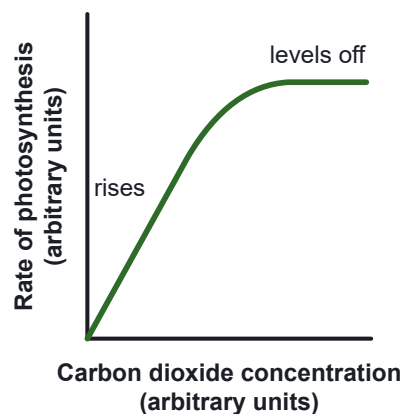
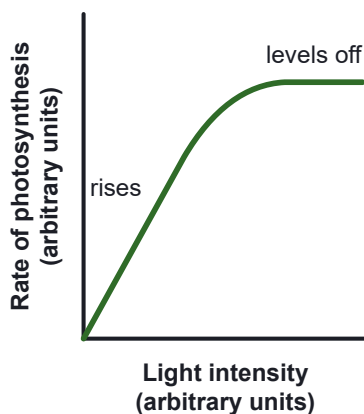
Exam tip: Light is the energy source, not a reactant, so it does not go in the word equation as a substance. Write 'in the presence of light' or put 'light energy' above the arrow. Check that the symbol equation is balanced: 6 carbon atoms, 12 hydrogen atoms and 18 oxygen atoms on each side.

Factors affecting the rate of photosynthesis Spec 2.20

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 is affected by **carbon dioxide concentration**, **light intensity** and **temperature**.

How each factor affects 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.



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: To describe a graph, state the trend, then quote data from it, for example the value where the line levels off. For a table of results, plot the factor you changed on the x-axis and the rate on the y-axis.

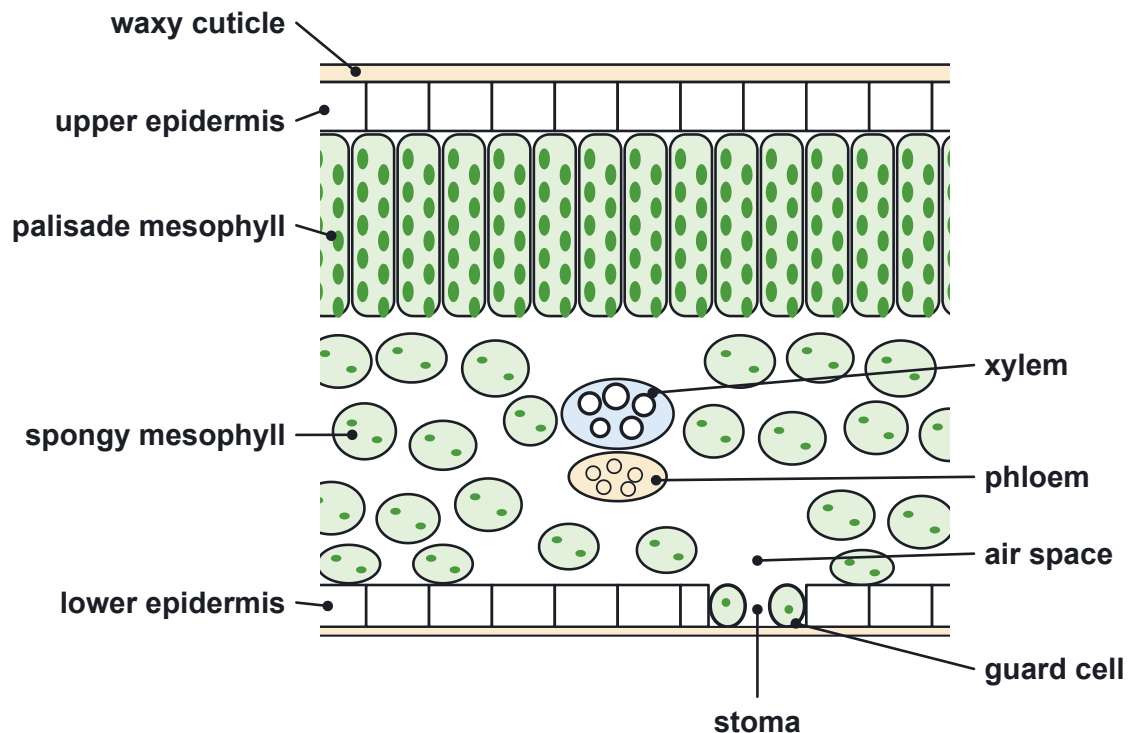
Common mistake: Do not write that the enzymes are 'killed' at high temperature. Enzymes are not alive. They are denatured, because their active site changes shape.

Leaf structure and adaptations Spec 2.21, 2.42B

A leaf is adapted to absorb light for **photosynthesis** and to allow **gas exchange** of carbon dioxide and oxygen.

Structures in a leaf and how they are adapted

Structure	Adaptation	How it helps
Whole leaf	Broad, flat and thin	Large surface area to absorb light, and a short distance for gases to diffuse
Waxy cuticle	A waxy, waterproof layer on the surface	Reduces water loss by evaporation
Upper epidermis	A thin layer of transparent cells	Lets light through to the cells underneath
Palisade mesophyll	Tightly packed, tall cells near the top of the leaf, with many chloroplasts	Most photosynthesis takes place here, close to the light
Spongy mesophyll	Loosely arranged cells with air spaces between them	Carbon dioxide can diffuse through the leaf to the cells, and oxygen can diffuse out
Stomata and guard cells	Pores, mostly in the lower epidermis, opened and closed by guard cells	Allow gases to enter and leave, and control water loss
Xylem and phloem (veins)	Vascular bundles running through the leaf	Xylem brings water for photosynthesis. Phloem carries sucrose away.



Leaf cross-section: most photosynthesis happens in the **palisade mesophyll**; gases diffuse through the air spaces and stomata.

Biology only

How the leaf is adapted for gas exchange

Biology only

Carbon dioxide and oxygen move into and out of a leaf by diffusion, down their concentration gradients. The structure of the leaf makes this diffusion fast.

Biology only

- Broad, flat shape: a large surface area for gases to diffuse in and out.
- Thin leaf: a short diffusion distance, so gases reach the cells quickly.
- Many stomata, mostly in the lower epidermis: pores that let carbon dioxide diffuse in and oxygen diffuse out. Guard cells open and close them.
- Air spaces in the spongy mesophyll: gases diffuse quickly between the stomata and the cells, and a large surface area of cells is exposed to the air.
- Moist cell surfaces: gases dissolve in the thin film of water on the mesophyll cells, then diffuse into or out of the cells.

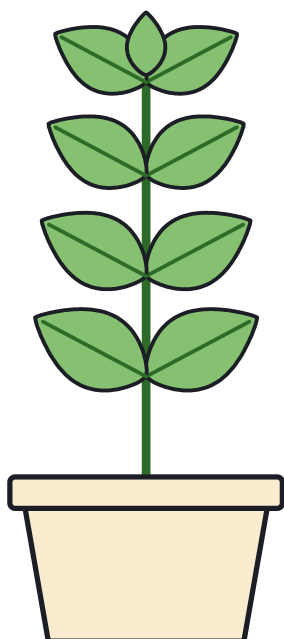
Exam tip: Always give an adaptation and the reason it helps. For example, 'the air spaces in the spongy mesophyll allow carbon dioxide to diffuse to the photosynthesising cells'.

Mineral ions: magnesium and nitrate Spec 2.22

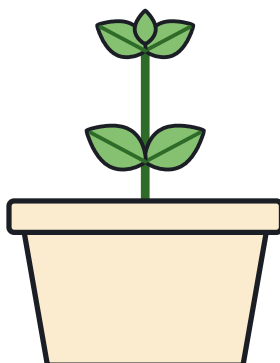
Plants need more than carbon dioxide, water and light. They also need mineral ions for healthy growth. The roots absorb these ions from the soil. You need to know two of them.

Two mineral ions that plants need		
Mineral ion	Why the plant needs it	Effect of a shortage
Magnesium ions	Needed to make chlorophyll	Leaves turn yellow, because there is less chlorophyll
Nitrate ions	Needed to make amino acids, which are joined to make proteins for growth	Stunted (poor) growth

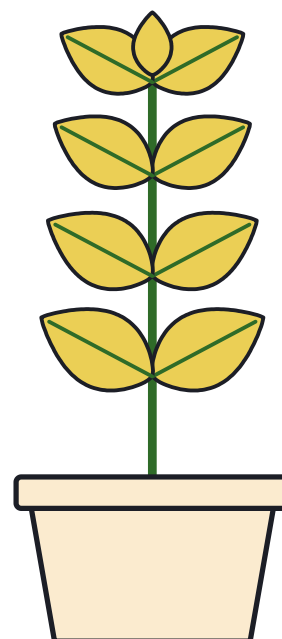
Without enough chlorophyll, a plant absorbs less light, so it photosynthesises more slowly and makes less glucose. Without enough amino acids, the plant cannot make the proteins it needs for new cells, so it grows slowly.



Healthy



**Lacks nitrate:
stunted growth**



**Lacks magnesium:
yellow leaves (chlorosis)**

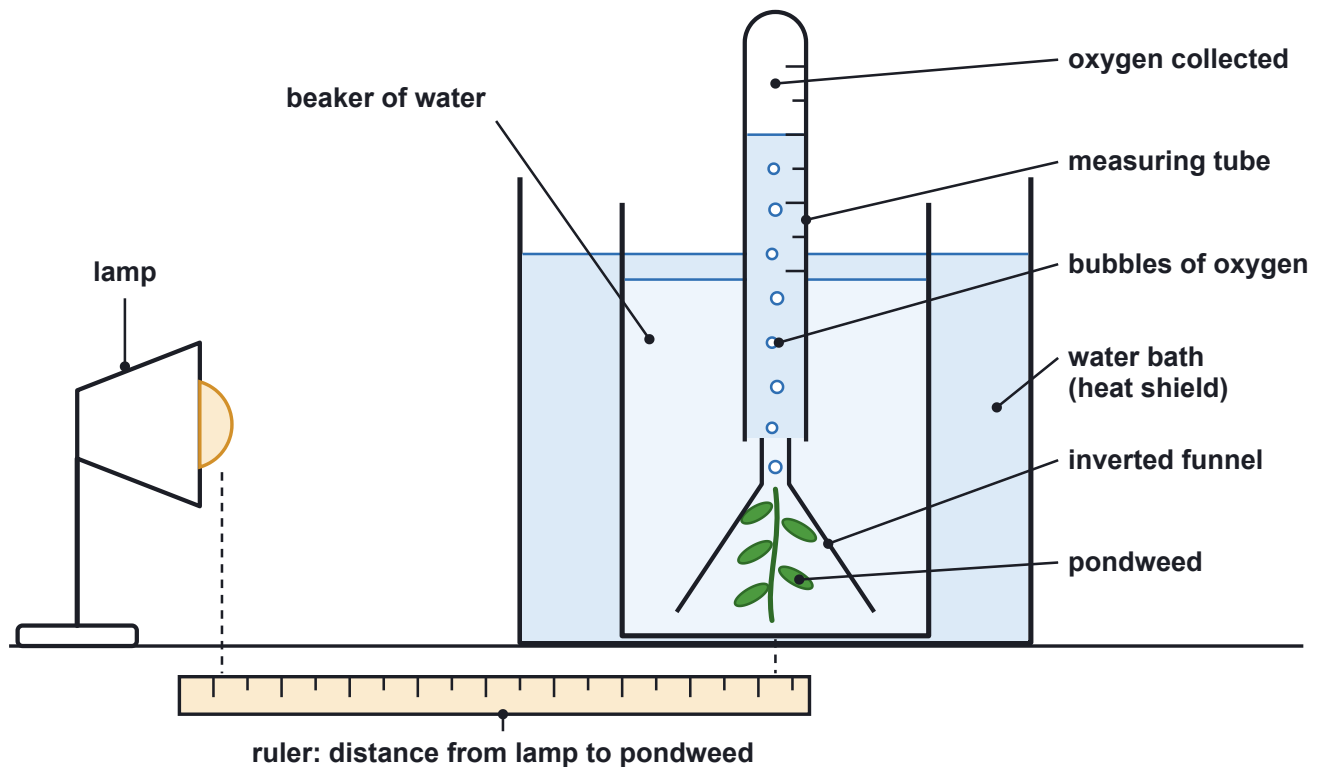
Lack of **nitrate** causes **stunted growth**; lack of **magnesium** causes **yellow leaves**.

Common mistake: Link each ion to its job: magnesium goes with chlorophyll (yellow leaves), nitrate goes with amino acids and proteins (stunted growth). Do not say that plants use nitrate to make chlorophyll or glucose.

Practical: oxygen from a water plant Spec 2.23

A water plant such as pondweed (*Elodea* or *Cabomba*) gives off bubbles of **oxygen** when it photosynthesises. Counting the bubbles, or measuring the volume of gas, gives a measure of the **rate of photosynthesis**. You can change the light intensity by moving a lamp to different distances from the plant.

1. Set up a beaker of water with a little sodium hydrogencarbonate, which supplies carbon dioxide. Place a piece of pondweed, cut end upwards, under an inverted funnel with a test tube or measuring tube over the end.
2. Place a clear container of water between the lamp and the beaker as a heat shield, or use an LED lamp, so the temperature stays constant.
3. Place the lamp a measured distance from the pondweed, for example 10 cm. Switch off other light sources.
4. Leave the plant for a few minutes to adjust to the new light level.
5. Count the bubbles released from the cut end of the stem in one minute. Alternatively, collect the gas and measure its volume over a set time.
6. Repeat at different distances, for example 20, 30, 40 and 50 cm. Repeat each distance at least three times and calculate a mean.



Investigating light intensity: change the **distance** of the lamp and measure the **oxygen** produced.

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	Number of bubbles per minute, or 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. The rate rises as the lamp is moved closer, then levels off when another factor becomes limiting. To show that the gas is oxygen, collect enough of it in a test tube and test it with a glowing splint, which relights.

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

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.

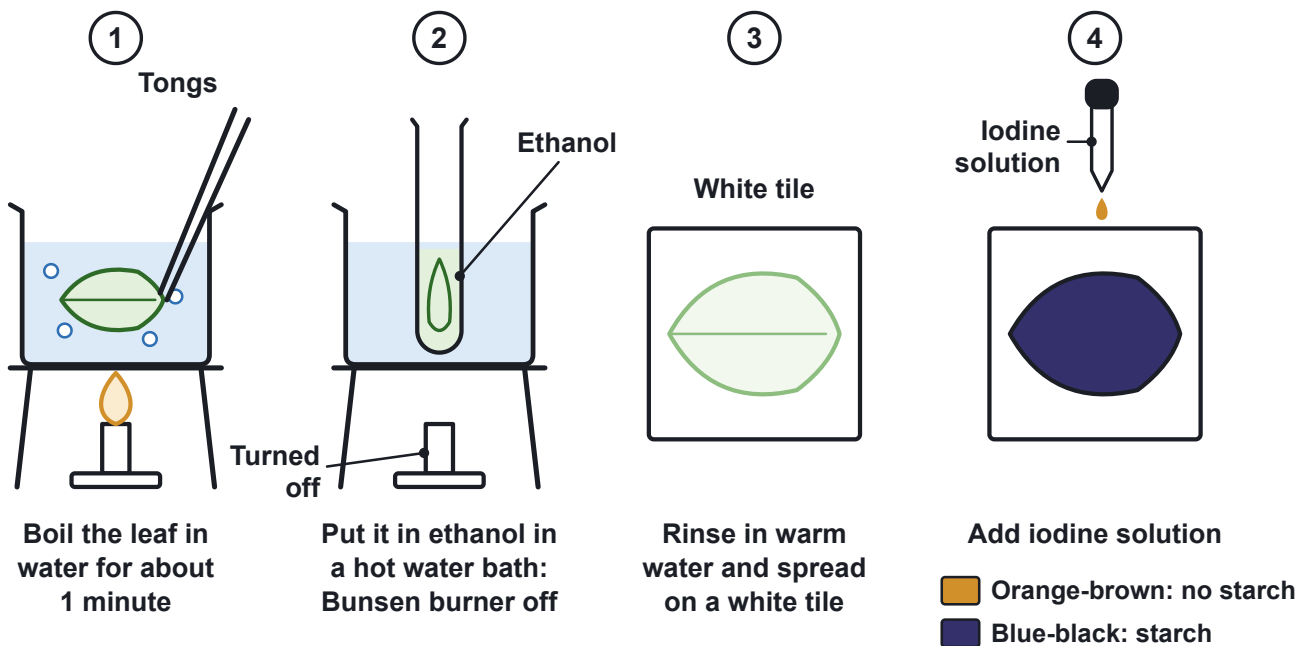
Practical: starch, light, carbon dioxide and chlorophyll Spec 2.23

Plants store the glucose they make as **starch**. A leaf that has been photosynthesising contains starch, so testing a leaf for starch shows that photosynthesis has happened. By changing one condition at a time, you can show that photosynthesis needs **light**, **carbon dioxide** and **chlorophyll**.

Before starting, the plant is **destarched**: it is left in a dark cupboard for 24 to 48 hours. With no light it cannot photosynthesise, and it uses up its stored starch.

The starch test on a leaf

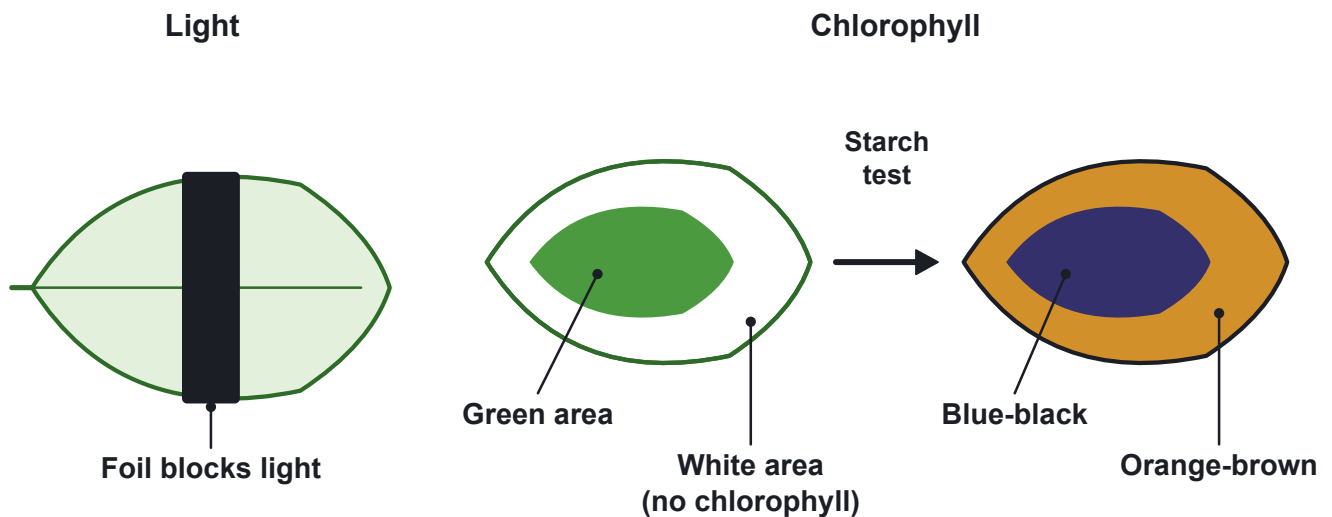
1. Dip the leaf in boiling water for about one minute. This kills the cells and stops chemical reactions, and it softens the leaf so the iodine can get in.
2. Turn off the Bunsen burner. Put the leaf in a boiling tube of ethanol and stand the tube in the hot water. The ethanol removes the chlorophyll, so the leaf turns pale. Ethanol is flammable, so there must be no naked flame.
3. Rinse the leaf in warm water to soften it, then spread it on a white tile.
4. Add drops of iodine solution. A **blue-black** colour shows that starch is present. If there is no starch, the iodine stays **orange-brown**.



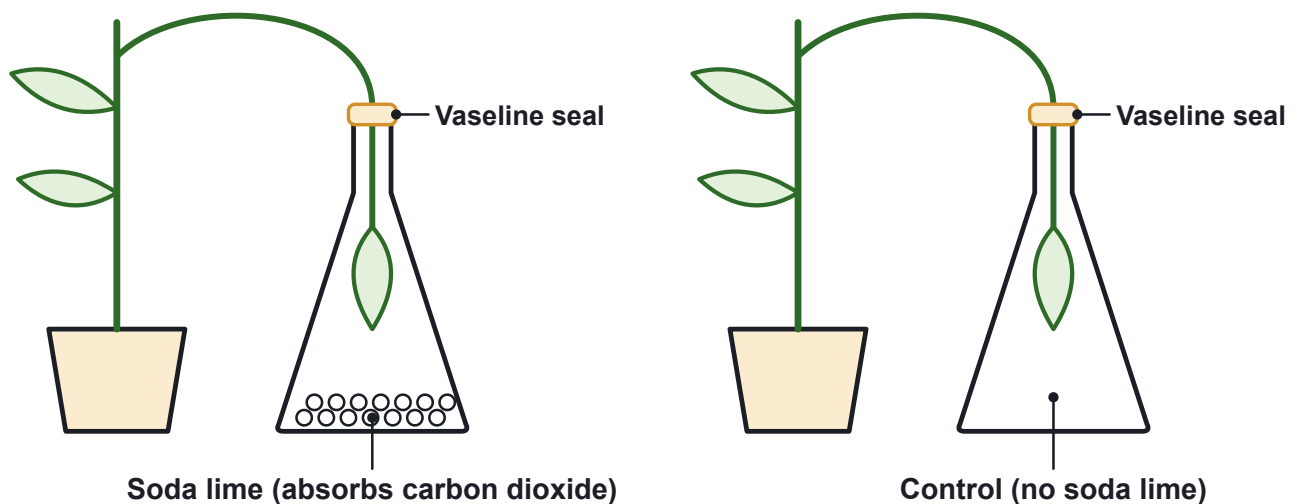
Testing a leaf for starch: boil, remove chlorophyll in ethanol (no flame), rinse, then add iodine. **Blue-black** means starch is present.

Showing what photosynthesis needs

Investigating the requirements for photosynthesis		
Requirement	Method	Result (after the starch test)
Light	Cover part of a leaf on a destarched plant with foil or black paper, or a stencil, and leave the plant in bright light for several hours.	Uncovered area turns blue-black. Covered area stays orange-brown, so light is needed.
Carbon dioxide	Enclose one leaf of a destarched plant, still attached to the plant, in a sealed flask containing soda lime (or sodium hydroxide solution), which absorbs carbon dioxide. Set up a control leaf in the same way in a flask without soda lime. Leave the plant in bright light for several hours.	Control leaf turns blue-black. Leaf without carbon dioxide stays orange-brown, so carbon dioxide is needed.
Chlorophyll	Destarch a plant with variegated leaves, which have green areas (with chlorophyll) and white areas (without). Leave it in bright light for several hours.	Green areas turn blue-black. White areas stay orange-brown, so chlorophyll is needed.



Carbon dioxide



Showing that photosynthesis needs **light**, **chlorophyll** and **carbon dioxide**: only the part of the leaf with all three turns blue-black.

Practical: Safety: wear eye protection. Ethanol is flammable, so turn off the Bunsen burner before heating it in a water bath. Soda lime and sodium hydroxide are corrosive, and iodine solution stains skin and clothes.

Exam tip: If asked why the plant is destarched, say it makes sure any starch found afterwards was made during the investigation. If asked why the leaf is boiled in ethanol, say it removes chlorophyll so the colour change can be seen.

Quick check

1. Give the word equation for photosynthesis.
2. Which form of energy is photosynthesis converting light into?
3. Name three factors that can affect the rate of photosynthesis.
4. Why do plants need magnesium ions and nitrate ions?
5. What colour does iodine solution turn when starch is present?

5 Human nutrition Spec 2.24-2.33B

A balanced diet and energy needs Spec 2.24, 2.26

A **balanced diet** contains the right proportions of all seven components: **carbohydrate, protein, lipid, vitamins, minerals, water and dietary fibre**. Most of the energy in a diet comes from carbohydrate and lipid. Smaller amounts are needed of vitamins and minerals, but they are still essential.

- Carbohydrate and lipid: the main sources of energy, so they are needed in larger amounts.
- Protein: needed for growth and repair of tissues.
- Vitamins and minerals: needed in small amounts to stay healthy.
- Water: needed in large amounts, because the body loses it all the time.
- Dietary fibre: needed to keep food moving through the gut.

The amount of energy a person needs each day depends on how much energy their body uses. Energy requirements vary with **activity level**, **age** and **pregnancy**.

How energy requirements vary		
Factor	Effect on energy needed	Why
Activity level	More active people need more energy	Contracting muscles use energy from respiration. A person who trains or has a physical job respire more than a person who sits at a desk.
Age	Teenagers need more energy than young children. Older adults need less than younger adults.	Teenagers are larger and growing quickly. Older people are usually less active and are no longer growing.
Pregnancy	A pregnant woman needs more energy	Extra energy is needed for the growth of the fetus and for the changes in the mother's body.

If a person takes in more energy than they use, the extra is stored, mainly as fat. If a person takes in less energy than they use, they lose body mass.

Exam tip: A balanced diet is about the right proportions, not the same amount of each nutrient. For energy questions, link the answer to respiration: more activity means more muscle contraction, so more respiration and more energy needed.

Nutrients: sources and functions Spec 2.25

You need to know a source and a function for each of the nutrients in the table.

Sources and functions of nutrients		
Nutrient	Sources	Functions
Carbohydrate	Bread, pasta, rice, potatoes	Provides energy (released by respiration)
Protein	Meat, fish, eggs, beans	Growth and repair of tissues. Proteins are made from amino acids.
Lipid (fats and oils)	Butter, cooking oils, nuts, oily fish	Energy store, insulation (keeps heat in), and part of cell membranes
Vitamin A	Liver, carrots, dairy foods	Healthy eyes and vision in dim light. A lack causes night blindness.
Vitamin C	Citrus fruits, fresh vegetables	Keeps skin and gums healthy. A lack causes scurvy.
Vitamin D	Oily fish, eggs, margarine (also made in skin in sunlight)	Helps the body absorb calcium. A lack causes weak bones (rickets in children).
Calcium (mineral ion)	Milk, cheese, green vegetables	Needed for strong bones and teeth
Iron (mineral ion)	Red meat, liver, spinach	Needed to make haemoglobin in red blood cells. A lack causes anaemia.
Water	Drinks and most foods	Solvent for chemical reactions, and the main part of blood plasma, which transports substances
Dietary fibre	Wholemeal bread, vegetables, fruit	Adds bulk, which helps peristalsis move food through the gut and prevents constipation

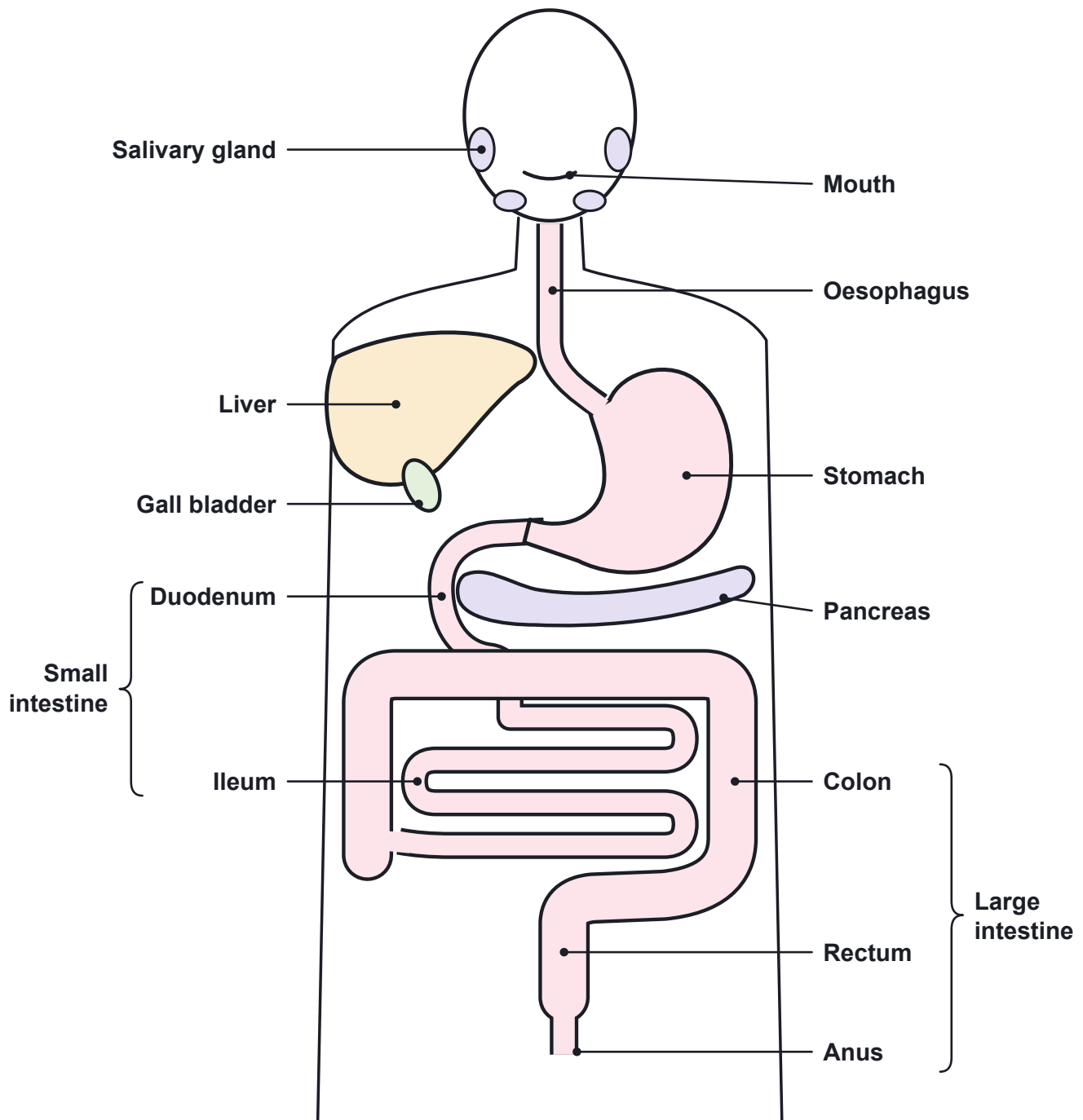
Exam tip: Mark schemes want a specific function, not just 'it is good for you'. Learn one clear function for each nutrient. Fibre is not digested, so it provides no energy.

The alimentary canal and peristalsis Spec 2.27, 2.28

The **alimentary canal** is the tube that runs from the mouth to the anus. Food is digested and absorbed as it moves through. The liver, gall bladder and pancreas are not part of the tube, but they help with digestion.

Structure and function of the alimentary canal

Part	Function
Mouth	Teeth chew food into smaller pieces. Saliva contains amylase, which starts the digestion of starch.
Oesophagus	Carries food from the mouth to the stomach by peristalsis
Stomach	Churns food with acidic juice. Hydrochloric acid kills many bacteria. Protease digests protein.
Small intestine: duodenum	First part. Receives bile and pancreatic juice. Digestion continues here.
Small intestine: ileum	Second, longest part. Digestion is finished and the small soluble molecules are absorbed into the blood.
Pancreas	Makes digestive enzymes (amylase, protease and lipase) and releases them into the duodenum
Large intestine: colon	Absorbs water from the remaining material
Large intestine: rectum	Stores faeces, which leave the body through the anus

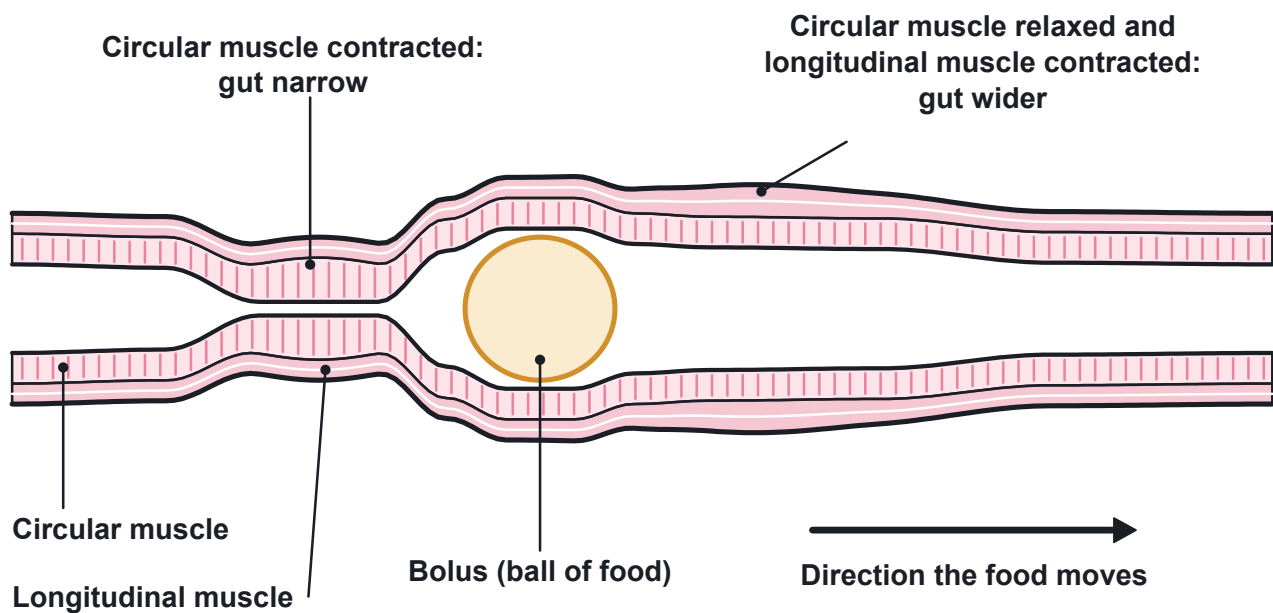


The **alimentary canal** runs from mouth to anus. The liver, gall bladder and pancreas are not part of the tube but help with digestion.

Peristalsis

Food is moved along the gut by **peristalsis**. The walls of the gut contain **circular muscles** and **longitudinal muscles**. Waves of muscle contraction pass along the gut.

1. The circular muscles behind the food contract. This squeezes the food forward.
2. The circular muscles in front of the food relax and the longitudinal muscles contract. This widens the tube ahead of the food.
3. The wave of contraction moves along the gut, pushing the food towards the stomach, then through the intestines.



Peristalsis: circular muscle contracts behind the bolus, squeezing it forward into the wider section in front.

Common mistake: Peristalsis is a wave of muscle contraction that pushes food along. It does not break food down chemically, and it is not the same as chewing.

Digestive enzymes Spec 2.29

Food contains large molecules of starch, protein and lipid. They are too big to pass into the blood.

Digestive enzymes break them down into small, soluble molecules that can be absorbed. Each type of enzyme breaks down one type of food molecule.

Digestive enzymes			
Enzyme	Breaks down	Into	Made in
Amylase	Starch	Maltose	Salivary glands, pancreas
Maltase	Maltose	Glucose	Small intestine
Proteases	Proteins	Amino acids	Stomach, pancreas, small intestine
Lipases	Lipids (fats and oils)	Fatty acids and glycerol	Pancreas, small intestine

The digestion of starch takes two steps. Amylase breaks starch down into the sugar maltose. Maltase then breaks maltose down into **glucose**.

starch → maltose (catalysed by amylase)

maltose → glucose (catalysed by maltase)

protein → amino acids (catalysed by proteases)

lipid → fatty acids + glycerol (catalysed by lipases)

The small molecules are absorbed into the blood. The body uses them to make new carbohydrates, proteins and lipids. Some glucose is used in respiration.

Exam tip: Learn the pairs: amylase with starch, protease with protein, lipase with lipid. Mark schemes ask for the name of the enzyme and the products, so write both.

Bile Spec 2.30, 2.31

Bile is produced by the liver and stored in the gall bladder. It is released into the small intestine (the duodenum).

Bile has two roles in digestion:

- It is alkaline, so it neutralises the acid that comes from the stomach. This gives the enzymes in the small intestine the alkaline conditions they work best in.
- It emulsifies lipids: it breaks large drops of fat into many tiny droplets. This increases the surface area of the lipid.

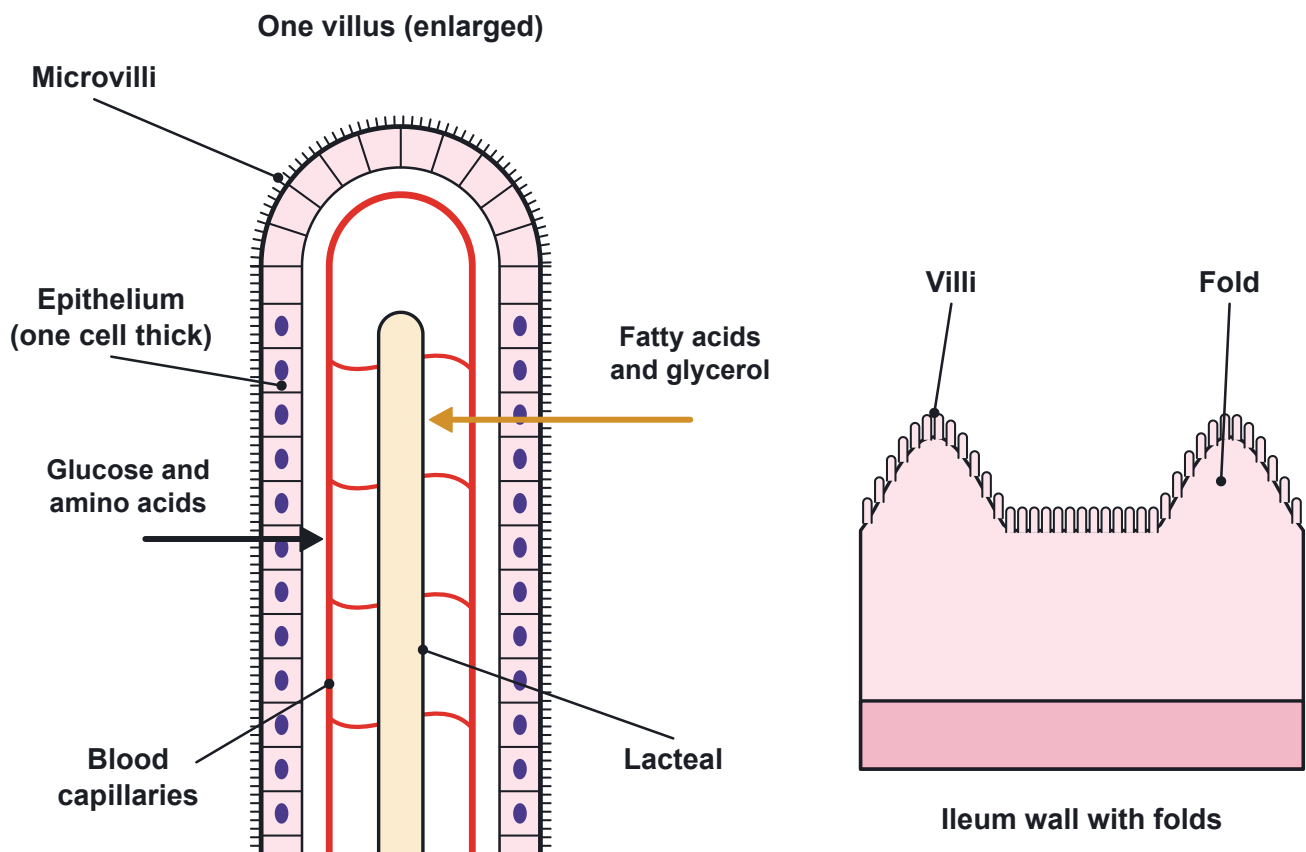
The larger surface area lets lipase work faster, so the lipid is digested more quickly.

Common mistake: Bile is not an enzyme and it does not chemically digest lipids. It only emulsifies them (physical breaking up) so that lipase can work faster. Emulsify is not the same as digest.

Absorption in the small intestine Spec 2.32

The products of digestion are absorbed in the small intestine, mostly in the ileum. The small intestine is adapted to absorb efficiently. It is long and its inner wall is folded. The wall is covered in millions of tiny finger-like projections called villi (one is a villus).

Adaptations of a villus for absorption	
Adaptation	How it helps absorption
Villi and microvilli (tiny projections on each surface cell)	Give a very large surface area
Wall (epithelium) is one cell thick	Short diffusion distance, so absorption is fast
Network of blood capillaries close to the surface	Carries glucose and amino acids away. This keeps a steep concentration gradient.
A lacteal (a lymph vessel) in the centre	Absorbs fatty acids and glycerol



A villus: **microvilli** and a **one-cell-thick epithelium** give a large surface area and short diffusion distance; capillaries and the **lacteal** carry absorbed food away.

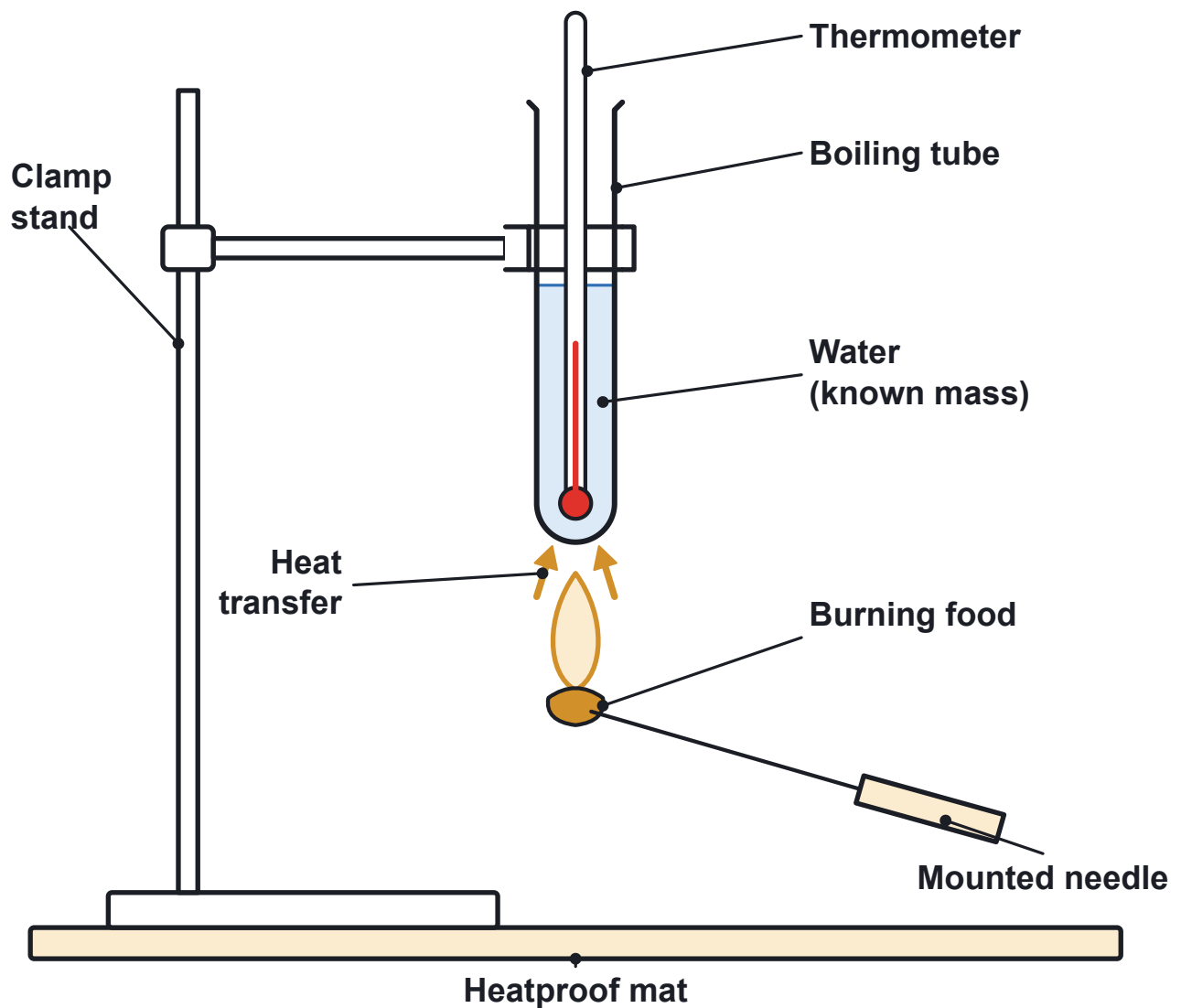
Glucose and amino acids move into the blood capillaries by **diffusion** and **active transport**. The blood carries them to the liver and then around the body. Fatty acids and glycerol move into the lacteal.

Exam tip: For an 'explain how it is adapted' question, give the feature and the reason: 'one cell thick, so there is a short diffusion distance'. Do not say the villi 'absorb more': say they 'increase the surface area'.

Practical: energy content of food Spec 2.33B Biology only

Food stores **chemical energy**. You can compare the energy in different foods by burning a sample and using the energy released to heat a known mass of water.

1. Measure a known volume of water (for example 20 cm³) into a boiling tube and record its starting temperature. 1 cm³ of water has a mass of 1 g.
2. Weigh a small piece of food and hold it on a mounted needle.
3. Light the food in a Bunsen burner flame, then hold it under the boiling tube straight away until the food stops burning. Stir the water gently.
4. Record the highest temperature of the water and work out the temperature change.



Burning food heats a **known mass of water**; the temperature rise is used to calculate the energy released.

$$\text{energy released (J)} = \text{mass of water (g)} \times 4.2 \times \text{temperature change (}^{\circ}\text{C)}$$

$$\text{energy per gram of food (J/g)} = \text{energy released (J)} \div \text{mass of food (g)}$$

Calculating the energy in food

Burning 0.5 g of a snack raises the temperature of 20 g of water by 12 °C. Calculate the energy released per gram of the snack.

1. energy released = $20 \times 4.2 \times 12 = 1008 \text{ J}$

2. energy per gram = $1008 \div 0.5 = 2016 \text{ J/g}$

Answer: 2016 J/g

The result is usually lower than the real energy in the food. **Heat is lost to the surroundings** and the food may not burn completely. A draught shield, holding the flame close to the tube and stirring the water improve the results. Foods rich in lipid, such as nuts, usually release more energy per gram than foods rich in carbohydrate.

Practical: Variables: the type of food is the independent variable; the temperature rise is the dependent variable. Keep the volume of water, the mass of food and the distance from the flame the same. Wear eye protection, take care with the burning food, and do not use nuts if anyone is allergic.

Quick check

1. Name the seven components of a balanced diet.
2. What is peristalsis?
3. What are the products of digestion by amylase and then maltase?
4. Give two roles of bile.
5. Where is bile made and where is it stored?
6. **Biology only** How do you calculate the energy released when food is burned under water?

6 Respiration Spec 2.34-2.39

Respiration and ATP Spec 2.34, 2.35

Respiration is the process that releases energy from food molecules such as glucose. It happens in every living cell, all the time. It is a chemical reaction in cells, so it is not the same as breathing.

Cells cannot use the energy in glucose directly. Instead, the energy released when glucose is broken down is used to make a molecule called **ATP** (adenosine triphosphate).

1. Glucose is broken down in respiration and energy is released.
2. This energy is used to join a phosphate group onto ADP (adenosine diphosphate), making ATP.
3. ATP moves to the part of the cell where energy is needed.
4. ATP is broken down back to ADP and phosphate, and this releases energy for the cell to use.
5. ADP and phosphate are then used again in respiration to make more ATP.

So ATP is the energy carrier of the cell. ATP **provides energy for cells** to carry out the processes of life.

- Muscle contraction, so that movement is possible.
- Active transport, which moves substances against a concentration gradient.
- Making large molecules from small ones, such as proteins from amino acids.
- Cell division and growth.
- Sending nerve impulses.

ATP	The molecule that provides energy for cells. It is made during respiration.
Respiration	The chemical process in cells that releases energy from food, such as glucose, and uses it to make ATP.

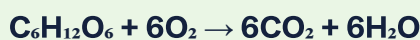
*Common mistake: Do not say that respiration 'makes energy'. Energy cannot be made. Say that respiration **releases** energy from glucose to make ATP, and ATP provides energy for cells.*

Aerobic and anaerobic respiration equations Spec 2.37, 2.38

Aerobic respiration

Aerobic respiration uses oxygen to break down glucose. It releases a large amount of energy to make ATP. You need to know both the word equation and the balanced symbol equation.

glucose + oxygen → carbon dioxide + water



Anaerobic respiration

Anaerobic respiration happens without oxygen. The products depend on the type of organism. You need to know the word equations only.

Anaerobic respiration in animals and in plants	
Organism	Word equation
Animals (for example muscle cells during hard exercise)	glucose → lactic acid
Plants (and yeast)	glucose → ethanol + carbon dioxide

Exam tip: Learn the symbol equation as $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$. To check it is balanced, count the atoms on each side: 6 carbon, 12 hydrogen and 18 oxygen.

*Common mistake: Animals make **lactic acid**, and plants make **ethanol and carbon dioxide**. Mixing these up is a very common way to lose marks.*

Comparing aerobic and anaerobic respiration Spec 2.36

Aerobic and anaerobic respiration compared		
	Aerobic respiration	Anaerobic respiration
Oxygen needed?	Yes	No
Glucose breakdown	Complete breakdown	Incomplete breakdown
Energy released	A large amount per glucose molecule	Much less per glucose molecule
Products in animals	Carbon dioxide and water	Lactic acid
Products in plants and yeast	Carbon dioxide and water	Ethanol and carbon dioxide
When it happens	Whenever enough oxygen is available	When oxygen is not available, for example in muscles during vigorous exercise

Aerobic respiration releases much more energy because glucose is **completely** broken down. Anaerobic respiration releases less energy because glucose is only **partly** broken down. Both types release energy from glucose to make ATP.

Exam tip: A comparison needs both sides in the same sentence, for example: aerobic respiration releases more energy per glucose than anaerobic respiration.

Practical: carbon dioxide and heat from respiring seeds Spec 2.39

Respiring organisms release carbon dioxide and heat. You can show both with germinating seeds, which respire quickly as they grow. A second set of seeds that have been boiled (and so are dead) acts as the **control**.

Heat released

1. Soak some seeds, such as peas, so that they start to germinate. Boil a second batch to kill them, then let them cool to room temperature.
2. Rinse both batches in a weak disinfectant solution. This kills microorganisms that would also respire.
3. Put the living seeds in one **vacuum flask** (which reduces heat loss) and the boiled seeds in another. Put a thermometer in each flask and plug the top with cotton wool.
4. Use the same mass of seeds in each flask and start both at the same temperature.
5. Record the temperature of each flask at the start and then at regular intervals, for example every day for several days.

Carbon dioxide released

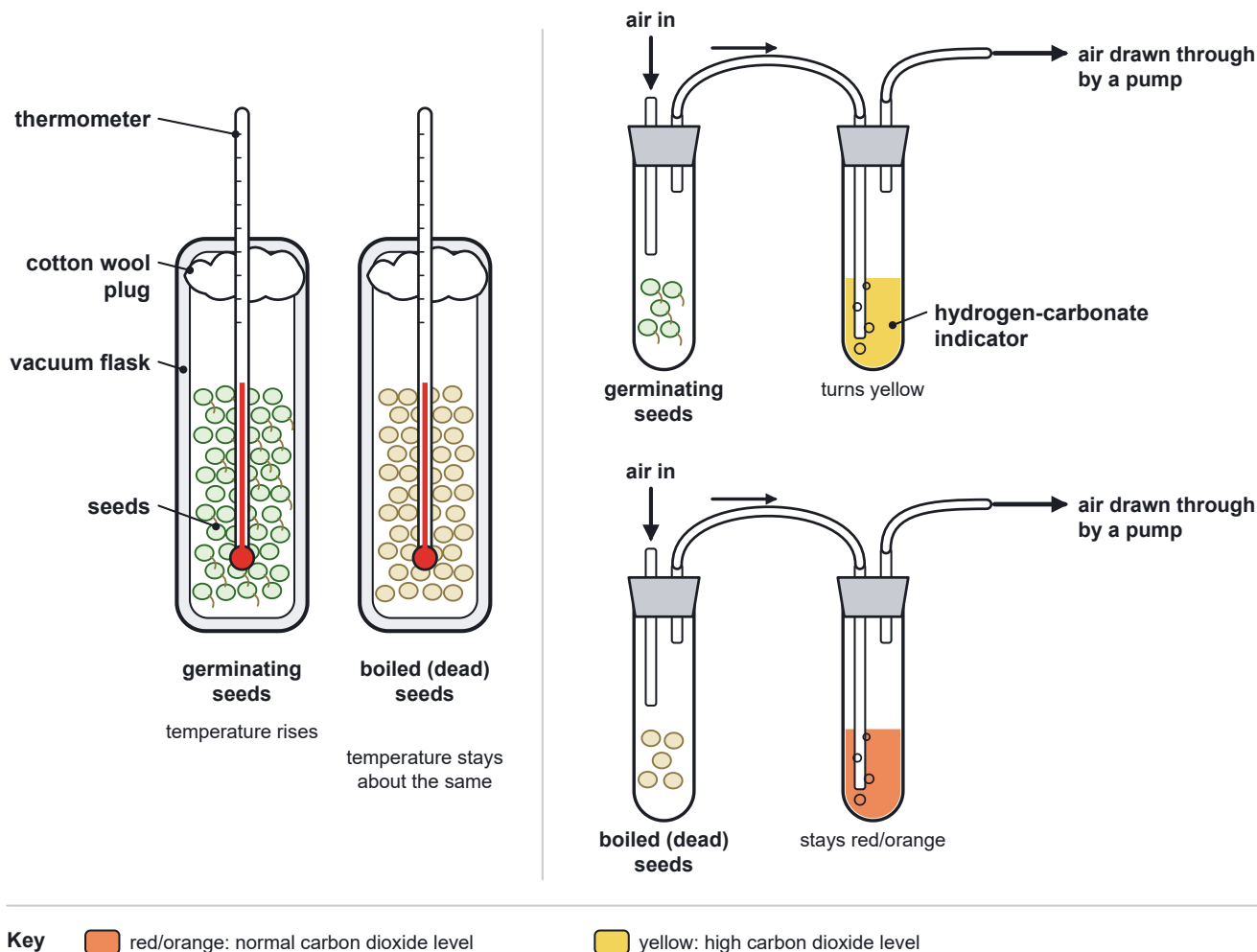
1. Set up a tube of germinating seeds and a tube of boiled seeds, each connected to a tube of hydrogen-carbonate indicator (or limewater). Alternatively, hold the seeds on gauze above the indicator in a sealed tube.
2. If the tubes are connected, draw air through each set of apparatus with a pump or syringe, so that any carbon dioxide released by the seeds bubbles through the indicator.

3 . Record the colour of the indicator after a set time.

Variables in the investigation	
Type of variable	Example
Independent variable	Living seeds or boiled seeds
Dependent variable	Temperature of the flask, or the colour of the indicator
Control variables	Mass of seeds, starting temperature, volume of indicator, volume of air drawn through, time

Expected results		
Test	Living seeds	Boiled seeds
Temperature	Rises, because respiration releases heat	Stays about the same
Hydrogen-carbonate indicator	Changes from red/orange to yellow (carbon dioxide released)	Stays red/orange
Limewater	Turns cloudy	Stays clear

Practical: Wash your hands after handling seeds and disinfectant, and wear eye protection. Limewater is an irritant. The boiled seeds are the control because they show that the changes are caused by living seeds, not by the apparatus.



Germinating seeds release **heat** (the temperature rises) and **carbon dioxide** (the indicator turns **yellow**). Boiled seeds are the control.

Quick check

1. What is the name of the molecule that provides energy for cells?
2. State the word equation for aerobic respiration.
3. What is made in anaerobic respiration in animals?
4. What is made in anaerobic respiration in plants?
5. Why are boiled seeds used as a control in the respiring seeds practical?

7 Gas exchange in flowering plants Spec 2.40B, 2.41B, 2.43B-2.45B, 2.70

Gas exchange, diffusion and stomata Spec 2.40B, 2.41B, 2.43B, 2.70

Waste products of metabolism

Metabolism is all the chemical reactions in a cell. Two of its products are waste products in a plant.

Carbon dioxide is a waste product of respiration. Oxygen is a waste product of photosynthesis. Both leave the plant from the leaves by diffusion through the stomata.

Biology only

Diffusion in gas exchange

Biology only

Diffusion is the net movement of particles from a region of higher concentration to a region of lower concentration, down a concentration gradient. Gases move into and out of leaves by diffusion, so no energy is needed to move them.

Biology only

Plants use and make both gases. Gas exchange of carbon dioxide and oxygen therefore depends on two processes at the same time.

Biology only

Gas exchange in relation to respiration and photosynthesis

Process	Takes in	Gives out	When it happens
Respiration	Oxygen	Carbon dioxide	All the time, in light and dark
Photosynthesis	Carbon dioxide	Oxygen	Only when there is light

Biology only

Gases reach the mesophyll cells through the stomata and the air spaces inside the leaf. How the structure of the leaf is adapted for gas exchange is covered in Leaf structure and adaptations.

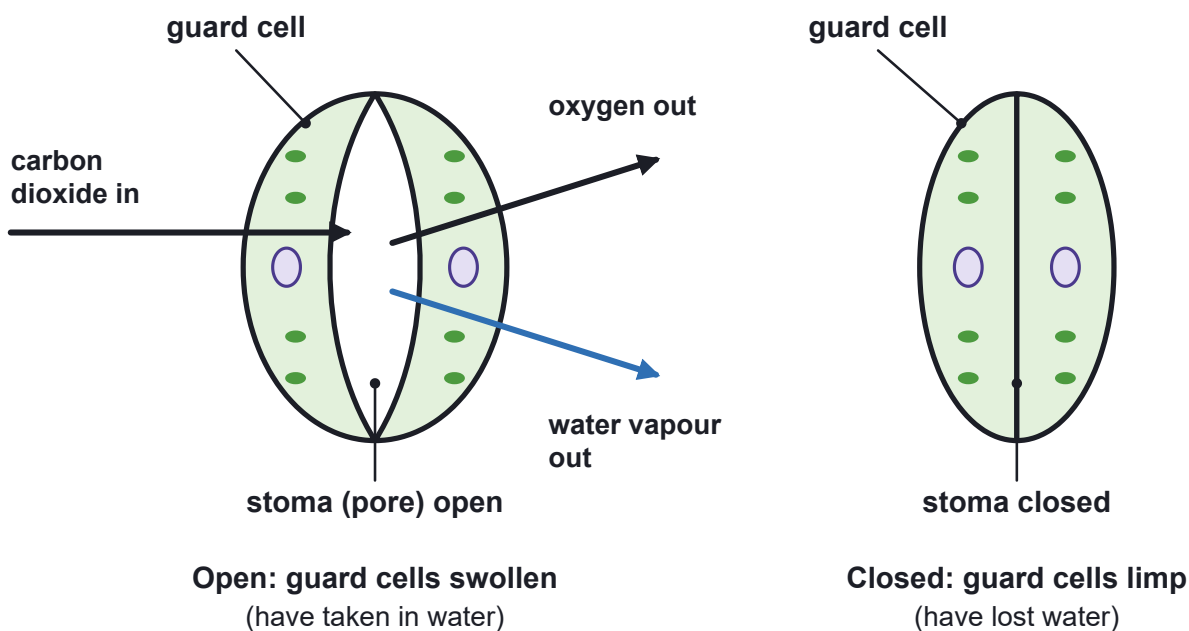
Biology only

The role of stomata

Biology only

A stoma is a pore in the leaf surface. It is surrounded by two guard cells. When the guard cells take in water they swell and the stoma opens. When they lose water they become limp and the stoma closes. Carbon dioxide enters and oxygen leaves through open stomata. Water vapour is also lost through them, so the plant closes its stomata when it loses too much water.

Biology only



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

Biology only

Exam tip: In the day, carbon dioxide diffuses into the leaf because photosynthesis uses it up, so its concentration inside the leaf is lower than in the air.

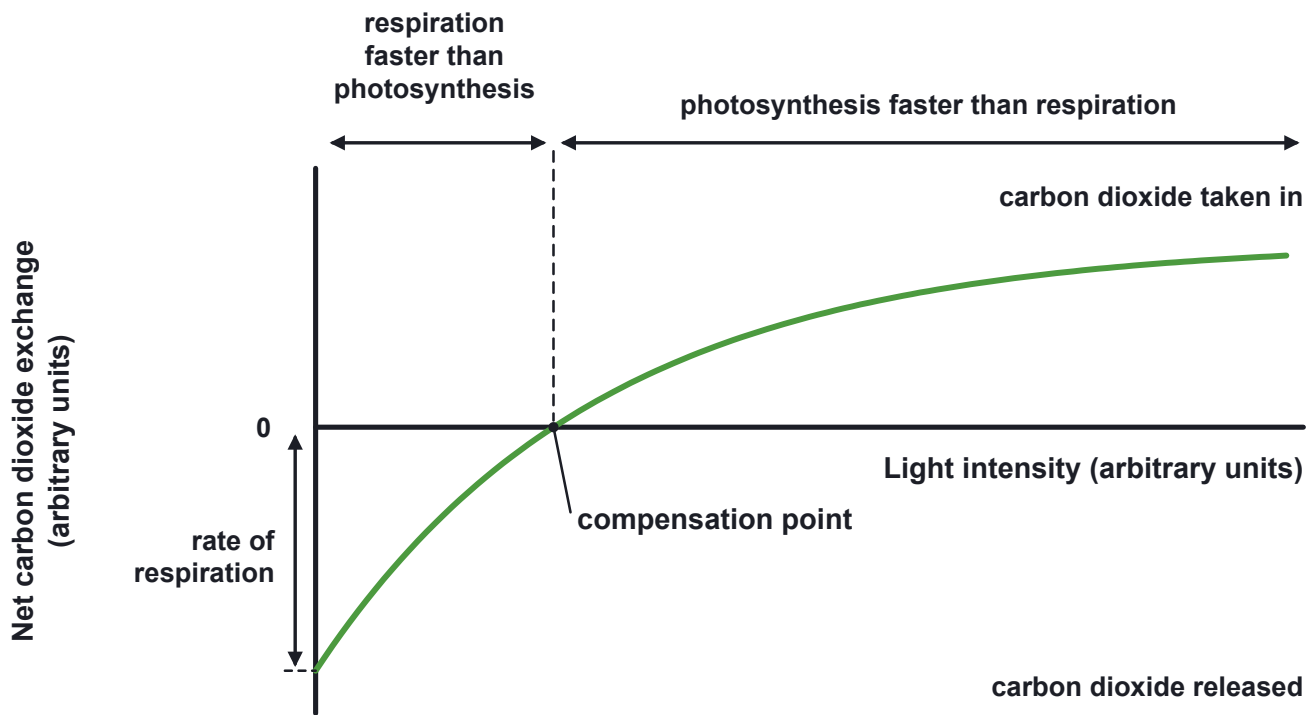
Net gas exchange by day and night Spec 2.44B Biology only

A plant respire **all the time**. It photosynthesises **only when there is light**. This means that the **net** exchange of carbon dioxide and oxygen with the air changes with the light intensity.

Net gas exchange at different light intensities			
Light	Rate of photosynthesis compared with respiration	Net exchange of carbon dioxide	Net exchange of oxygen
Darkness (night)	No photosynthesis, only respiration	Carbon dioxide released	Oxygen taken in
Dim light	Photosynthesis slower than respiration	Carbon dioxide released	Oxygen taken in
Compensation point	Photosynthesis equals respiration	None	None
Bright light (day)	Photosynthesis faster than respiration	Carbon dioxide taken in	Oxygen released

At the **compensation point** the carbon dioxide made in respiration is used up by photosynthesis, and the oxygen made in photosynthesis is used up by respiration. No gas moves in or out overall, but both processes are still happening.

As light intensity rises, the rate of photosynthesis rises while the rate of respiration stays about the same. A graph of net carbon dioxide uptake against light intensity therefore starts below zero (carbon dioxide released), crosses zero at the compensation point, then rises above zero.



Below the **compensation point** the plant releases carbon dioxide; above it, the plant takes carbon dioxide in.

Exam tip: Never say that plants only respire at night. They respire all the time. In the day the carbon dioxide from respiration is simply hidden by faster photosynthesis.

Practical: light and net gas exchange Spec 2.45B Biology only

Hydrogen-carbonate indicator changes colour as the carbon dioxide concentration of the air around it changes. It turns **yellow** when carbon dioxide rises and **purple** when carbon dioxide falls. You can use it to see whether a leaf takes in or releases carbon dioxide in different light intensities.

Colours of hydrogen-carbonate indicator

Colour	Carbon dioxide concentration
Red/orange (starting colour)	Same as in normal air
Yellow	Higher than normal air (carbon dioxide has been added)
Purple	Lower than normal air (carbon dioxide has been removed)

- Put the same volume of hydrogen-carbonate indicator into four boiling tubes.
- Put a similar leaf (same size and mass) into three of the tubes, held above the indicator on gauze or a wire so it does not touch the liquid. Leave the fourth tube with no leaf as a control.
- Seal each tube with a bung.
- Place the first tube in bright light. Place the second in dim light (wrapped in one layer of gauze or netting). Wrap the third completely in foil so it is in darkness.
- Leave all the tubes for the same time, for example one to two hours, at the same distance from the lamp. Do not breathe into the tubes, as this adds carbon dioxide.
- Record the colour of the indicator in each tube.

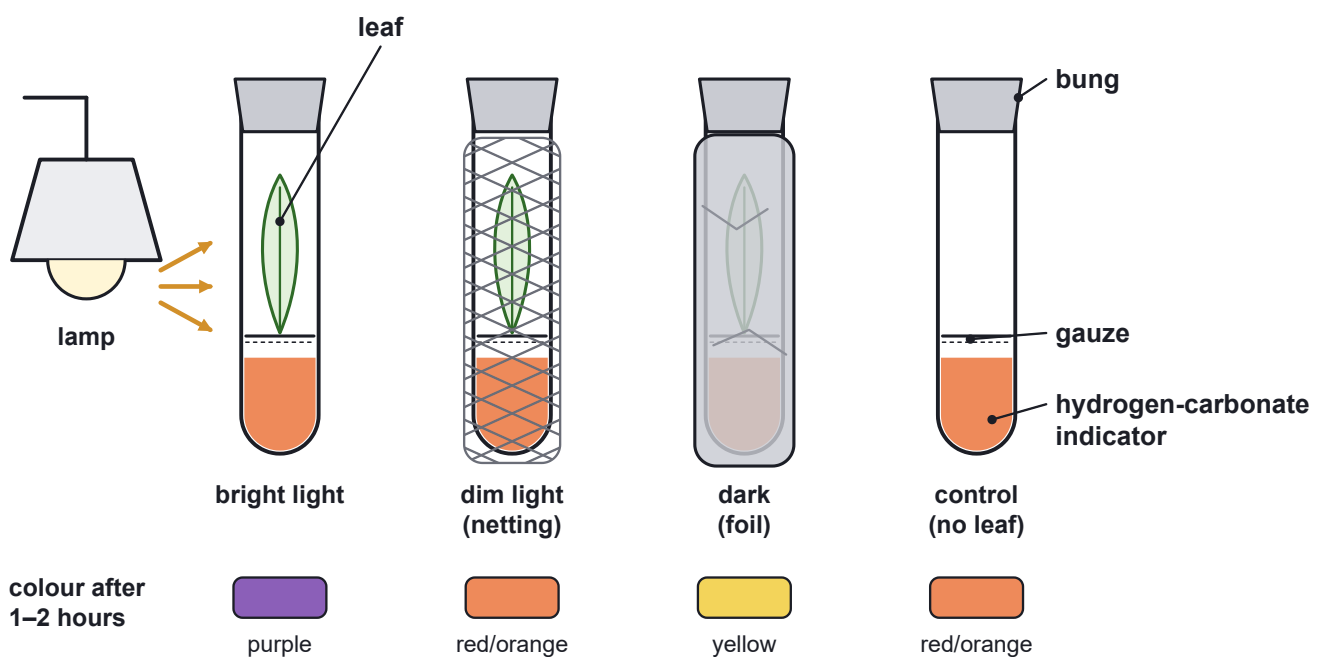
Expected results

Tube	Colour after the time	Explanation
Bright light	Purple	Photosynthesis faster than respiration, so net uptake of carbon dioxide
Dim light	Stays red/orange	Photosynthesis about equal to respiration, so no net change
Dark (foil)	Yellow	Only respiration, so net release of carbon dioxide
No leaf (control)	Stays red/orange	Shows the colour change is caused by the leaf

Variables in the investigation

Type of variable	Example
Independent variable	Light intensity (bright, dim, dark)
Dependent variable	Colour of the hydrogen-carbonate indicator
Control variables	Size and mass of leaf, volume of indicator, time, temperature, distance from the lamp

Practical: Put a water tank (heat shield) between the lamp and the tubes so that heat from the lamp does not change the temperature. The lamp gets hot, so do not touch it. The dim light result depends on the light level: the indicator may turn slightly yellow or slightly purple.



Key

- purple: carbon dioxide lower than in normal air
- red/orange: carbon dioxide same as in normal air
- yellow: carbon dioxide higher than in normal air

Bright light: the indicator turns **purple** (carbon dioxide taken in). Dark: it turns **yellow** (carbon dioxide released).

Quick check

1. **Biology only** Name the process by which gases move into and out of a leaf.
2. **Biology only** What do guard cells do?
3. Which gas is a waste product of photosynthesis and leaves through the stomata?
4. **Biology only** What is happening at the compensation point?
5. **Biology only** What colour does hydrogen-carbonate indicator turn when carbon dioxide is added?

8 Gas exchange in humans Spec 2.46-2.50

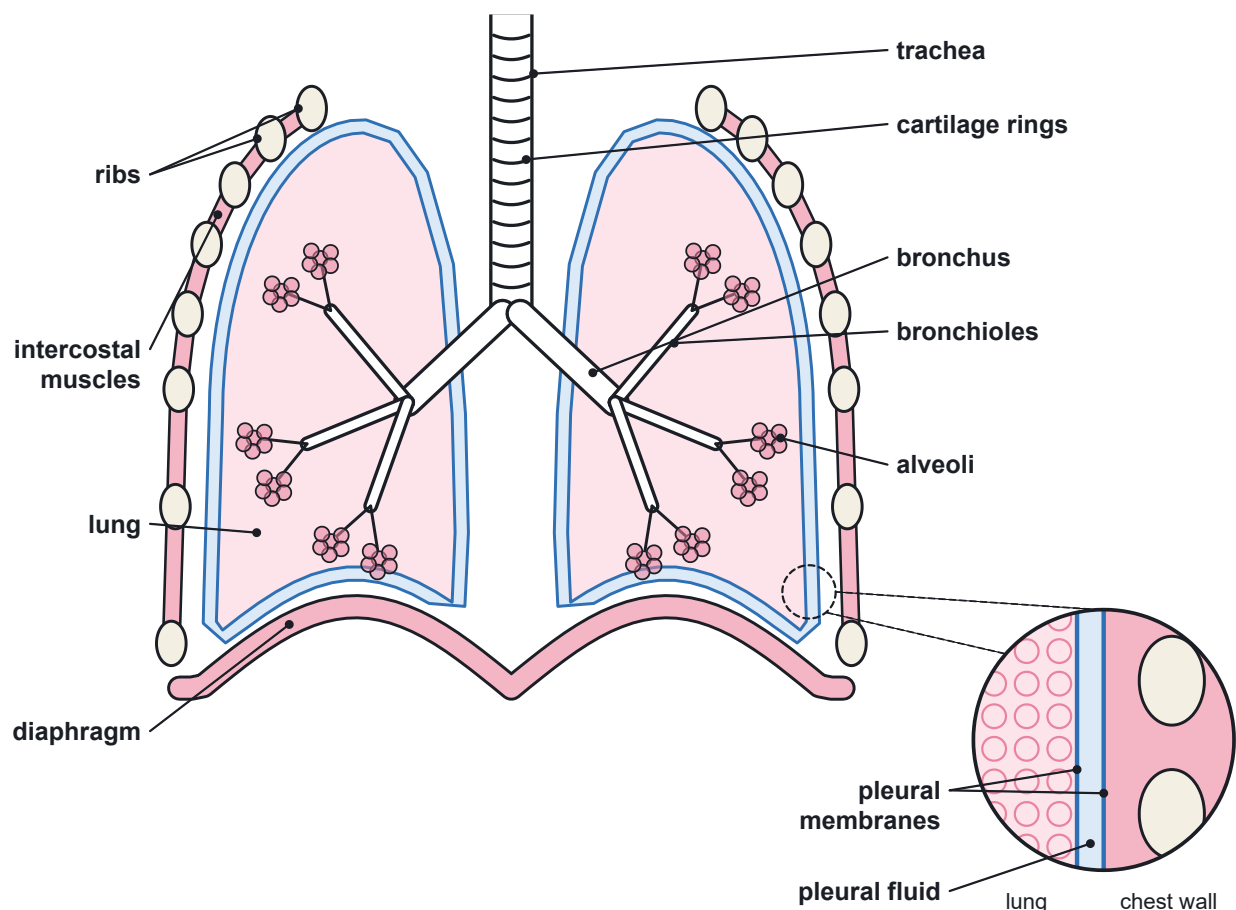
The structure of the thorax Spec 2.46

The **thorax** is the chest. It contains the lungs and the heart, and it is protected by the ribs. Air enters through the nose or mouth and passes along the airways to the alveoli.

Structures of the thorax	
Structure	Description and function
Ribs	Bones that form a cage and protect the lungs and heart. They can move up and out, and down and in.
Intercostal muscles	Muscles between the ribs. They move the rib cage.
Diaphragm	A sheet of muscle under the lungs that separates the thorax from the abdomen.
Trachea	The windpipe. It carries air to the lungs. Rings of cartilage keep it open.
Bronchi (one is a bronchus)	Two tubes that branch from the trachea, one to each lung.
Bronchioles	Small tubes that branch from the bronchi and carry air to the alveoli.
Alveoli	Tiny air sacs at the ends of the bronchioles, where gas exchange happens.
Pleural membranes	Two thin membranes around the lungs and lining the chest wall, with a thin layer of fluid between them. The fluid reduces friction when the lungs move.

The path of air when you breathe in is: nose or mouth, **trachea**, **bronchi**, **bronchioles**, **alveoli**.

Exam tip: Learn the order of the airways. Marks are often lost by writing bronchi and bronchioles the wrong way round: the bronchi are the larger tubes.



Air passes down the **trachea**, **bronchi** and **bronchioles** to the **alveoli**. The ribs, intercostal muscles and diaphragm surround the lungs.

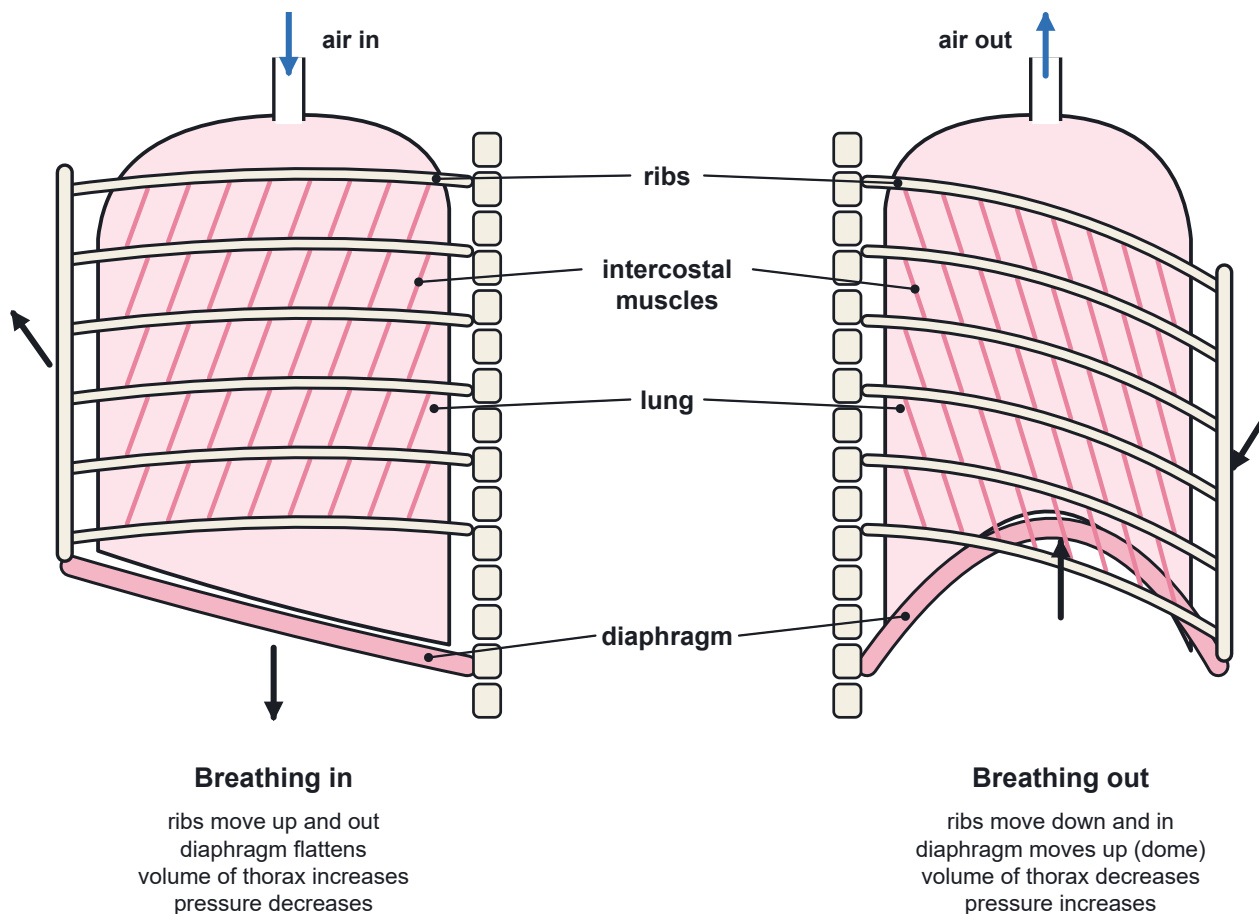
Ventilation: breathing in and out Spec 2.47

Ventilation is the movement of air into and out of the lungs. The lungs have no muscle of their own. Air moves because the **intercostal muscles** and the **diaphragm** change the volume of the thorax, and this changes the air pressure inside it.

Breathing in and breathing out		
	Breathing in (inhaling)	Breathing out (exhaling)
Intercostal muscles	Contract	Relax
Ribs	Move up and out	Move down and in
Diaphragm	Contracts and flattens	Relaxes and moves up (dome shape)
Volume of the thorax	Increases	Decreases
Pressure in the thorax	Decreases, below atmospheric pressure	Increases, above atmospheric pressure
Movement of air	Air moves into the lungs	Air moves out of the lungs

Air always moves from a region of higher pressure to a region of lower pressure. When you breathe in, the pressure inside the thorax falls below the pressure of the air outside, so air moves in. When you breathe out, the pressure inside rises above the outside pressure, so air moves out.

Common mistake: Do not say that the lungs 'pull in' air or that the ribs 'push' air in. The muscles change the volume and pressure of the thorax, and the difference in pressure moves the air.



Breathing in: volume up, pressure down, so air moves in. Breathing out: volume down, pressure up, so air moves out.

Alveoli and gas exchange Spec 2.48

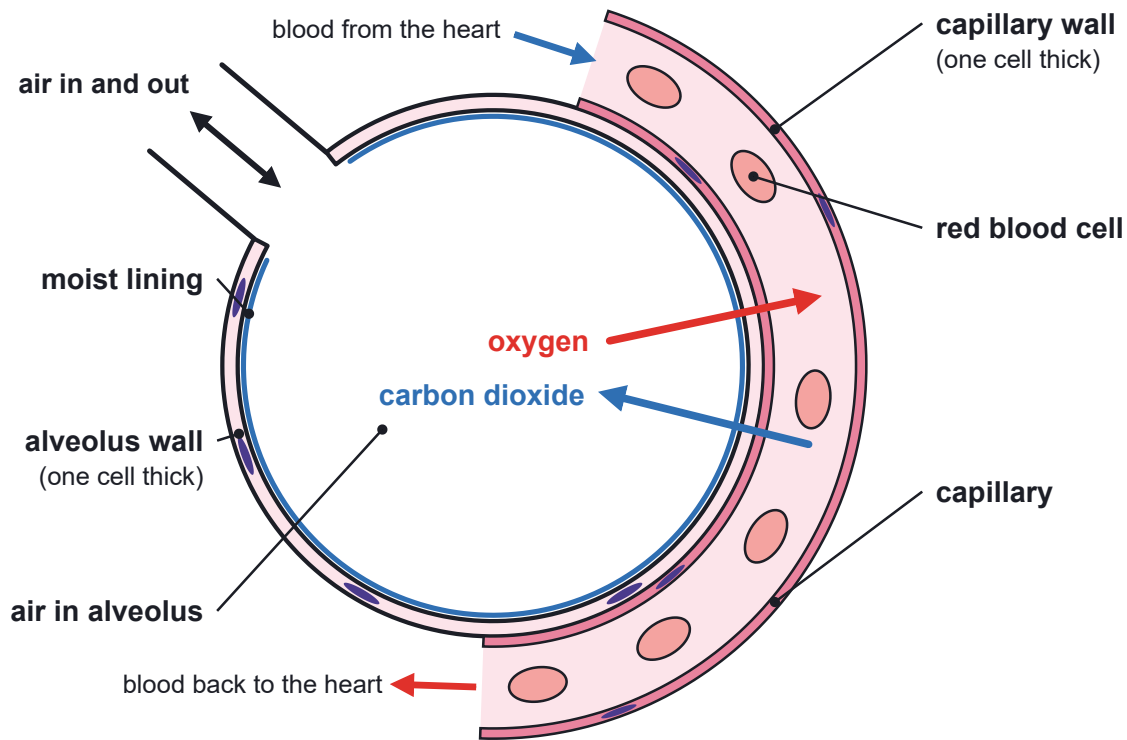
The lungs are the exchange surface for oxygen and carbon dioxide. Each lung contains millions of tiny air sacs called **alveoli**. Gases move between the air in the alveoli and the blood in the capillaries around them by **diffusion**.

- Oxygen diffuses from the air in the alveoli (high concentration) into the blood (low concentration).
- Carbon dioxide diffuses from the blood (high concentration) into the air in the alveoli (low concentration), and is breathed out.

How alveoli are adapted for gas exchange

Adaptation	Why it helps
Millions of alveoli	Gives a very large surface area for diffusion
Walls only one cell thick	Short diffusion distance, so gases diffuse quickly
Capillary walls only one cell thick	Short diffusion distance between the air and the blood
Rich network of capillaries (good blood supply)	Blood carries oxygen away and brings carbon dioxide, keeping a steep concentration gradient
Moist lining	Gases dissolve, which helps them to diffuse
Ventilation (breathing in and out)	Keeps a high oxygen concentration in the alveoli and a low carbon dioxide concentration, which maintains the concentration gradient

Exam tip: Do not stop at the adaptation. Link every feature to its effect: for example, thin walls means a short diffusion distance, so faster diffusion.



Oxygen diffuses into the blood and carbon dioxide diffuses out, across two walls that are each one cell thick.

Smoking, the lungs and the circulatory system Spec 2.49

Tobacco smoke contains many harmful substances. The three you need to know about are tar, carbon monoxide and nicotine.

Harmful substances in tobacco smoke	
Substance	Effect
Tar	Contains carcinogens (chemicals that cause cancer), so increases the risk of lung cancer. Also damages the airway lining.
Carbon monoxide	Combines with haemoglobin in red blood cells, so they carry less oxygen. The heart has to work harder to supply the body with oxygen.
Nicotine	An addictive drug. It increases heart rate and blood pressure.

Effects on the lungs

- The airways are lined with ciliated cells, which have tiny hairs (cilia), and goblet cells, which make mucus. Mucus traps dust and bacteria, and the cilia sweep it up to the throat.
- Tar damages and destroys the cilia, so mucus and the microorganisms in it stay in the airways. This causes infections and a smoker's cough.
- **Chronic bronchitis**: smoke irritates the airways, so goblet cells make more mucus. The airways become inflamed and blocked with mucus, which makes breathing difficult.
- **Emphysema**: the walls of the alveoli break down, so the surface area for gas exchange is much smaller. The person is short of breath.
- **Lung cancer**: carcinogens in tar can make lung cells divide out of control and form a tumour.

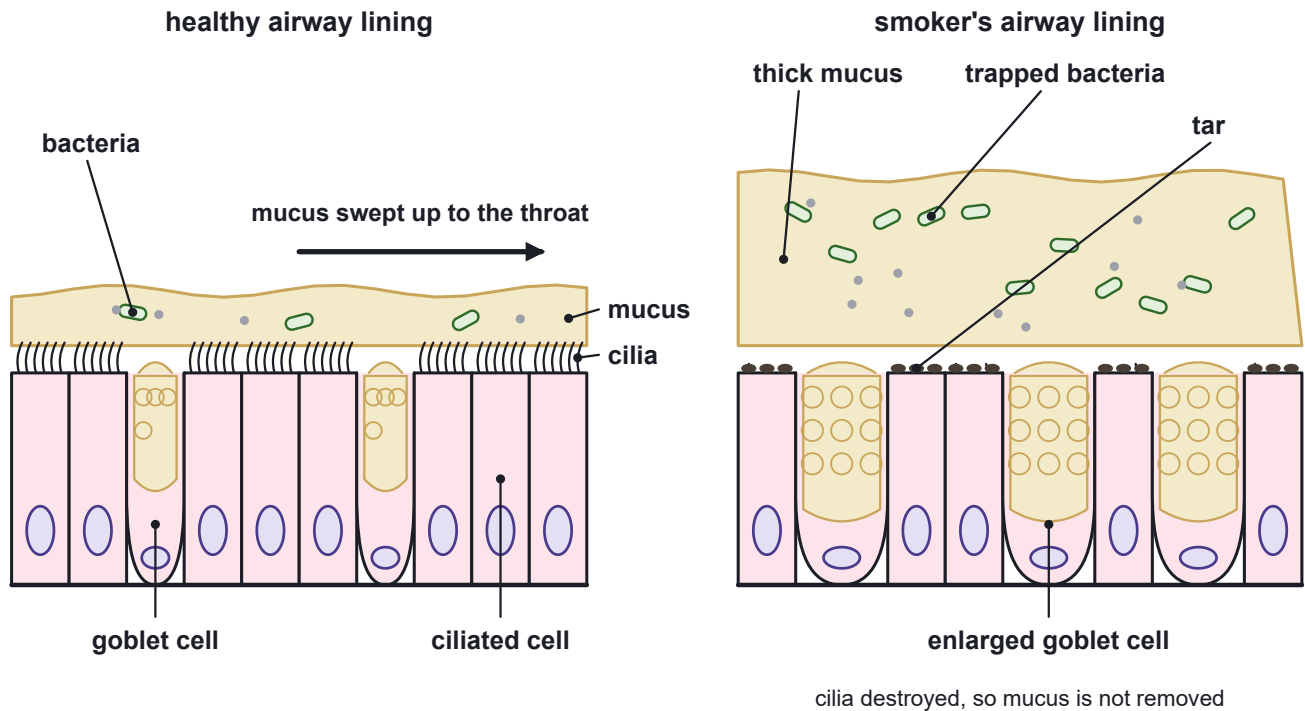
Effects on the circulatory system

Smoking raises the risk of **coronary heart disease**. In this disease the coronary arteries, which supply the heart muscle with oxygenated blood, become narrowed by fatty deposits. Less blood reaches the

heart muscle, so it gets less oxygen. If a coronary artery is completely blocked, part of the heart muscle is starved of oxygen and a heart attack results.

Smoking makes this more likely. Chemicals in smoke and raised blood pressure damage the lining of the arteries, so fatty deposits build up more easily and blood clots are more likely to form. Nicotine raises heart rate and blood pressure, and carbon monoxide reduces the oxygen carried by the blood, so the heart has to work harder.

Exam tip: Name the substance, then state its effect. 'Smoking damages the lungs' gains nothing: say that tar destroys the cilia, so mucus is not removed.



Tar destroys the **cilia**, so mucus and the bacteria trapped in it are **not removed** from the airways.

Practical: breathing, carbon dioxide and exercise Spec 2.50

You can investigate breathing in two ways: by finding the carbon dioxide in the air you breathe out, and by measuring how exercise changes your breathing rate.

Carbon dioxide in exhaled air

1. Set up two boiling tubes, each containing the same volume of limewater (or hydrogen-carbonate indicator). Join them with tubing and glass tubes so that air breathed in comes through one tube and air breathed out goes through the other.
2. Breathe gently in and out through a clean mouthpiece, so that you breathe in through the first tube and out through the second.
3. Observe the limewater in each tube.

Limewater turns **cloudy** (milky) when carbon dioxide is present, and hydrogen-carbonate indicator turns from red/orange to yellow. The limewater in the tube for exhaled air turns cloudy much faster than in the tube for inhaled air, because exhaled air contains more carbon dioxide. This carbon dioxide comes from respiration in body cells.

The effect of exercise

1. Sit still and count the number of breaths in one minute. Repeat and calculate a mean breathing rate at rest.

- Exercise for a set time, for example two minutes of stepping or running on the spot.
- Count the number of breaths in one minute straight away after exercise.
- Continue to record the breathing rate each minute until it returns to the resting rate.

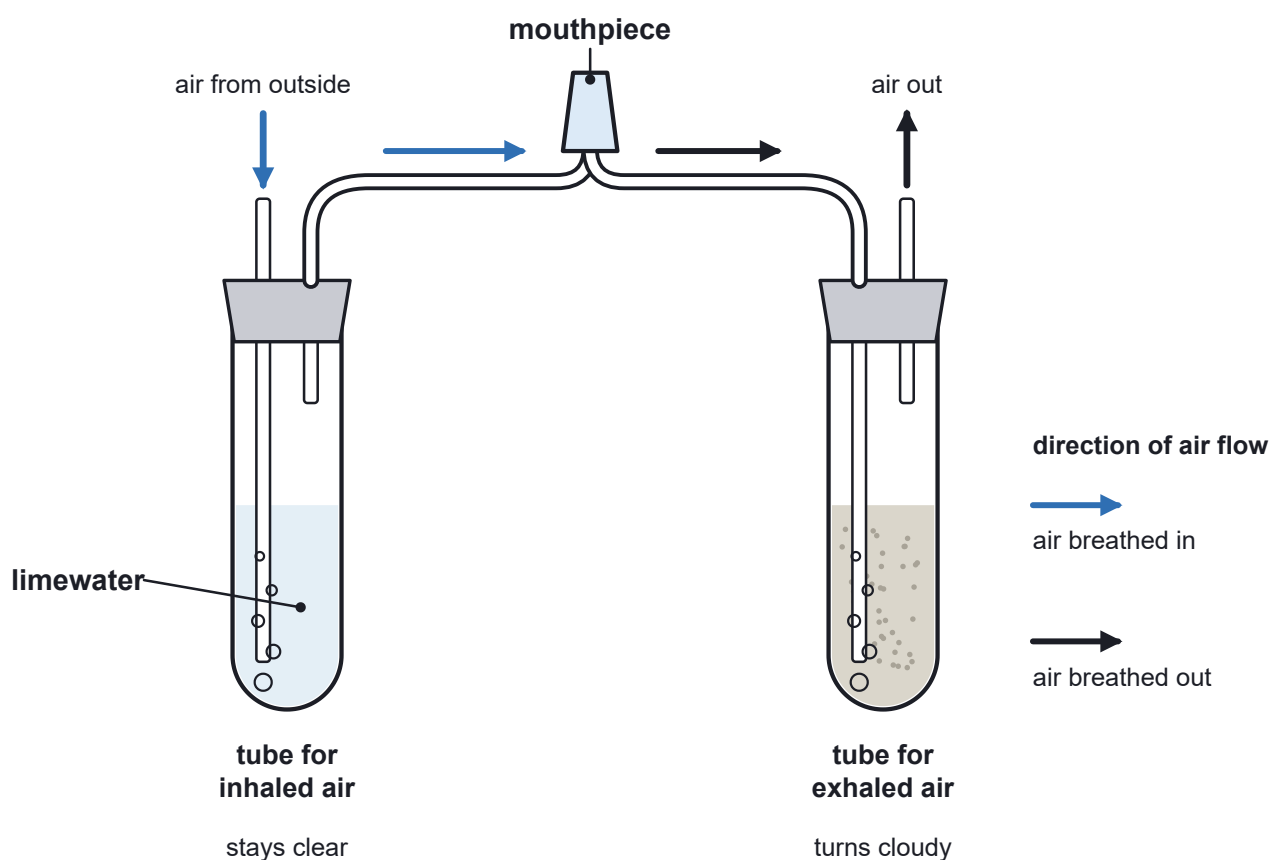
$$\text{breathing rate (breaths per minute)} = \text{number of breaths} \div \text{time in minutes}$$

Expected result: the **breathing rate** is higher after exercise and takes a few minutes to return to normal. Breathing is also deeper. Exercising muscles respire faster, so they make more carbon dioxide. Faster, deeper breathing removes the extra carbon dioxide and takes in more oxygen for respiration. If you breathe out through limewater or indicator after exercise, it changes faster than at rest.

Variables in the investigation

Type of variable	Example
Independent variable	Rest or exercise (or the length or type of exercise)
Dependent variable	Breathing rate, or time for the indicator to change colour
Control variables	Volume of limewater or indicator, same person, same type of exercise, same time of counting

Practical: Never suck liquid back into your mouth: use a clean (disinfected) mouthpiece and tubes arranged so you cannot. Limewater is an irritant, so wear eye protection. Anyone with asthma or a medical condition should not do the exercise, and everyone should stop if they feel dizzy.



Limewater turns **cloudy** in the tube for exhaled air, because exhaled air contains more carbon dioxide.

Quick check

- 1 . Name the muscles that contract when you breathe in.
- 2 . What happens to the pressure in the thorax when you breathe in?
- 3 . Why are alveolus walls only one cell thick?
- 4 . Which substance in tobacco smoke combines with haemoglobin?
- 5 . What happens to limewater when carbon dioxide is bubbled through it?

9 The need for transport and transport in plants Spec 2.51-2.58B

Why multicellular organisms need transport systems Spec 2.51, 2.52

Every cell needs a supply of oxygen and dissolved food molecules, and must get rid of waste such as carbon dioxide. In a unicellular (single-celled) organism these substances move in and out by **diffusion** across the cell surface.

This works because a single cell has a **large surface area compared with its volume**. No part of the cell is far from the surface, so the diffusion distance is short and diffusion is fast enough to meet the cell's needs.

Multicellular organisms

A multicellular organism is much bigger. Its surface area : volume ratio is **small**, and most of its cells are deep inside the body, far from the outside world. Diffusion over such long distances is far too slow to supply every cell with enough oxygen and food, or to remove waste quickly enough.

Multicellular organisms therefore need a **transport system**. In humans this is the blood in the circulatory system. In flowering plants it is the xylem and phloem.

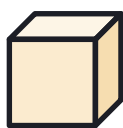
surface area : volume ratio = surface area ÷ volume

Surface area : volume ratio of a cube

A cube-shaped block of tissue has sides of 3 cm. Calculate its surface area : volume ratio.

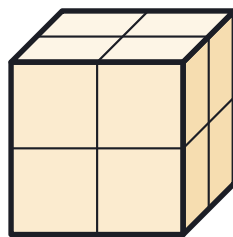
1. A cube has 6 faces. Area of one face = $3 \times 3 = 9 \text{ cm}^2$.
2. Surface area = $6 \times 9 = 54 \text{ cm}^2$.
3. Volume = $3 \times 3 \times 3 = 27 \text{ cm}^3$.
4. Ratio = 54 : 27. Divide both sides by 27.

Answer: 2 : 1



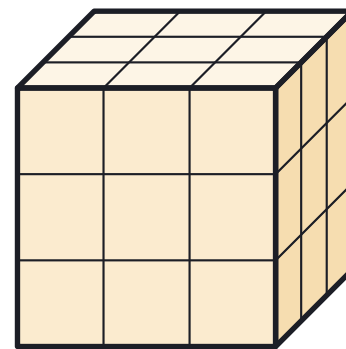
1 cm

surface area = 6 cm^2
volume = 1 cm^3
surface area : volume
= 6 : 1



2 cm

surface area = 24 cm^2
volume = 8 cm^3
surface area : volume
= 3 : 1



3 cm

surface area = 54 cm^2
volume = 27 cm^3
surface area : volume
= 2 : 1

As the cube gets bigger, its **surface area : volume ratio gets smaller**.

Substances that a transport system carries		
Substance	Direction	Reason
Oxygen	Into cells	Used in aerobic respiration to release energy
Carbon dioxide	Out of cells	Waste product of respiration
Digested food (glucose, amino acids)	Into cells	Source of energy and materials for growth and repair
Urea	Out of cells	Waste product made in the body, removed in urine

Exam tip: Do not just say that large organisms 'need more oxygen'. Link the idea: small surface area : volume ratio, so a long diffusion distance, so diffusion alone is too slow.

Xylem and phloem Spec 2.53, 2.54

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

Xylem

The **xylem** carries **water and mineral ions** from the roots to the other parts of the plant, such as the stem and leaves. It is made of dead cells joined end to end.

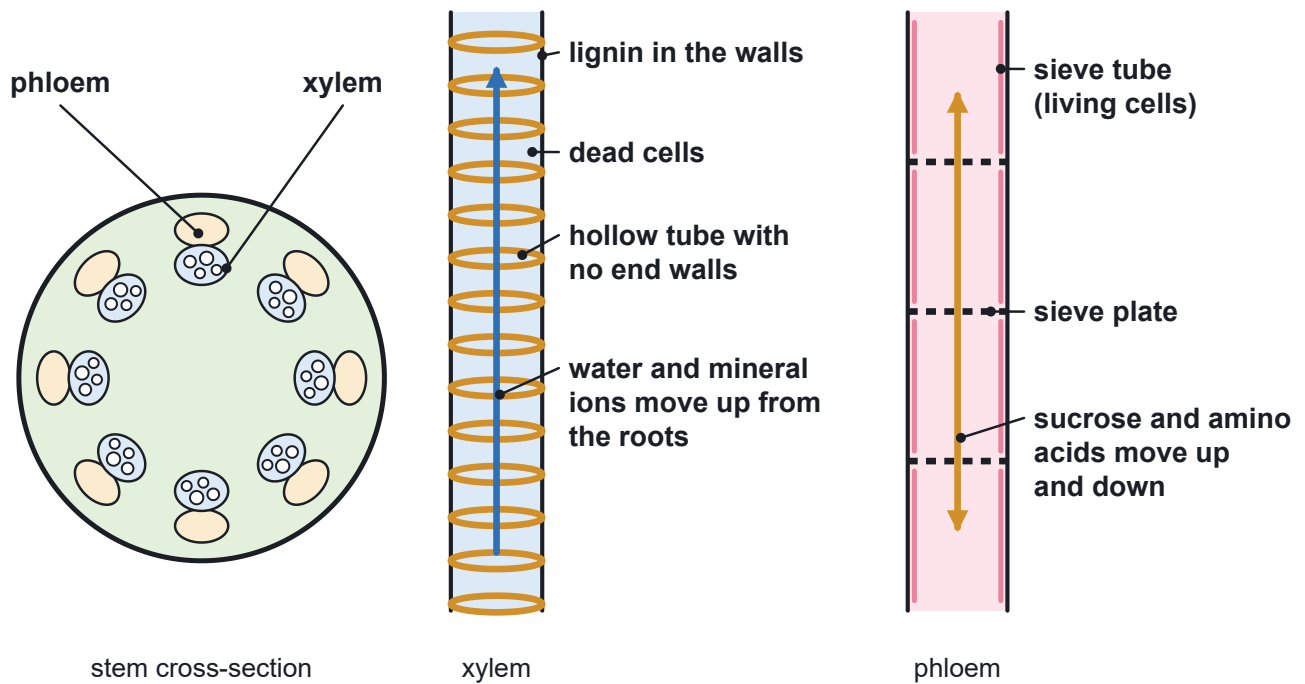
- The cells are dead with no cytoplasm, and the end walls between them have broken down. This makes a continuous hollow tube that water can flow through easily.
- The walls are strengthened with **lignin**. This is strong and waterproof, so it stops the tubes collapsing and helps to support the plant.

Phloem

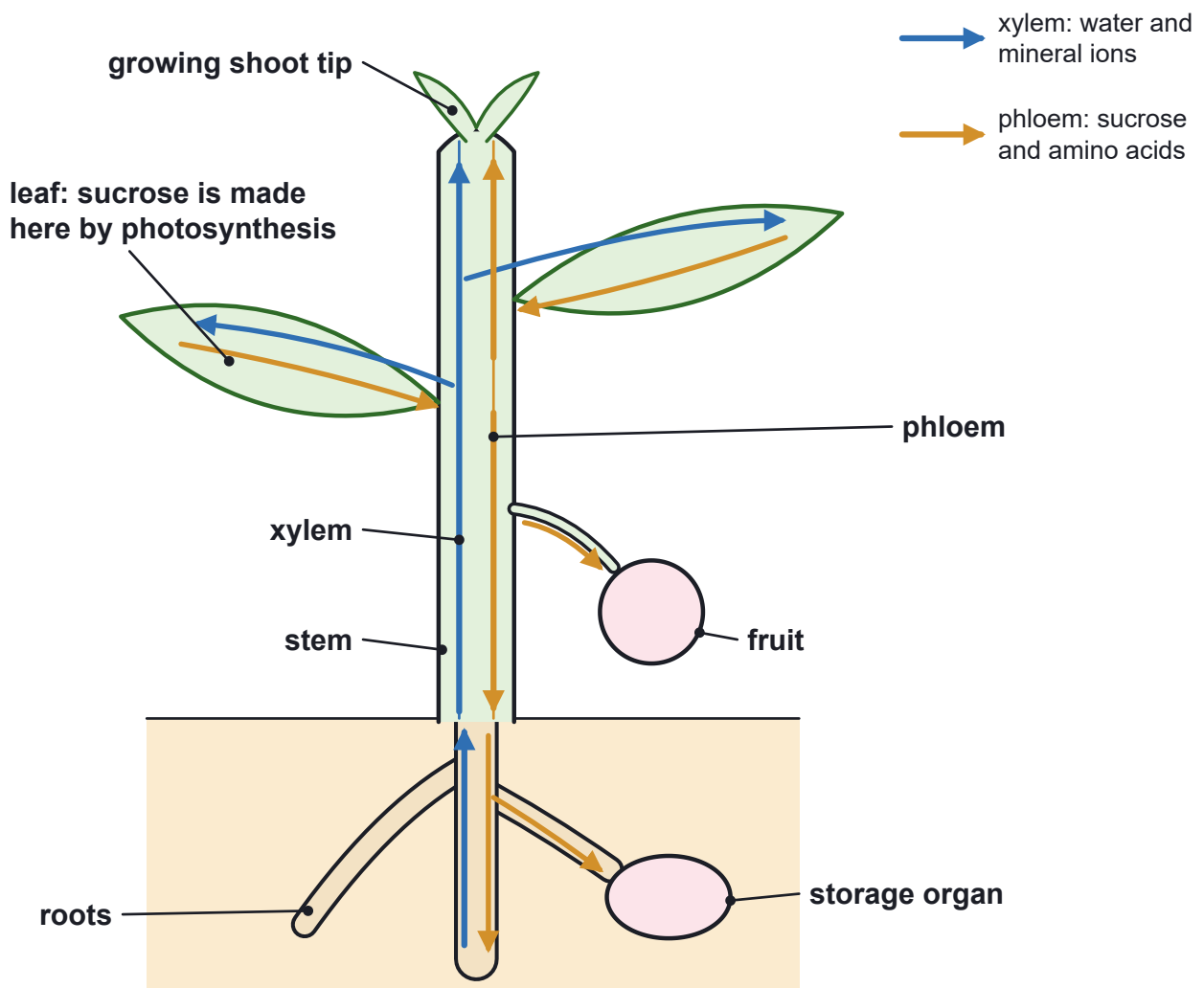
The **phloem** carries **sucrose and amino acids** between the leaves and other parts of the plant. Sucrose is made from the glucose produced in photosynthesis. Phloem is made of living cells, and the substances can move up or down the plant, depending on where they are needed.

- Sucrose and amino acids travel from the leaves to growing tips, roots, flowers, fruits and storage organs.
- The phloem tubes (sieve tubes) are made of living cells joined end to end. Their end walls have small holes (sieve plates), so the solution can flow from one cell to the next.

Xylem and phloem compared		
	Xylem	Phloem
Substances carried	Water and mineral ions	Sucrose and amino acids
Direction	Roots to the rest of the plant (upwards)	Between the leaves and other parts, up or down
Cells	Dead, hollow tubes	Living cells
Cell walls	Strengthened with lignin	Sieve plates in end walls



Xylem: dead, hollow tubes strengthened with lignin. **Phloem:** living sieve tubes with sieve plates.



Xylem carries water and mineral ions **up** the plant. Phloem carries sucrose and amino acids **up or down** to where they are needed.

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

Water uptake by root hair cells Spec 2.55B Biology only

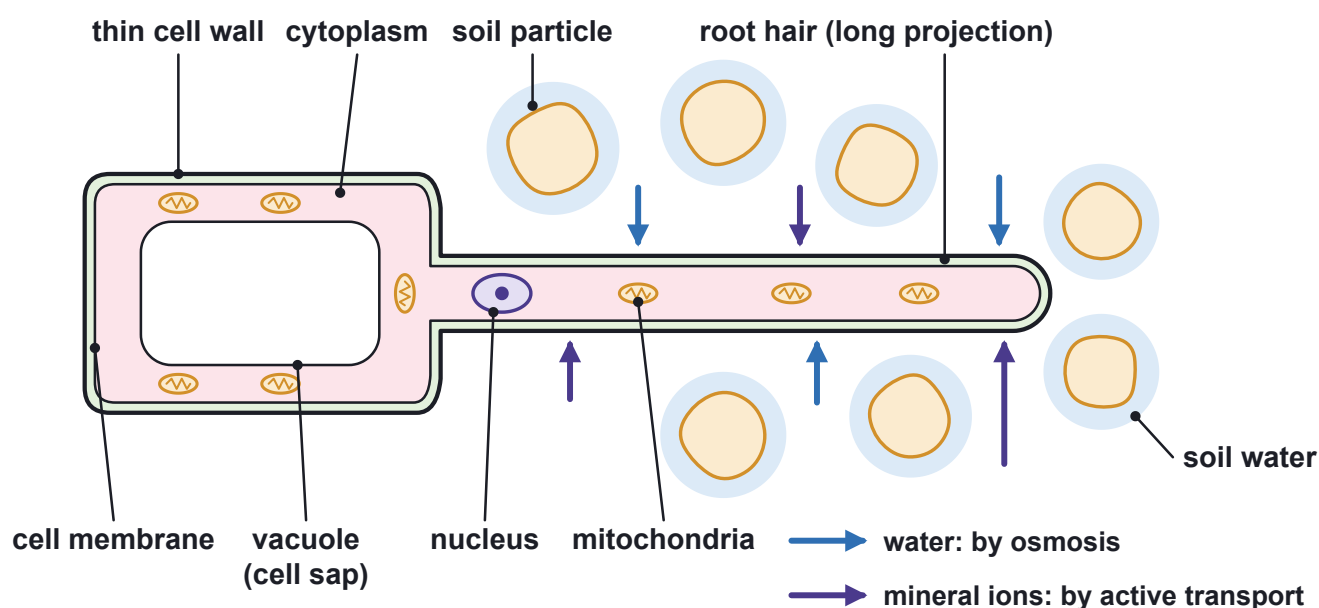
Root hair cells are found near the tips of roots. Each has a long, thin projection (the **root hair**) that reaches between the soil particles. They absorb water and mineral ions from the soil.

How water is absorbed

1. Soil water is a dilute solution, so it has a higher concentration of water molecules than the cell sap inside the root hair cell.
2. Water moves into the cell by **osmosis**: from the dilute solution outside to the more concentrated cell sap, through the partially permeable cell membrane.
3. The water then passes from cell to cell across the root into the xylem, which carries it up the plant.

Adaptations of a root hair cell	
Adaptation	How it helps
Long, thin projection (the root hair)	Large surface area, so more water can be absorbed
Thin cell wall and membrane	Short diffusion distance for water
Cell sap more concentrated than the soil water	Keeps a concentration gradient so water moves in by osmosis
Many mitochondria	Release energy for the active transport of mineral ions into the cell

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



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 its function: 'the root hair gives a large surface area, so more water can be absorbed'.

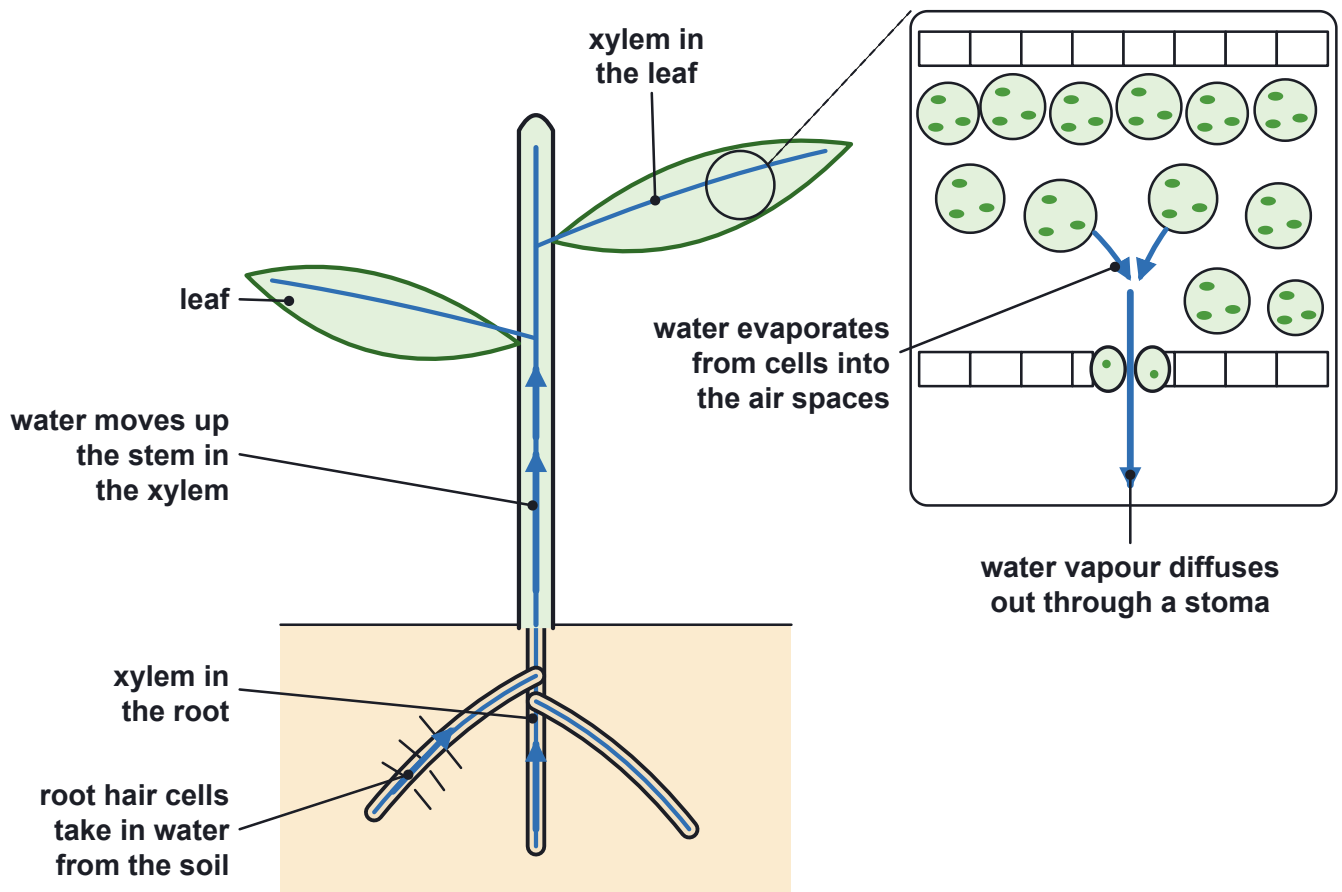
Transpiration Spec 2.56B Biology only

Transpiration The evaporation of water from the surface of a plant.

Most transpiration happens in the leaves. Water evaporates from the surface of the cells inside the leaf into the air spaces, then water vapour diffuses out through the **stomata** into the air.

1. Water is absorbed from the soil by the root hair cells.
2. Water moves up through the xylem to the leaves.
3. Water evaporates from the surface of the cells in the leaf into the air spaces.
4. Water vapour diffuses out of the leaf through the stomata.

As water leaves the leaf, more water is pulled up the xylem to replace it. This continuous flow is called the **transpiration stream**. It carries mineral ions from the roots to the leaves, and it supplies water for photosynthesis and keeps the cells firm.



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

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

Factors affecting transpiration and the potometer Spec 2.57B, 2.58B Biology only

The rate of transpiration changes with the conditions around the leaves. You need to know the effect of **humidity**, **wind speed**, **temperature** and **light intensity**.

Factors affecting the rate of transpiration			
Factor	Change	Effect on rate	Reason
Temperature	Increase	Increases	Water evaporates faster and diffuses out of the leaf faster
Humidity	Increase	Decreases	The air already holds a lot of water vapour, so the concentration gradient is smaller and diffusion is slower
Wind speed	Increase	Increases	Moving air carries water vapour away from the stomata, keeping a steep concentration gradient
Light intensity	Increase	Increases	Stomata open wider in the light, so more water vapour can leave

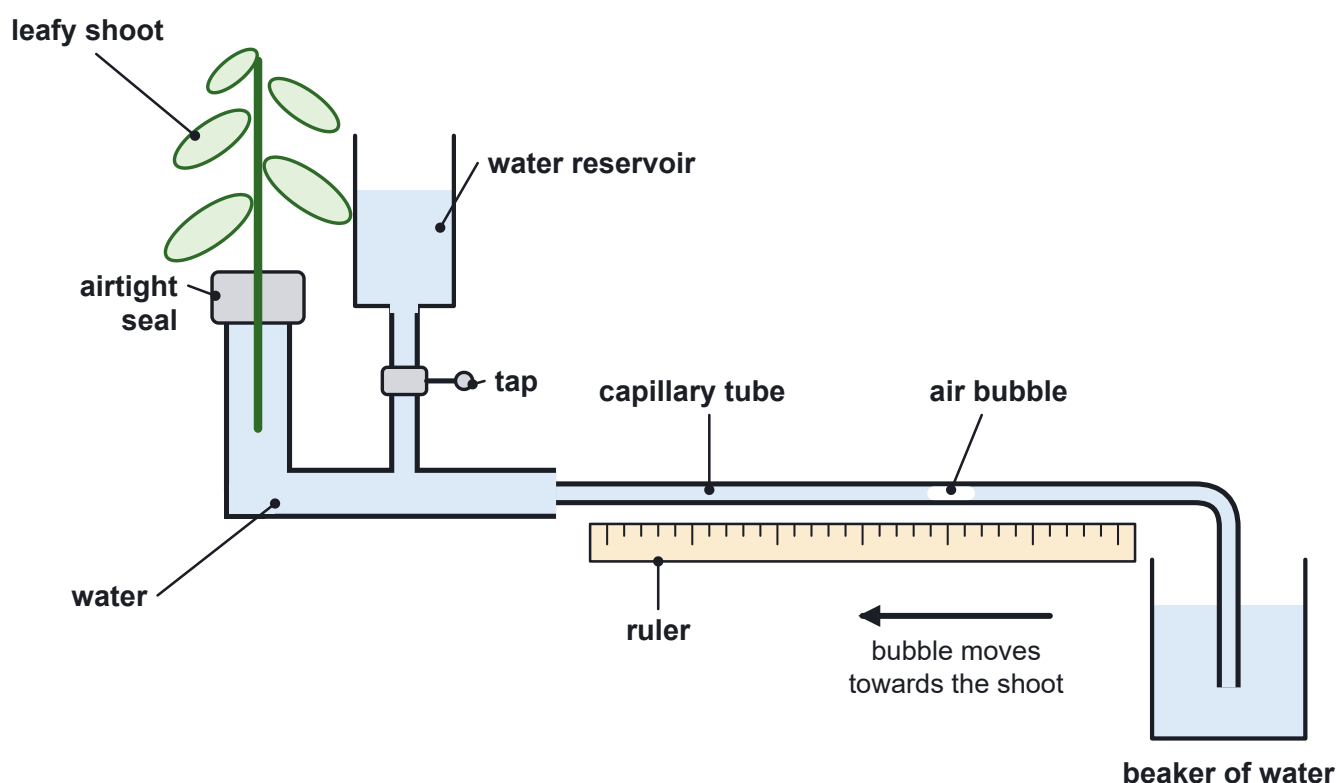
The opposite changes have the opposite effects. Low temperature, high humidity, still air and darkness all reduce the rate of transpiration.

Practical: investigating transpiration from a leafy shoot

A **potometer** measures how much water a cut shoot takes up. Almost all the water taken up is lost by transpiration, so uptake is used to measure the rate of transpiration.

1. Cut a leafy shoot under water, so no air enters the xylem, and fit it into the potometer under water.
2. Make sure the apparatus is full of water, with no air bubbles, and that the joints are airtight.
3. Dry the leaves, then introduce one air bubble into the capillary tube and record its starting position.
4. Measure the distance the bubble moves in a set time.
5. Change one factor (for example switch on a fan), keep the others the same and repeat. Calculate the mean of repeats.

Practical: Independent variable: one environmental factor, for example wind speed (fan distance), light (lamp distance), temperature or humidity (plastic bag over the shoot). Control the other factors, the same shoot size and the time. Safety: cut the shoot with care, and keep electrical equipment away from water. Expected results: the bubble moves further in a set time when it is warm, windy or bright, and less in humid air. You can also weigh the shoot and its container: the faster the mass falls, the higher the rate.



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

rate of water uptake = distance moved by bubble ÷ time

Rate of water uptake

An air bubble in a potometer moves 36 mm in 12 minutes. Calculate the rate of water uptake in mm per minute.

1. Rate = distance ÷ time.
2. Rate = $36 \div 12$.

Answer: 3 mm/min

Volume of water taken up

The capillary tube has a cross-sectional area of 0.8 mm^2 . The bubble moves 40 mm in 10 minutes. Calculate the rate of water uptake in mm^3 per minute.

1. Volume = cross-sectional area $\times$ distance = $0.8 \times 40 = 32 \text{ mm}^3$.
2. Rate = volume $\div$ time = $32 \div 10$.

Answer: $3.2 \text{ mm}^3/\text{min}$

Maths skill: Give the unit with every rate. Repeat readings and find the mean to reduce the effect of random errors.

Quick check

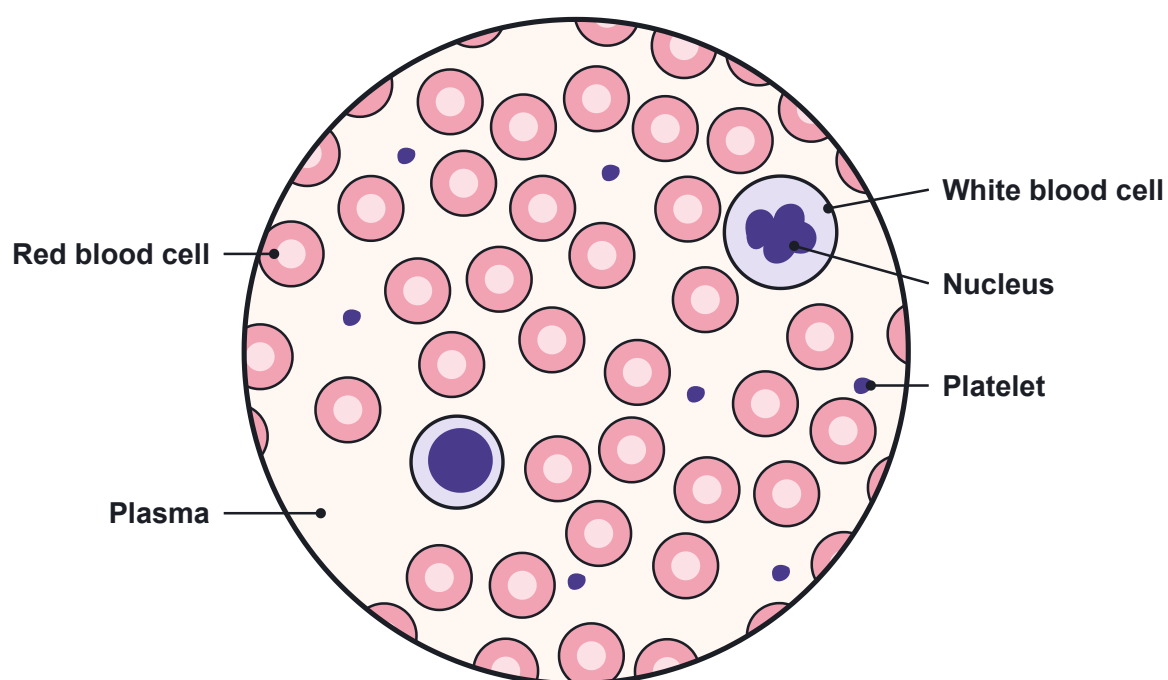
1. Why can a unicellular organism rely on diffusion?
2. Which tissue carries water and mineral ions from the roots?
3. Which substances does phloem transport?
4. **Biology only** Define transpiration.
5. **Biology only** How does an increase in humidity affect the rate of transpiration?

10 Blood and the immune system Spec 2.59-2.64B

Blood: composition, plasma and red blood cells Spec 2.59, 2.60, 2.61

Blood is a tissue made of a liquid, **plasma**, with red blood cells, white blood cells and platelets suspended in it.

Components of blood		
Component	Description	Main job
Red blood cells	Biconcave discs with no nucleus, full of haemoglobin	Transport oxygen
White blood cells	Larger cells with a nucleus. Phagocytes and lymphocytes are two types	Defend the body against pathogens
Platelets	Small fragments of cells with no nucleus	Help the blood to clot
Plasma	Pale yellow liquid	Transports blood cells and dissolved substances



Red blood cells are the most numerous. White blood cells have a **nucleus**. Platelets are tiny fragments.

Plasma

Plasma is mostly water. It transports substances around the body, dissolved or carried in it.

Substances transported by plasma		
Substance	Transported from	Transported to
Carbon dioxide	Respiring cells	The lungs
Digested food (such as glucose and amino acids)	The small intestine	All the cells of the body
Urea	The liver, where it is made	The kidneys, to be removed in urine
Hormones	The glands that make them	Their target organs
Heat energy	Warm, active organs such as the liver and muscles	Other parts of the body, including the skin

Red blood cells

Red blood cells transport **oxygen** from the lungs to all the cells of the body. Three adaptations help them to do this.

- The **biconcave disc** shape gives a large surface area, so oxygen can diffuse in and out quickly.
- They contain **haemoglobin**, a red pigment that combines with oxygen in the lungs to form oxyhaemoglobin, and releases it in the tissues.
- They have **no nucleus**, which leaves more room inside the cell for haemoglobin.

Common mistake: Red blood cells carry oxygen. Haemoglobin is the substance inside them that binds to oxygen. Do not say that the cells 'carry haemoglobin'.

White blood cells and the immune response Spec 2.62

The immune system protects the body from disease. White blood cells are the main part of this defence. Two types do different jobs: **phagocytes** and **lymphocytes**.

Pathogen	A microorganism that causes disease.
Antigen	A molecule on the surface of a pathogen that the immune system recognises as foreign.
Antibody	A protein released by a lymphocyte that is specific to one antigen and helps to destroy the pathogen.

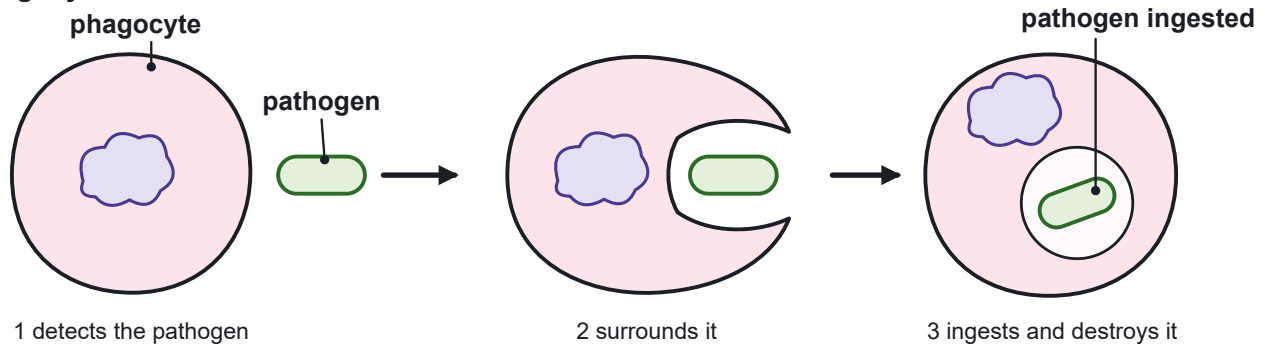
Phagocytes

1. A phagocyte detects a pathogen.
2. It surrounds the pathogen and **ingests** (takes in) it. This is called phagocytosis.
3. The pathogen is then destroyed inside the phagocyte.

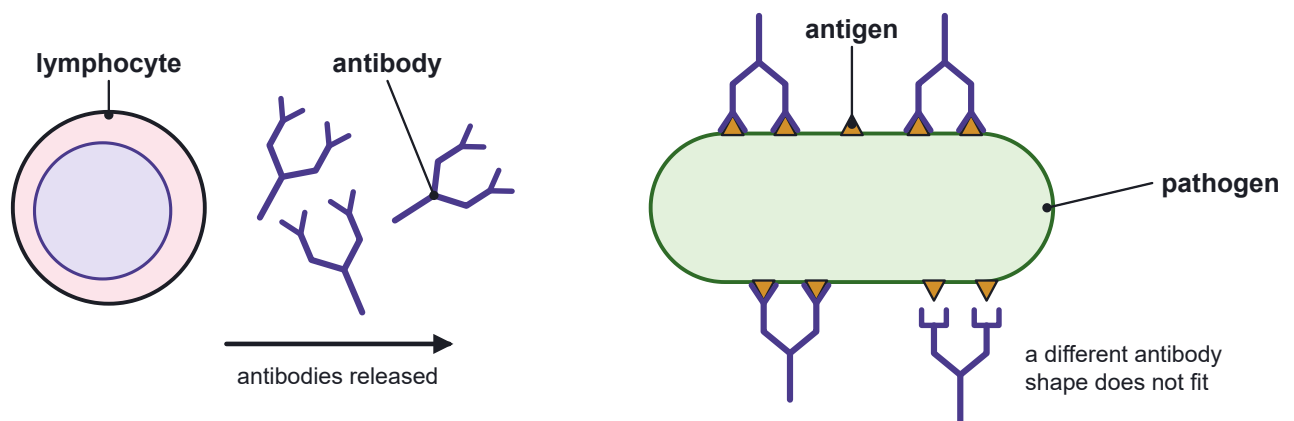
Lymphocytes

1. Lymphocytes recognise the antigens on the surface of a pathogen.
2. They release **antibodies** into the blood.
3. Each antibody is **specific** to one pathogen. Its shape fits the antigens on that pathogen only.
4. The antibodies attach to the pathogen and help to destroy it.

Phagocytosis



Antibodies



Phagocytes **ingest** pathogens. Lymphocytes release **antibodies** that fit only the matching **antigens**.

Exam tip: Antibodies are specific. Say that the antibody has a shape that fits the antigen on that pathogen, and that a different pathogen needs a different antibody.

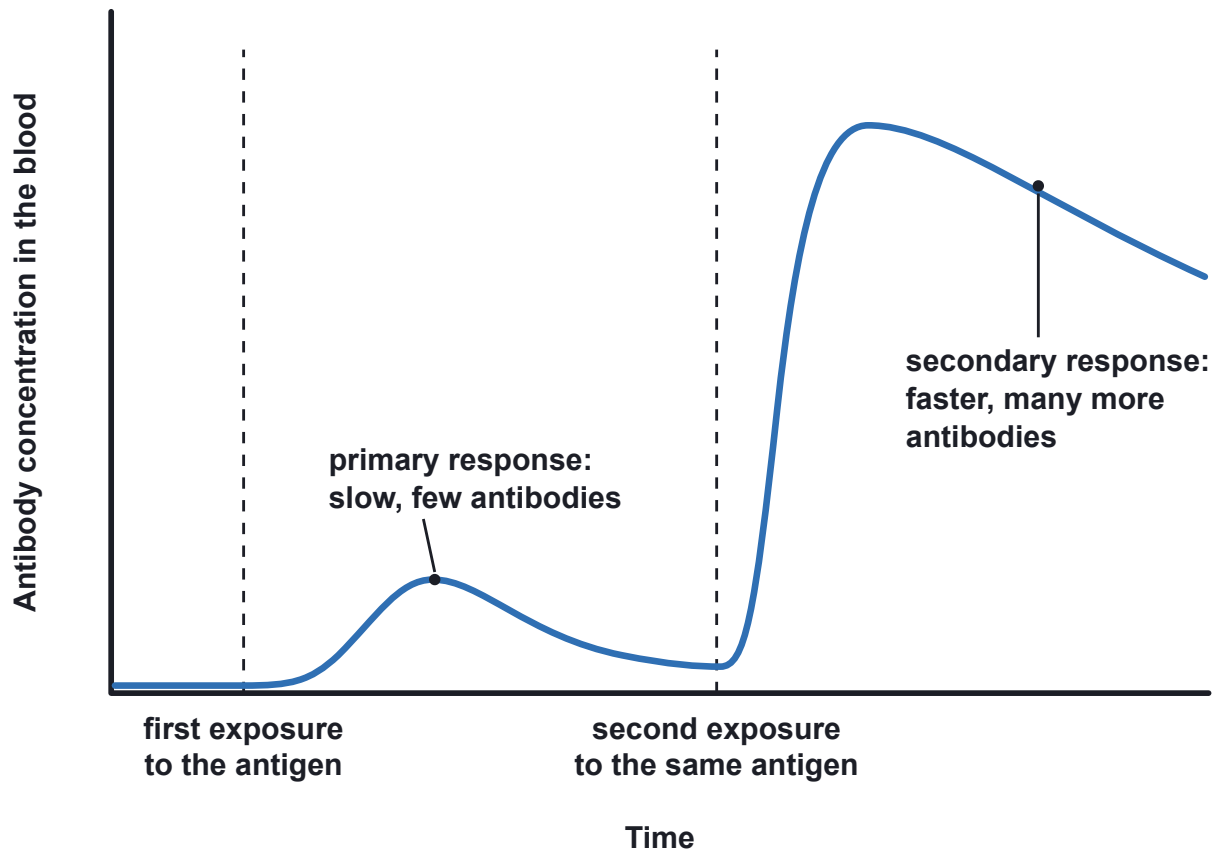
Vaccination and memory cells

Spec 2.63B

Biology only

After an infection, some lymphocytes stay in the blood as memory cells. Vaccination uses this to protect a person before they meet the pathogen.

1. A person is given a **vaccine**: a harmless form of the pathogen, such as a dead or weakened one, with its antigens still present.
2. The antigens trigger lymphocytes to release antibodies. The person does not become ill.
3. The immune system makes **memory cells**, which stay in the body.
4. If the live pathogen enters later, the memory cells recognise it. Antibody production happens **sooner**, **faster** and in **greater quantity**.
5. The pathogen is destroyed before it can make the person ill.



Memory cells make the second response **sooner, faster and in greater quantity** than the first.

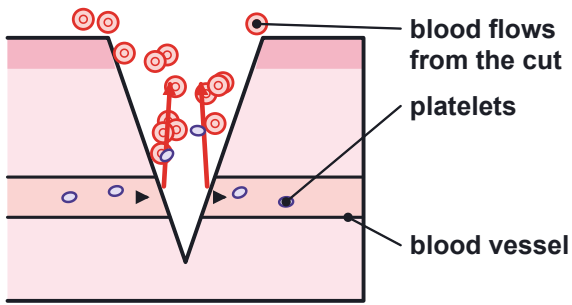
Common mistake: A vaccine does not put antibodies into the body. It makes your own body produce antibodies and memory cells.

Platelets and blood clotting Spec 2.64B Biology only

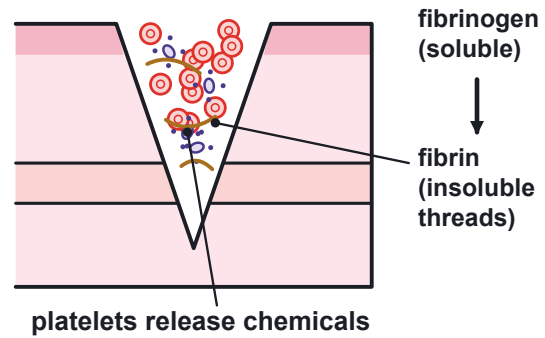
When a blood vessel is cut, the blood must clot. **Platelets** are small fragments of cells that take part in this. Clotting **prevents blood loss** and stops **micro-organisms entering** the body through the wound.

1. Platelets collect at the cut and release chemicals.
2. These chemicals cause the soluble protein **fibrinogen** in the plasma to change into insoluble **fibrin**.
3. Fibrin forms a mesh of fibres across the wound.
4. The mesh traps red blood cells and forms a clot.
5. The clot dries to form a scab, which seals the wound while the skin underneath repairs.

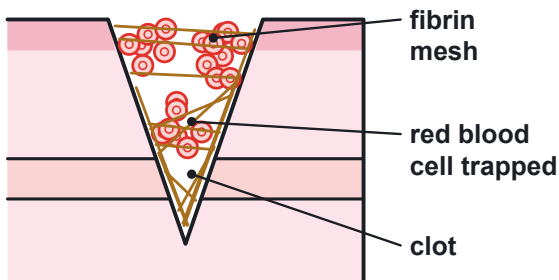
1 Platelets collect at the cut



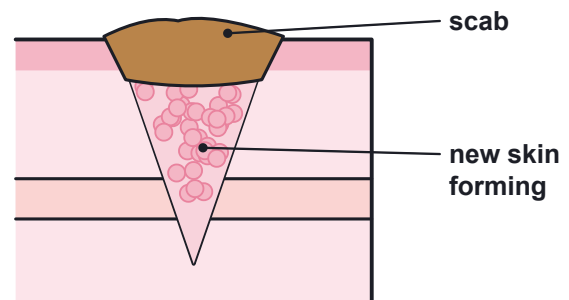
2 Fibrinogen is changed to fibrin



3 The fibrin mesh traps red blood cells



4 The clot dries to form a scab



Platelets trigger the change of **fibrinogen to fibrin**. The fibrin mesh traps red blood cells to form a **clot**, which dries to a **scab**.

Exam tip: Give two reasons why clotting matters: it stops blood loss and it stops pathogens (micro-organisms) entering the body.

Quick check

1. Name the four components of blood.
2. Give three adaptations of a red blood cell for carrying oxygen.
3. How do phagocytes destroy pathogens?
4. What do lymphocytes release?
5. **Biology only** What do memory cells allow after vaccination?

11 The heart and circulation Spec 2.65-2.69

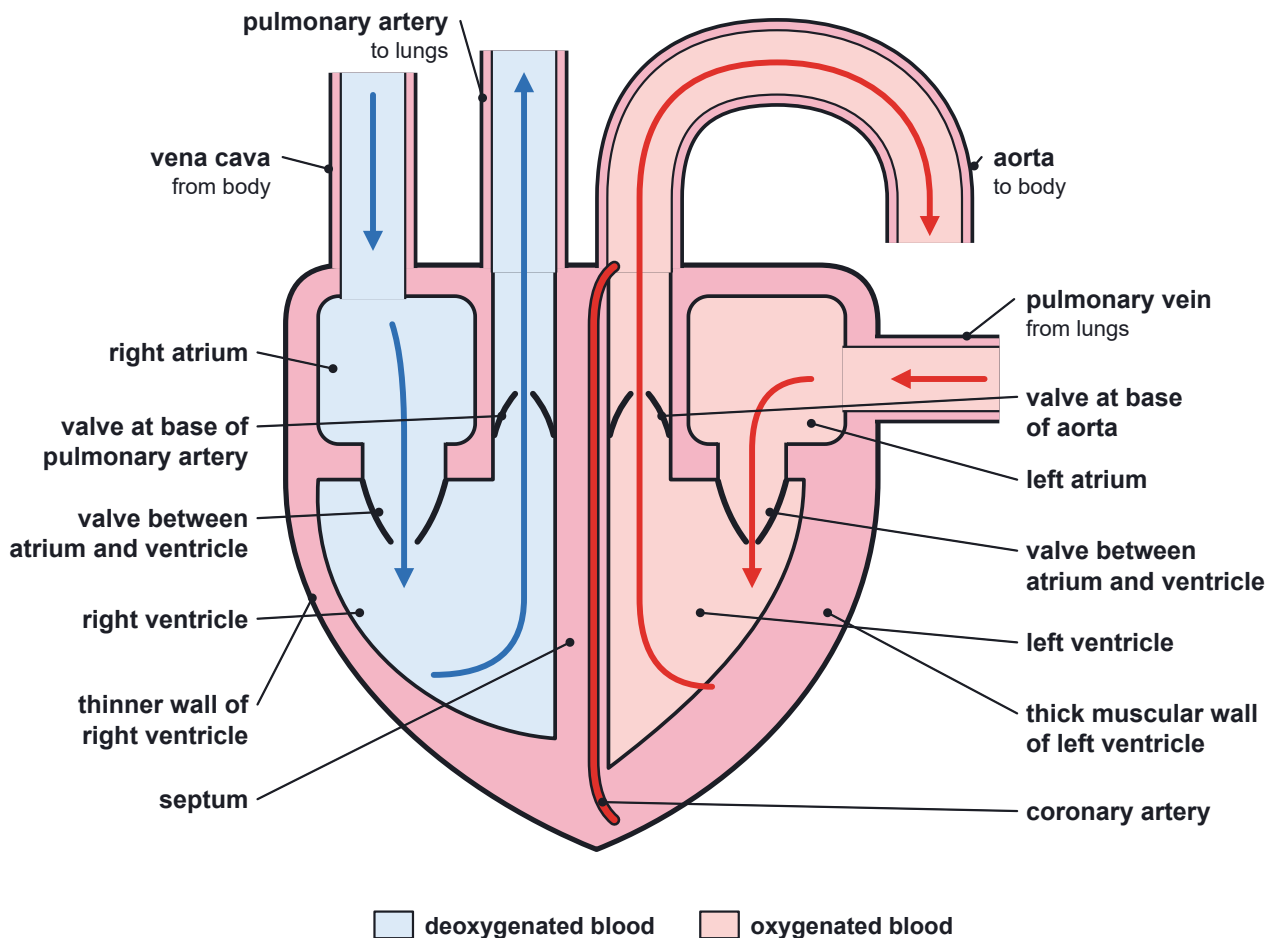
Structure and function of the heart Spec 2.65

The heart is a muscular pump. It has four chambers: two **atria** at the top, which receive blood, and two **ventricles** below, which pump blood out. A wall of muscle called the **septum** separates the left side from the right side, so oxygenated and deoxygenated blood do not mix.

1. Deoxygenated blood from the body enters the right atrium through the vena cava.
2. The right atrium contracts and pushes blood into the right ventricle.
3. The right ventricle contracts and pumps blood to the lungs through the pulmonary artery.
4. Oxygenated blood returns from the lungs through the pulmonary vein into the left atrium.
5. The left atrium contracts and pushes blood into the left ventricle.
6. The left ventricle contracts and pumps blood around the body through the aorta.

Blood vessels connected to the heart

Blood vessel	Carries blood	Between
Vena cava	Deoxygenated	Body to right atrium
Pulmonary artery	Deoxygenated	Right ventricle to lungs
Pulmonary vein	Oxygenated	Lungs to left atrium
Aorta	Oxygenated	Left ventricle to body



The heart is drawn as if you are facing the person, so the **left side is on the right** of the page. The left ventricle has the **thickest wall**.

Valves

The heart has valves between the atria and ventricles, and at the bases of the aorta and pulmonary artery. They open to let blood flow forwards and close to **prevent backflow**.

Wall thickness

- The ventricles have thicker, more muscular walls than the atria, because they pump blood out of the heart.
- The **left ventricle** has a thicker wall than the right. It pumps blood all the way around the body, which needs a higher pressure. The right ventricle pumps blood only to the nearby lungs.

The heart muscle needs its own supply of oxygen and glucose. This is brought by the coronary arteries, which run over the surface of the heart.

Common mistake: The heart is drawn as if you are facing the person, so the left side of the heart is on the right of the page. Check which side is which before you answer.

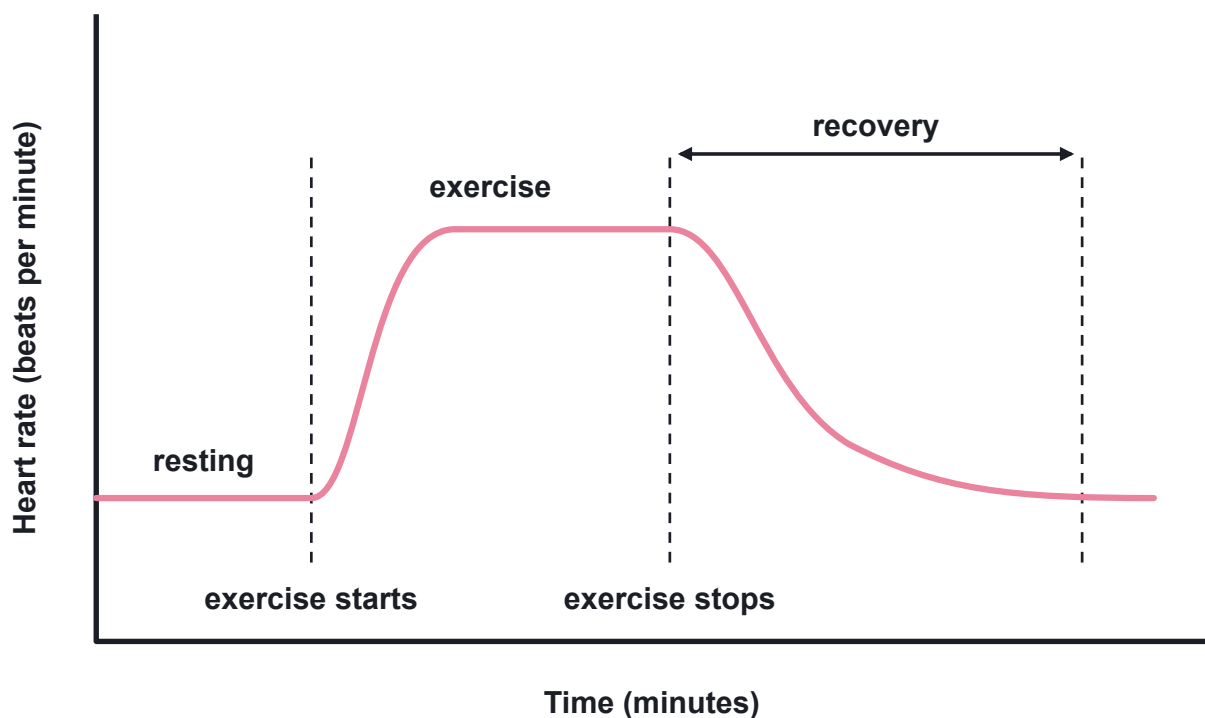
Heart rate, exercise and adrenaline Spec 2.66

The heart rate is the number of heartbeats per minute. At rest it is steady, but it changes to match what the body needs.

Exercise

1. During exercise the muscles respire faster to release more energy.
2. They need more **oxygen and glucose**, and they produce more **carbon dioxide**.
3. The heart rate increases, so blood flows to the muscles faster.
4. More oxygen and glucose are delivered, and carbon dioxide is carried away more quickly.

After exercise, the heart rate stays high for a while and then gradually returns to its resting rate.



Heart rate **rises** during exercise, then falls gradually back to the resting rate during **recovery**.

Adrenaline

Adrenaline is a hormone released by the adrenal glands when you are frightened or excited. It prepares the body for 'fight or flight'. It makes the **heart rate increase**, so more blood, with more oxygen and glucose, reaches the muscles and they can release more energy quickly.

Heart rate from a pulse count

A student counts 18 pulses in 15 seconds at rest and 36 pulses in 15 seconds straight after exercise. Calculate the increase in heart rate in beats per minute.

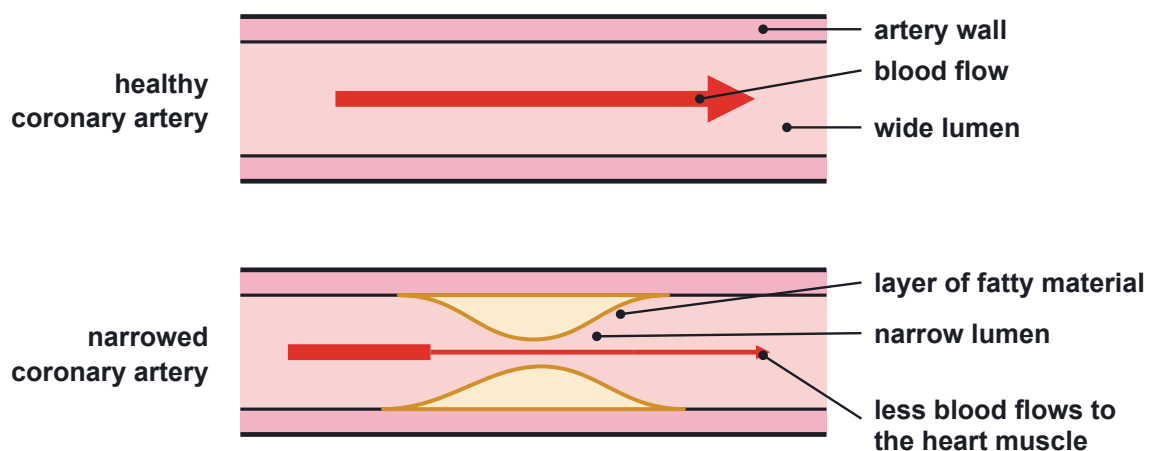
1. There are 4 lots of 15 seconds in a minute.
2. Resting rate = $18 \times 4 = 72$ beats per minute.
3. Rate after exercise = $36 \times 4 = 144$ beats per minute.
4. Increase = $144 - 72$.

Answer: 72 beats per minute

Exam tip: In an 'explain' answer, link the steps: exercise, so more respiration, so more oxygen and glucose needed and more carbon dioxide made, so higher heart rate.

Coronary heart disease and its risk factors Spec 2.67

The **coronary arteries** supply the heart muscle with oxygen and glucose. In **coronary heart disease** (CHD), layers of fatty material build up inside these arteries and narrow them. Less blood flows through, so the heart muscle gets less oxygen and may not be able to respire enough. This can cause chest pain and a heart attack.



Fatty material **narrows the lumen**, so less blood (and oxygen) reaches the heart muscle.

Risk factors

A **risk factor** is something that increases the chance of developing a disease. It does not mean that the disease is certain.

Risk factors for CHD	
Risk factor	How it increases the risk
Diet high in saturated fat and cholesterol	Fatty material builds up in the artery walls
Smoking	Damages the artery lining, raises blood pressure and reduces the oxygen carried by the blood
High blood pressure	Damages the artery walls, making fatty deposits more likely
Lack of exercise	Linked to obesity and high blood pressure
Obesity	Linked to high blood pressure and a diet high in fat
Stress	Linked to raised blood pressure
Genetic factors (family history)	Some people inherit a greater risk
Age	The risk increases as people get older

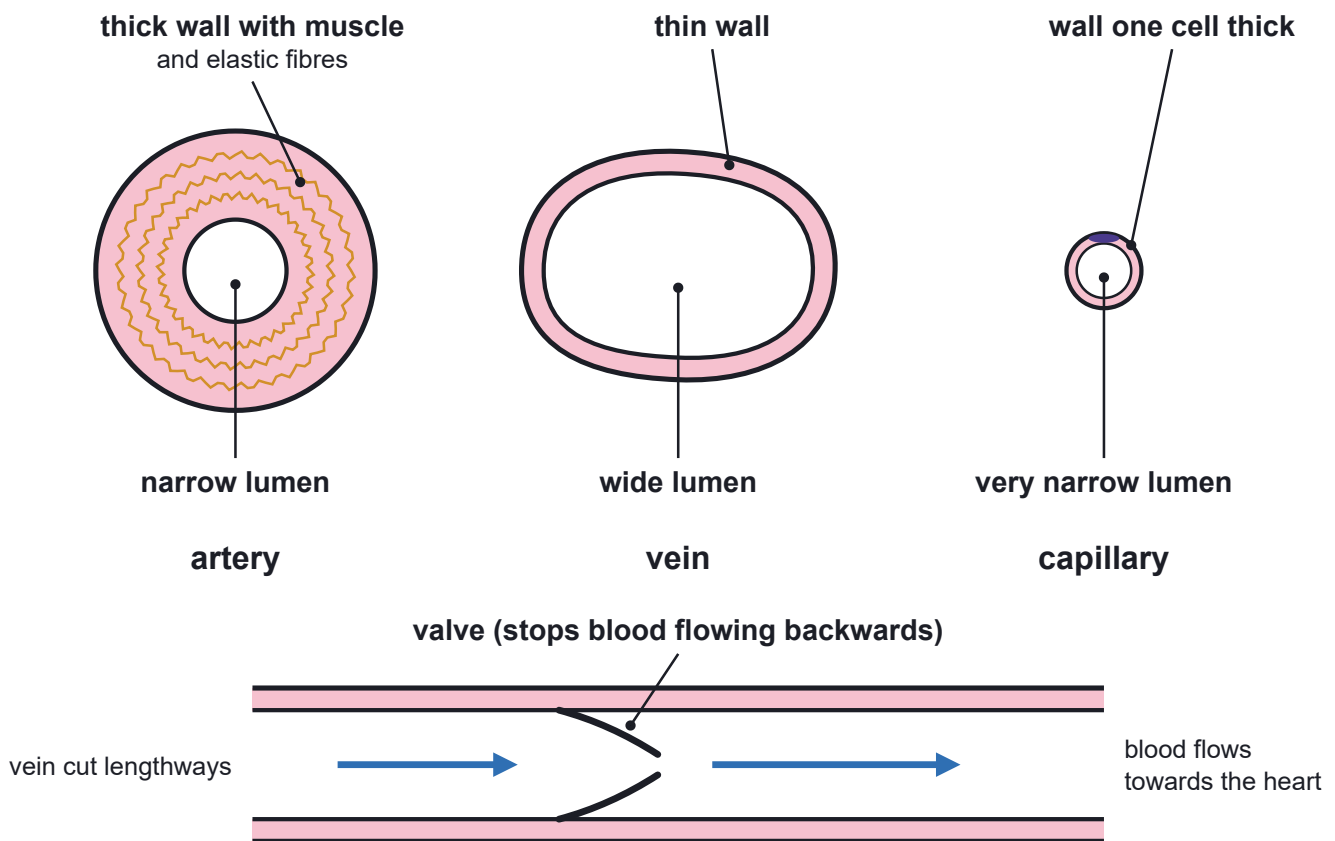
Exam tip: When asked how a factor increases the risk, state the factor and its effect, for example 'a diet high in saturated fat raises blood cholesterol, so more fatty material builds up in the coronary arteries'.

Arteries, veins and capillaries Spec 2.68

There are three types of blood vessel. Each has a structure that suits its function.

Arteries, veins and capillaries			
	Artery	Vein	Capillary
Direction of blood	Away from the heart	Towards the heart	Between arteries and veins, through the tissues
Blood pressure	High	Low	Falls as blood passes through
Wall	Thick, muscular, with elastic fibres	Thinner wall	One cell thick
Lumen	Narrow	Wide	Very narrow
Valves	No	Yes	No
Function	Carry blood at high pressure to the organs	Carry blood back to the heart	Exchange substances with cells

- **Arteries** have thick, muscular walls with elastic fibres. The wall can stand the high pressure, and it stretches and springs back with each heartbeat.
- **Veins** carry blood at low pressure. They have a wide lumen, which lets blood flow easily, and **valves** to stop the blood flowing backwards.
- **Capillaries** have walls only one cell thick, so there is a short diffusion distance. They are very narrow and form a huge network, so they reach every cell and give a large surface area for exchange.



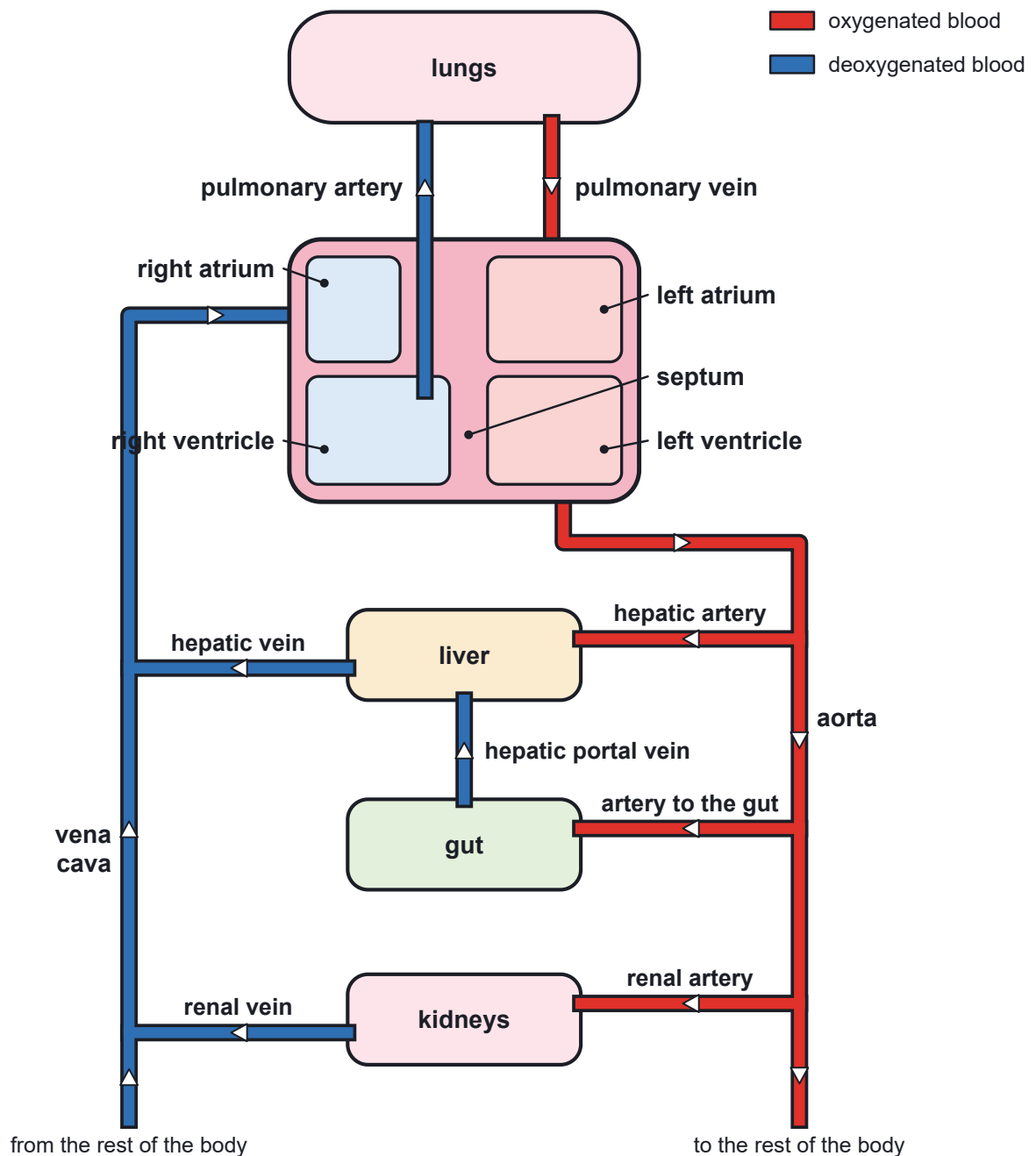
Arteries have **thick walls**, veins have a **wide lumen and valves**, capillaries have walls **one cell thick**. (The capillary is drawn much larger than its real size.)

Exam tip: Do not say that arteries always carry oxygenated blood and veins always carry deoxygenated blood. The pulmonary artery and pulmonary vein are the exceptions.

The circulation system Spec 2.69

Humans have a **double circulatory system**. In one circuit, blood goes from the heart to the lungs and back. In the other, it goes from the heart to the rest of the body and back. Blood passes through the heart twice on each complete circuit of the body.

Blood vessels to and from the main organs		
Organ	Vessel	Carries blood
Heart and body	Vena cava	From the body to the right atrium
Heart and body	Aorta	From the left ventricle to the body
Lungs	Pulmonary artery	From the right ventricle to the lungs (deoxygenated)
Lungs	Pulmonary vein	From the lungs to the left atrium (oxygenated)
Liver	Hepatic artery	From the aorta to the liver (oxygenated)
Liver	Hepatic portal vein	From the gut to the liver, carrying digested food
Liver	Hepatic vein	From the liver to the vena cava
Kidneys	Renal artery	From the aorta to the kidneys
Kidneys	Renal vein	From the kidneys to the vena cava



Blood from the gut goes to the liver in the **hepatic portal vein** before it returns to the heart.

Notice that the **hepatic portal vein** carries blood from the gut to the liver, not to the heart. After a meal this blood is rich in digested food. The liver processes it before the blood returns to the heart in the hepatic vein.

Common mistake: Do not mix up the hepatic artery (blood to the liver from the aorta), the hepatic portal vein (blood from the gut to the liver) and the hepatic vein (blood from the liver towards the heart).

Quick check

- 1 . What is the function of the septum?
- 2 . Why is the wall of the left ventricle thicker than the right?
- 3 . Why does heart rate rise during exercise?
- 4 . Name the blood vessels that supply the heart muscle.
- 5 . Which vessel carries blood from the gut to the liver?

12 Excretion Spec 2.71-2.79B

Excretion: lungs, kidneys and skin Spec 2.71

Excretion The removal from the body of the waste products of metabolism.

Cells make waste products as they carry out chemical reactions. Some of these are poisonous or harmful if they build up, so they must be removed. Three organs carry out **excretion** in humans: the lungs, the kidneys and the skin.

Organs of excretion and their excretory products

Organ	Excretory products
Lungs	Carbon dioxide (and water vapour), lost when we breathe out
Kidneys	Urea, with excess water and ions, lost in urine
Skin	Water, salts (ions) and urea, lost in sweat

Carbon dioxide is a waste product of respiration. **Urea** is a nitrogen-containing waste product. The blood carries both to the organs that remove them.

Common mistake: Faeces are not excretory products. They are undigested food that has never been part of the cells' chemistry, so removing them is egestion, not excretion.

Exam tip: Always match the product to the organ: carbon dioxide from the lungs, urea from the kidneys. Sweat also contains urea, but its main job is cooling.

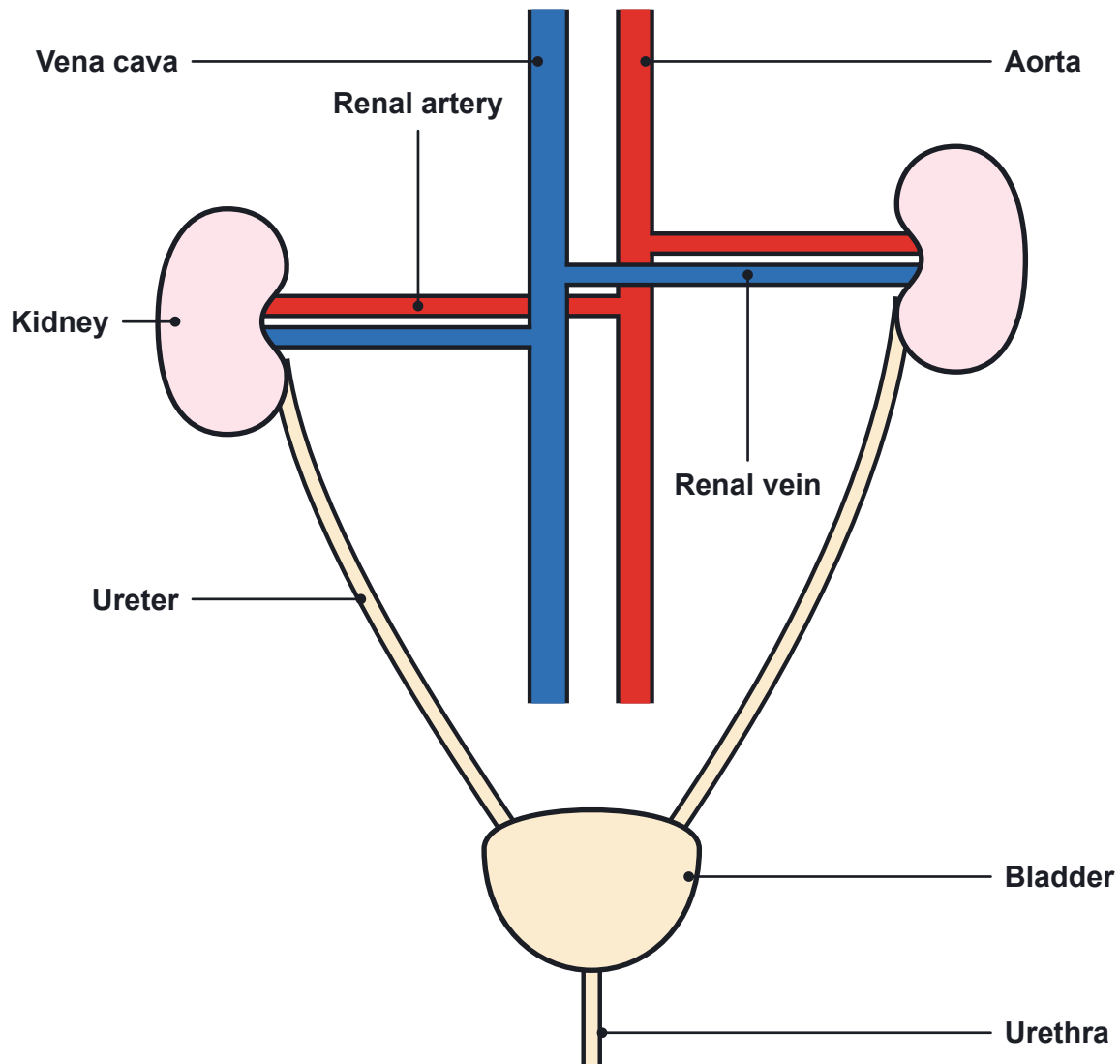
The kidney and the urinary system Spec 2.72B, 2.73B Biology only

The kidneys do two jobs. **Excretion**: they remove urea from the blood. **Osmoregulation**: they control the water content and the ion content of the blood. Both jobs happen as the kidneys make **urine**.

- Excretion: urea is filtered out of the blood and is not taken back, so it leaves the body in urine.
- Osmoregulation: the kidney changes how much water (and how many ions) it reabsorbs back into the blood, so only the excess is lost in urine.

Parts of the urinary system

Part	Function
Kidneys	Filter the blood and make urine
Renal artery	Brings blood to the kidney
Renal vein	Takes blood away from the kidney
Ureters	Tubes that carry urine from the kidneys to the bladder
Bladder	Stores urine
Urethra	Tube that carries urine out of the body



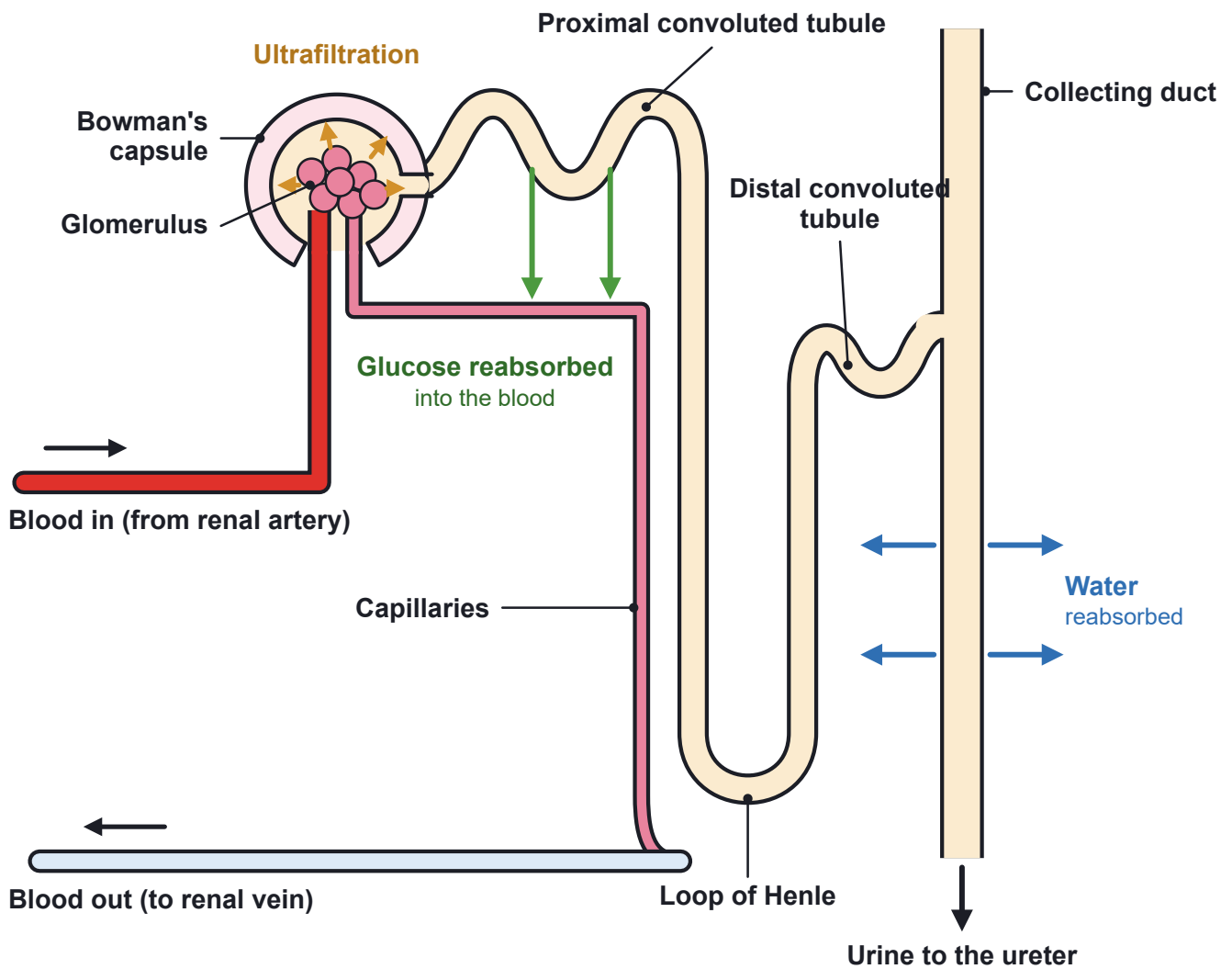
The **urinary system**. The renal artery brings blood to each kidney and the renal vein takes it away.

Common mistake: The ureter carries urine from the kidney to the bladder. The urethra carries urine from the bladder out of the body. Do not swap them.

The nephron and ultrafiltration Spec 2.74B, 2.75B Biology only

Each kidney contains many tiny tubes called **nephrons**. A nephron filters the blood and forms urine. Blood enters a knot of capillaries, the **glomerulus**, which sits inside a cup-shaped **Bowman's capsule**.

- **Bowman's capsule** and **glomerulus**: where blood is filtered.
- **Proximal convoluted tubule**: the first coiled part of the tubule, after the Bowman's capsule.
- **Loop of Henle**: the long loop that dips down and comes back up.
- **Distal convoluted tubule**: the second coiled part of the tubule.
- **Collecting duct**: the tube that several nephrons drain into, which carries urine towards the ureter.



A nephron. **Ultrafiltration** happens at the Bowman's capsule, **glucose is reabsorbed** at the proximal convoluted tubule and **water is reabsorbed** at the collecting duct.

Ultrafiltration

Blood in the glomerulus is at high pressure. This forces small molecules out of the blood and into the Bowman's capsule. This is **ultrafiltration**. The liquid that enters the capsule is the **glomerular filtrate**. Large molecules and cells are too big to pass through, so they stay in the blood.

Composition of the glomerular filtrate

Substance	In the glomerular filtrate?
Water	Yes
Glucose	Yes
Urea	Yes
Ions	Yes
Proteins	No (too large)
Blood cells	No (too large)

Exam tip: Say that filtration is based on size: small molecules pass into the capsule and proteins and cells do not. Use the word **ultrafiltration**.

Selective reabsorption and urine Spec 2.76B, 2.77B, 2.79B Biology only

The glomerular filtrate contains useful substances as well as waste. The body cannot afford to lose them, so the useful substances are taken back into the blood. This is **selective reabsorption**.

Glucose: proximal convoluted tubule

All the glucose in the filtrate is reabsorbed into the blood at the **proximal convoluted tubule**. It is reabsorbed by **active transport**, which uses energy from respiration. Glucose is needed by cells as a fuel for respiration, so none must be lost in the urine. Normal urine contains no glucose.

Water: collecting duct

Water is reabsorbed back into the blood from the **collecting duct**. It moves out of the collecting duct by **osmosis**, into the more concentrated tissue around it, and then into the blood capillaries. The amount that is reabsorbed depends on the body's needs, and is controlled by ADH (next section). The more water that is reabsorbed, the less water is left in the urine.

What is in urine

What remains after reabsorption is **urine**. It contains **water, urea and ions**. It flows from the collecting duct to the ureter, then the bladder.

What happens to each substance in the nephron		
Substance	Filtered at the glomerulus?	In urine?
Water	Yes	Yes, the amount not reabsorbed
Glucose	Yes	No, all reabsorbed
Urea	Yes	Yes
Ions	Yes	Yes, the excess
Proteins and blood cells	No	No

Exam tip: For a mark on glucose, give the place (proximal convoluted tubule), the process (active transport) and the reason (needed for respiration).

ADH and the water content of the blood Spec 2.78B Biology only

ADH (antidiuretic hormone) is released into the blood by the pituitary gland. It controls how much water is reabsorbed in the kidney, which keeps the water content of the blood steady. ADH changes the **permeability of the collecting duct** to water.

How ADH regulates the water content of the blood		
	Blood water content too low	Blood water content too high
ADH released	More	Less
Collecting duct	More permeable to water	Less permeable to water
Water reabsorbed into blood	More	Less
Urine	Small volume, concentrated	Large volume, dilute
Blood water content	Rises back to normal	Falls back to normal

Common mistake: More ADH means less urine, not more. ADH makes the collecting duct more permeable, so more water goes back into the blood.

Quick check

1. Name the excretory product of the lungs.
2. Name three substances lost from the skin in sweat.
3. **Biology only** Which part of the nephron does ultrafiltration take place in?
4. **Biology only** Where is glucose reabsorbed, and by what process?
5. **Biology only** What does ADH do to the collecting duct?

13 Coordination, homeostasis and plant responses Spec 2.80-2.85

Responding to change: stimulus, receptor, effector Spec 2.80, 2.82

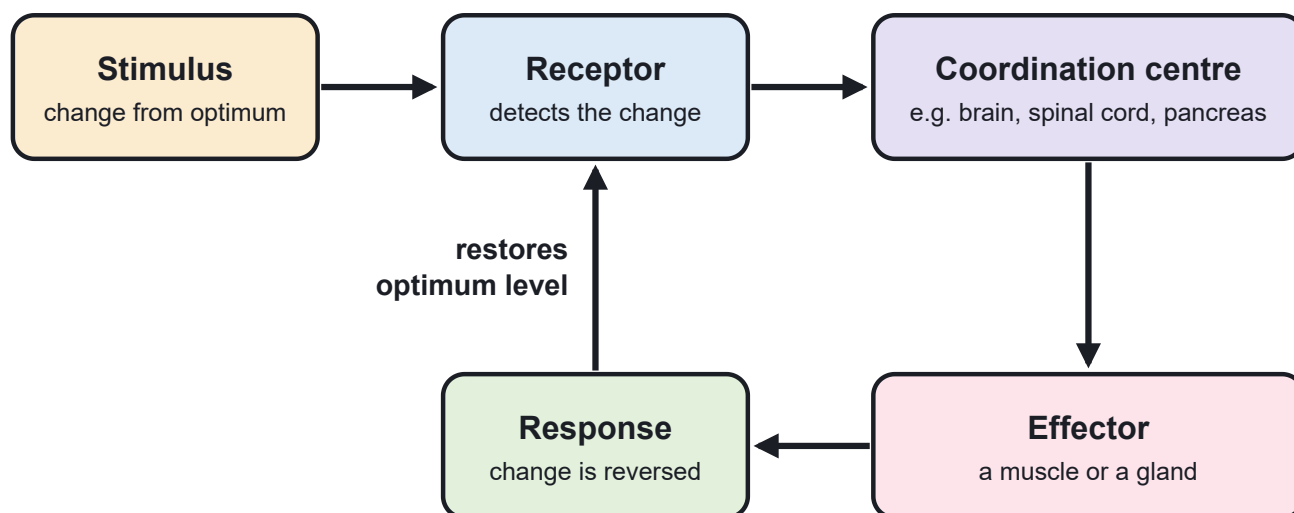
Organisms must respond to changes in their environment to survive. A change in the environment is a **stimulus**. Animals and plants both respond to stimuli, but they do it in different ways.

- Animals use the **nervous system** (fast, electrical impulses) and **hormones** (chemical messengers in the blood).
- Plants respond mainly by changing the way they **grow**, using plant hormones.

A **co-ordinated response** needs three parts: a stimulus, a receptor and an effector.

The parts of a co-ordinated response		
Part	What it does	Example
Stimulus	A change in the environment	A hot object touching the hand
Receptor	A cell or organ that detects the stimulus	Temperature receptors in the skin
Effector	A muscle or gland that carries out the response	A muscle that contracts to pull the hand away

In animals, a coordination centre (such as the brain or spinal cord) usually links the receptor to the effector. It receives information from the receptor and sends signals to the effector.



A control system in homeostasis: **stimulus** → **receptor** → **coordination centre** → **effector** → **response**. Here the response reverses the change and restores the optimum level.

Common mistake: Effectors are muscles or glands only. Do not write that the brain or a receptor is an effector.

Homeostasis Spec 2.81

Homeostasis	The maintenance of a constant internal environment.
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Conditions inside the body change when we eat, exercise, or move between hot and cold places. The body responds to keep the conditions inside the body **constant**.

Two examples of homeostasis

Condition	Example of a change
Body water content	Sweating, or drinking a lot
Body temperature	Hot or cold surroundings, or exercise

This matters because **enzymes and cells work best in a narrow range of conditions**. If conditions move too far from normal, reactions in cells slow down or stop.

Exam tip: Constant does not mean the level never changes. It means the body brings it back to a set level, so say 'kept within narrow limits'.

Plant tropisms and auxin Spec 2.83, 2.84, 2.85

Plants respond to stimuli, such as light and gravity. They respond by growing in a particular direction. A growth response to a stimulus is called a **tropism**. Growth towards the stimulus is positive. Growth away from the stimulus is negative.

- **Phototropism**: growth in response to light.
- **Geotropism** (also called gravitropism): growth in response to gravity.

Tropisms of shoots and roots

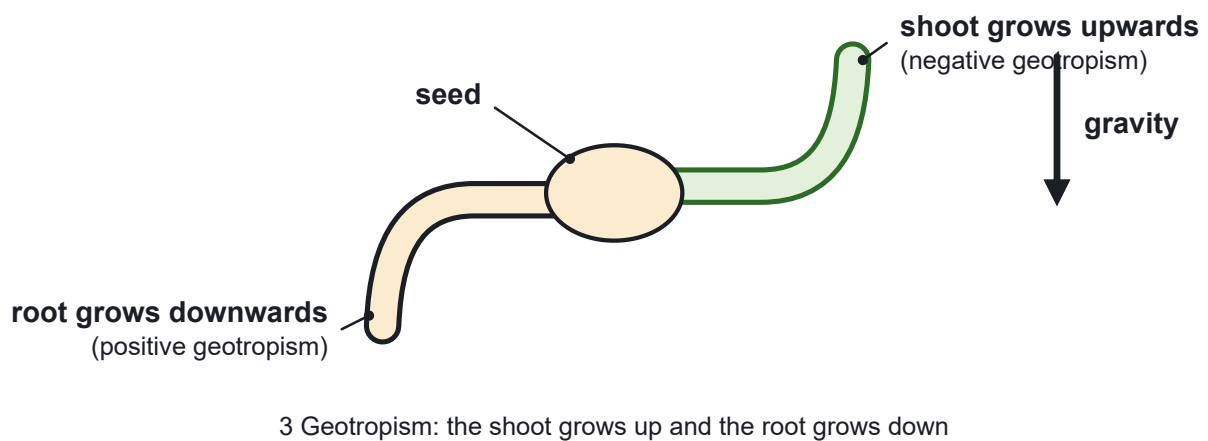
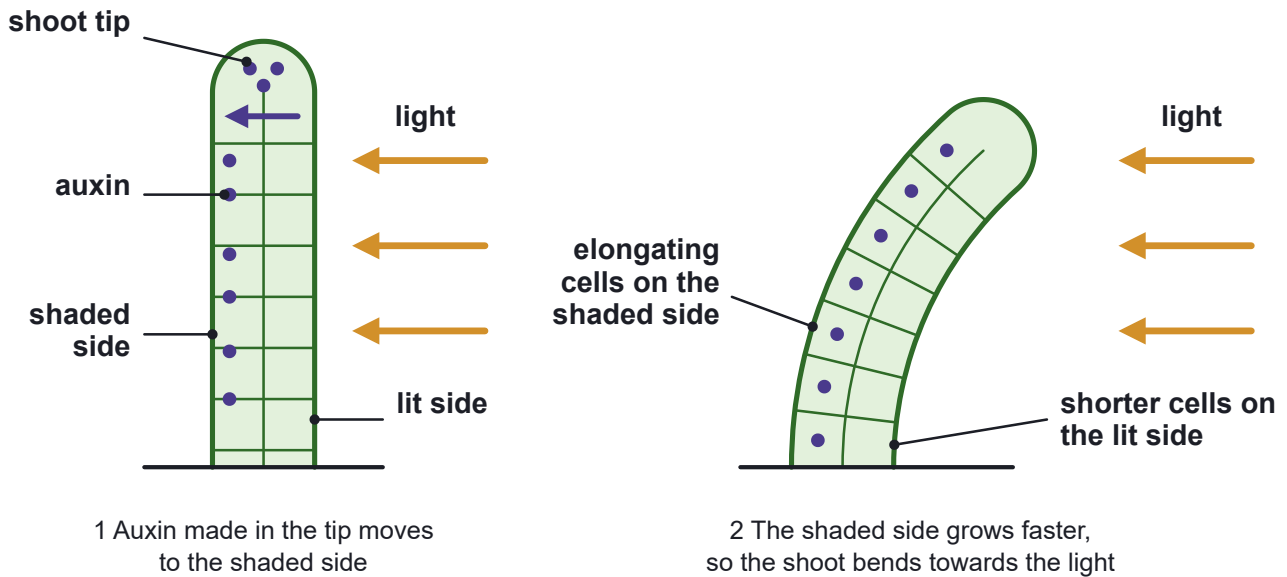
	Response to light	Response to gravity
Shoot (stem)	Positive phototropism (grows towards light)	Negative geotropism (grows upwards, away from gravity)
Root	Negative phototropism (grows away from light)	Positive geotropism (grows downwards, towards gravity)

These responses help the plant. Shoots grow towards light to take in more light for photosynthesis. Roots grow down into the soil, where they take in water and ions.

The role of auxin in phototropism of stems

Auxin is a plant hormone. It is made in the tip of the shoot and controls growth by making cells **elongate** (get longer).

1. Auxin is made in the tip of the shoot.
2. When light shines from one side, auxin moves to the shaded side of the shoot.
3. Auxin makes the cells on the shaded side elongate more, so they grow faster than the cells on the lit side.
4. The shoot bends towards the light.



Phototropism: auxin moves to the shaded side, those cells **elongate more** and the shoot bends towards the light.

Geotropism: shoots grow up and roots grow down.

Exam tip: Tell the story in order: where auxin is made, where it moves to, what it does to cell growth there, and which way the shoot bends as a result.

Quick check

1. What three parts are needed for a co-ordinated response?
2. What is homeostasis?
3. Give two examples of homeostasis.
4. Which way do roots respond to gravity?
5. Where does auxin move to when light shines on a shoot from one side?

14 The nervous system and the eye Spec 2.87-2.92

The central nervous system and nerve impulses Spec 2.87, 2.88

The nervous system lets you react to your surroundings and coordinate your behaviour. The **central nervous system (CNS)** is made up of the **brain and spinal cord**. It is linked to the sense organs (such as the eye and the skin) by **nerves**.

When a **receptor** in a sense organ is stimulated, it sends electrical impulses along neurones in the nerves into the CNS. The CNS sends electrical impulses out along nerves to **effectors**. Effectors are muscles (which contract) or glands (which secrete). Impulses travel quickly, so the response is rapid.

1. Stimulus (a change in the surroundings)
2. Receptor in a sense organ is stimulated
3. Electrical impulses travel along nerves into the CNS (brain and spinal cord)
4. Electrical impulses travel out along nerves to an effector
5. Effector (muscle or gland) produces the response

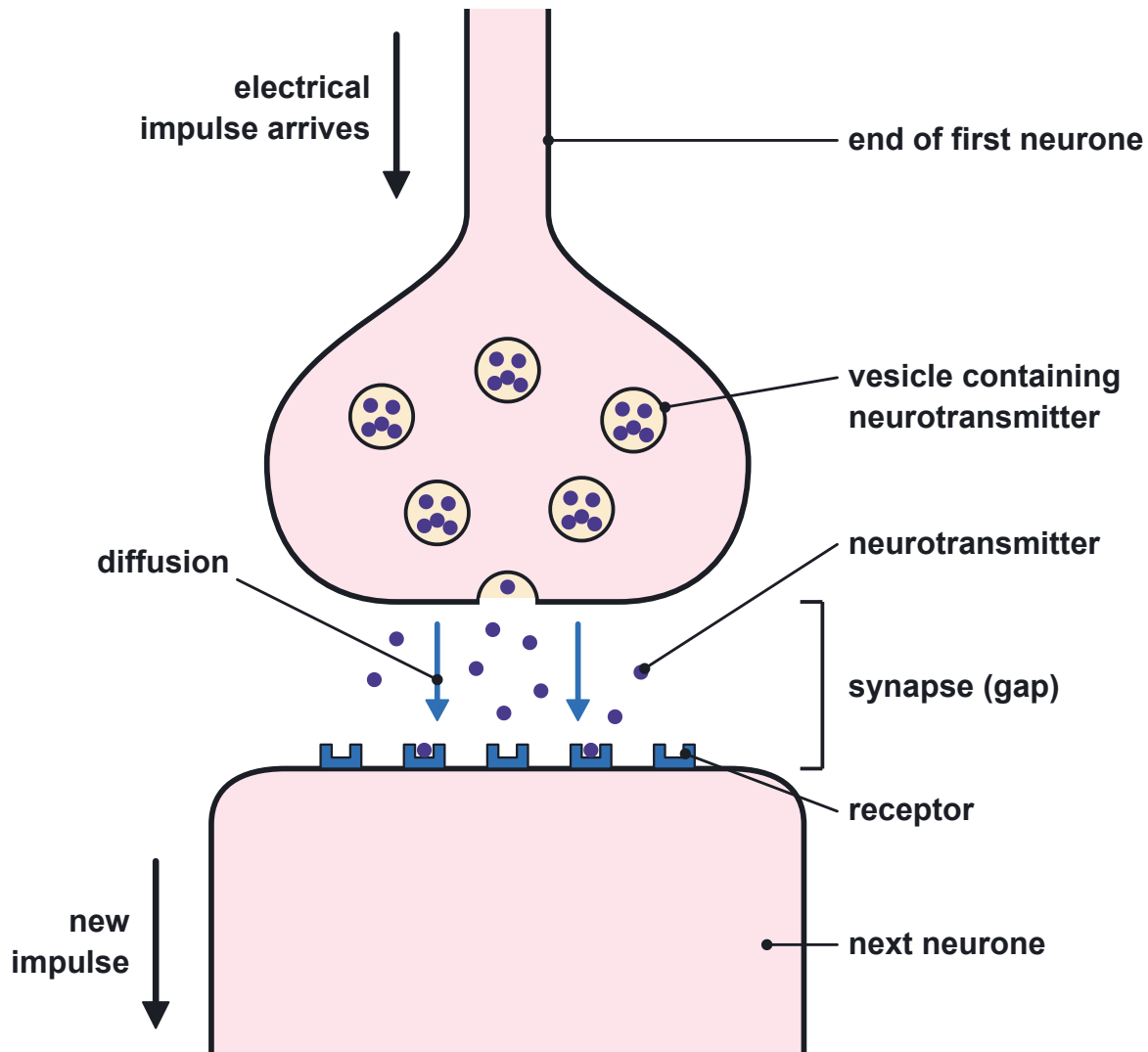
Parts of the nervous pathway	
Part	Job
Receptors	Detect a stimulus and start electrical impulses
Nerves	Bundles of neurones that carry impulses to and from the CNS
CNS (brain and spinal cord)	Receives impulses and coordinates the response
Effectors	Muscles or glands that carry out the response

Exam tip: The CNS is the brain and spinal cord only. Nerves are not part of the CNS; they link it to the sense organs and effectors.

Synapses and neurotransmitters Spec 2.89

A **synapse** is a gap between two neurones. The electrical impulse cannot cross the gap, so a chemical is used instead.

1. An electrical impulse arrives at the end of the first neurone.
2. The neurone releases a chemical called a **neurotransmitter** into the synapse.
3. The neurotransmitter **diffuses** across the gap.
4. It binds to receptors on the membrane of the next neurone.
5. This triggers a new electrical impulse in the next neurone.



At a synapse the neurotransmitter diffuses across the gap and binds to receptors on the next neurone.

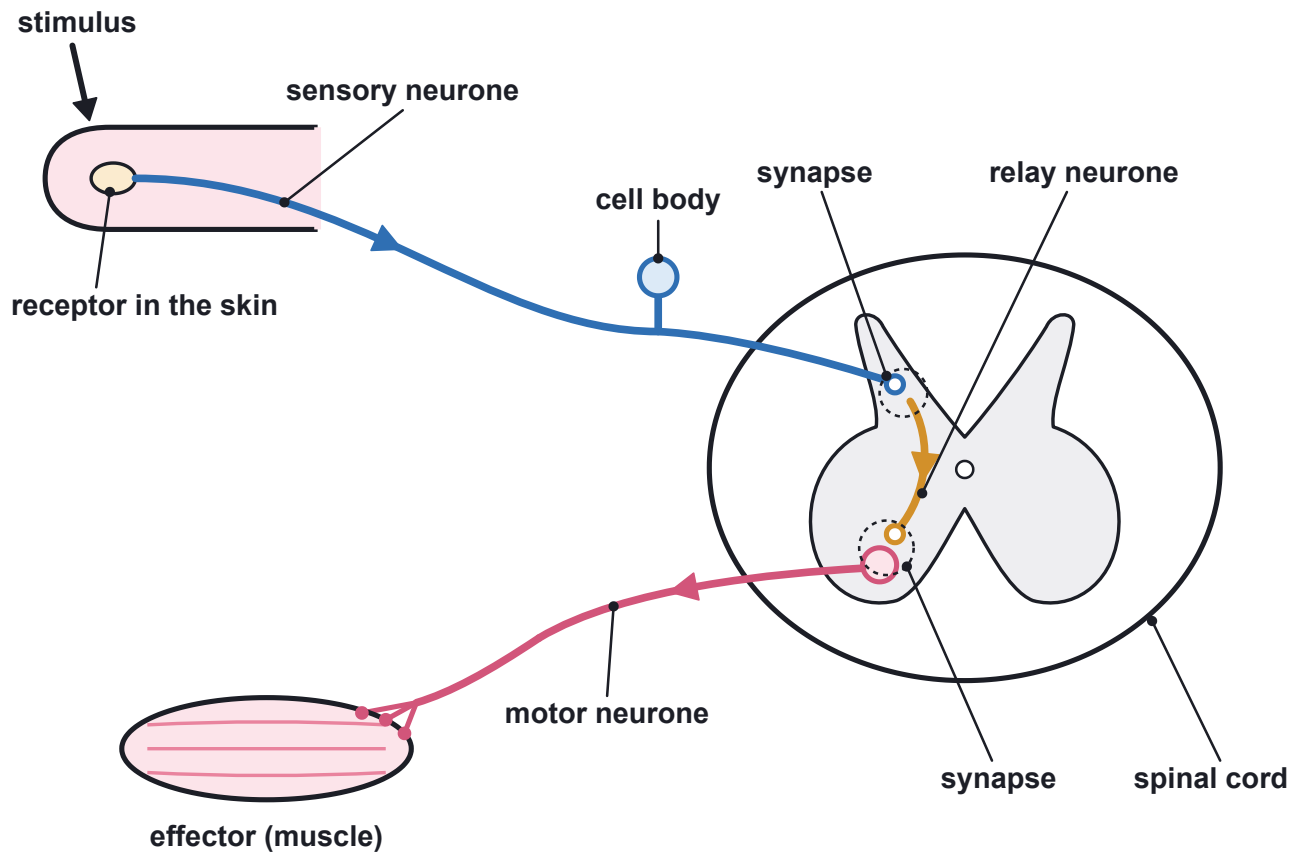
Common mistake: The impulse itself does not cross the synapse. A neurotransmitter diffuses across and starts a new impulse in the next neurone.

The reflex arc Spec 2.90

A **reflex** is a fast, automatic response to a stimulus that does not involve conscious thought. The pathway it follows is a **reflex arc**. Reflexes protect the body from harm. An example is pulling your finger away from a hot object.

1. A receptor in the skin of the finger detects the heat (the stimulus).
2. A **sensory neurone** carries impulses to the spinal cord (CNS).
3. At a synapse the impulses pass to a **relay neurone** in the spinal cord.
4. At another synapse the impulses pass to a **motor neurone**.
5. The motor neurone carries the impulses to an effector, a muscle in the arm.
6. The muscle contracts and the finger is pulled away.

The impulses do not have to reach the conscious part of the brain before the response happens, so the reflex is very fast.



A reflex arc: receptor, **sensory neurone**, **relay neurone**, **motor neurone**, effector. Impulses cross a **synapse** between each pair of neurones.

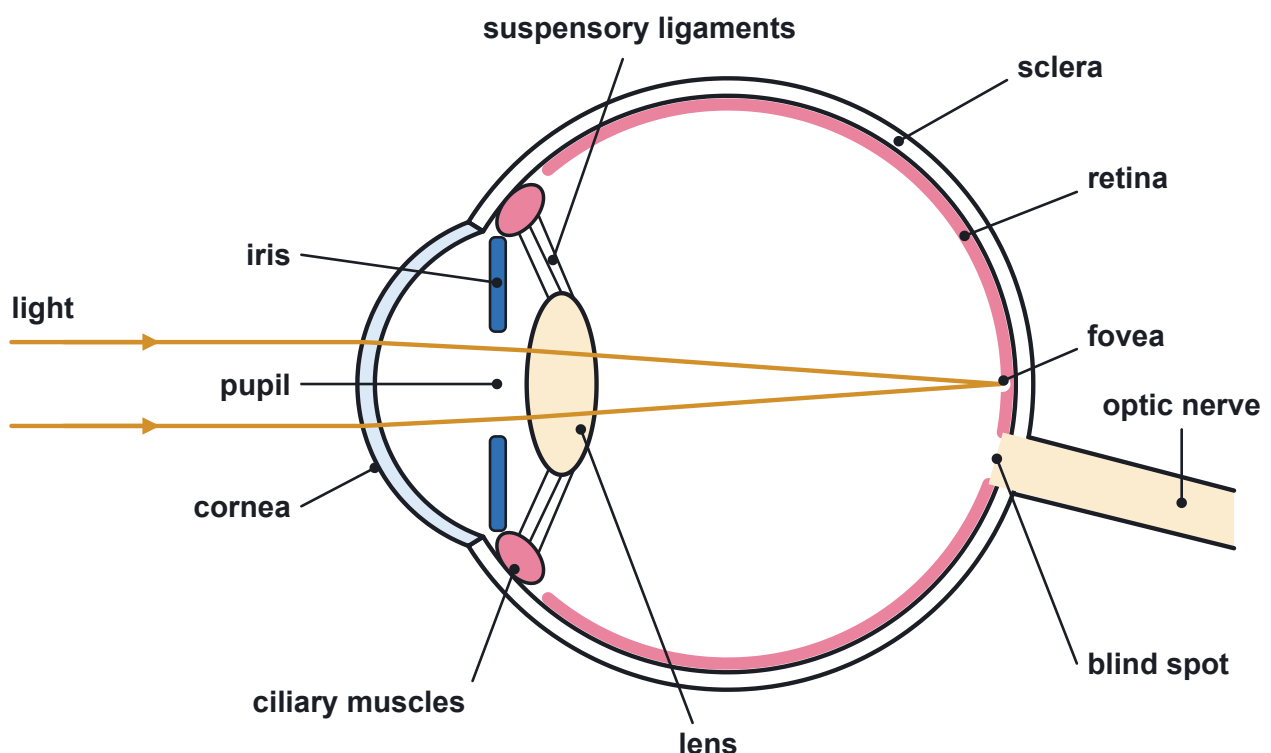
Exam tip: Write the pathway in order and name each neurone: sensory, relay, motor. The effector is the muscle, not the motor neurone.

Structure and function of the eye Spec 2.91

The eye is a sense organ and acts as a **receptor**. It detects light and sends impulses to the brain.

Parts of the eye

Part	Function
Sclera	Tough white outer layer that protects the eye
Cornea	Transparent front surface. It refracts (bends) light as it enters the eye
Iris	Ring of muscle that changes the size of the pupil, so controls how much light enters the eye
Pupil	The hole in the middle of the iris that lets light through
Lens	Refracts light to focus it on the retina
Ciliary muscles	Ring of muscle around the lens. Contracts or relaxes to change the shape of the lens
Suspensory ligaments	Hold the lens in place and connect it to the ciliary muscles
Retina	Contains the light receptor cells (rods and cones)
Fovea	Part of the retina with the most cones. Gives the sharpest, most detailed vision
Blind spot	Where the optic nerve leaves the eye. It has no receptor cells, so no light is detected there
Optic nerve	Carries impulses from the retina to the brain



The structure of the eye. The **cornea** and **lens** refract light so it focuses on the retina at the **fovea**.

Rods and cones

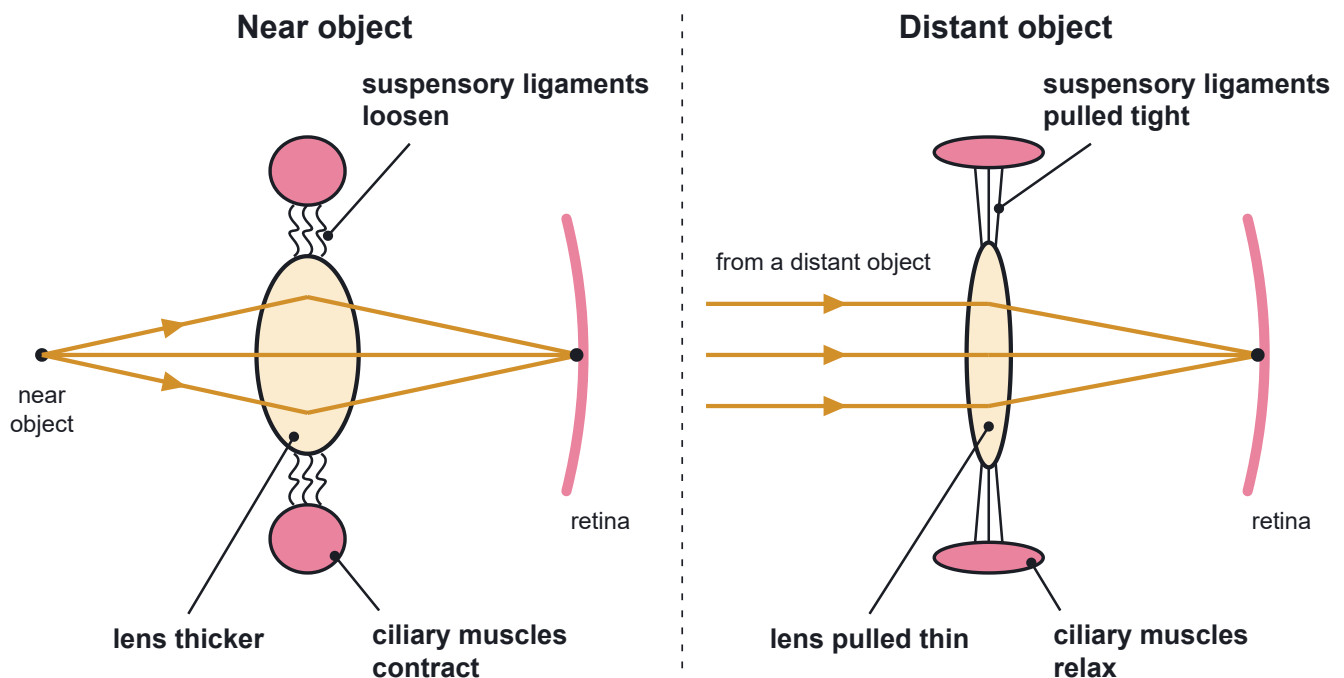
The retina has two types of receptor cell. **Rod cells** are sensitive to dim light but do not detect colour. **Cone cells** detect colour and work in bright light.

Exam tip: Give each part with its job and a reason, for example 'the cornea refracts light', not just 'the cornea is at the front'.

Focusing and the pupil reflex Spec 2.92

The eye can focus on both near and distant objects. The lens changes shape to do this. The ciliary muscles (a ring of muscle around the lens) and the suspensory ligaments (which hold the lens in place) control the lens shape.

Focusing on near and distant objects		
	Near object	Distant object
Ciliary muscles	Contract	Relax
Suspensory ligaments	Loosen	Pulled tight
Lens shape	Thicker (more curved)	Pulled thin (flatter)
Refraction of light	Light rays refracted more	Light rays refracted less



Near object: **muscles contract, ligaments loosen, lens thicker**. Distant object: muscles relax, ligaments tight, lens thin.

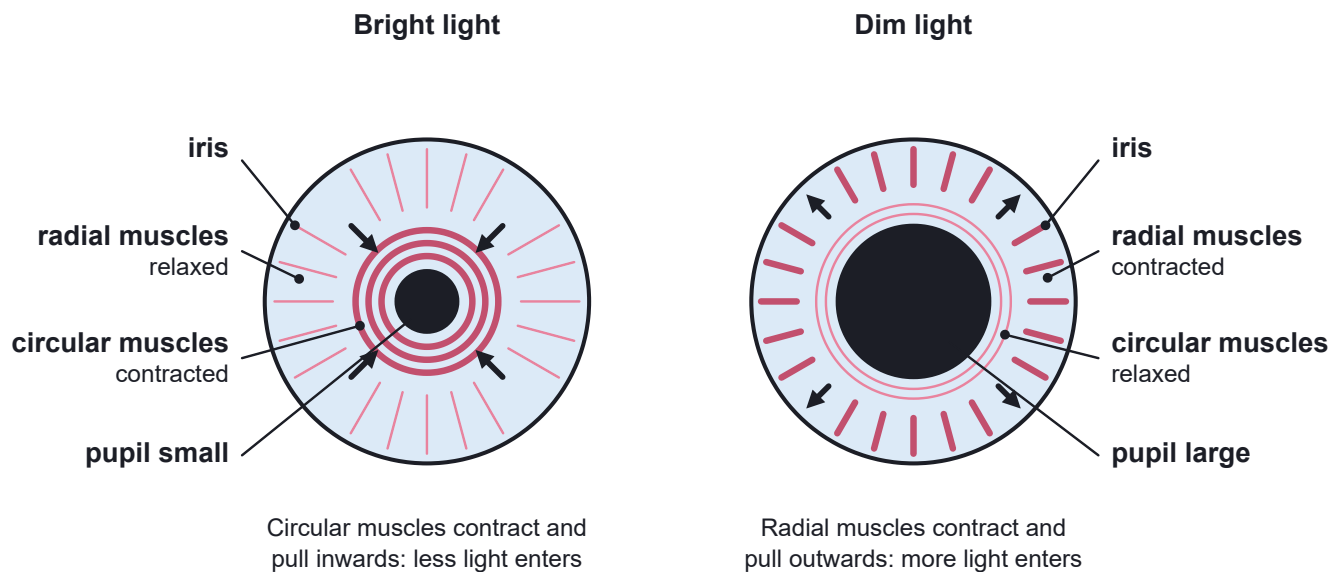
Common mistake: For a near object the ciliary muscles contract and the ligaments go slack. Many students reverse this. Remember: contracted muscle, loose ligaments, fat lens.

Changes in light intensity: the pupil reflex

The size of the pupil changes automatically in response to light intensity. This is a reflex, so it is fast and protects the retina. The iris has two sets of muscle: circular muscles (in rings around the pupil) and radial muscles (running out from the pupil like spokes).

The pupil reflex

	Bright light	Dim light
Circular muscles	Contract	Relax
Radial muscles	Relax	Contract
Pupil	Gets smaller (constricts)	Gets larger (dilates)
Effect	Less light enters, so the retina is protected from damage	More light enters, so you can see better



The pupil reflex. Bright light: **circular muscles contract**, pupil smaller. Dim light: **radial muscles contract**, pupil larger.

Exam tip: Name the muscles and say what each does. 'Circular muscles contract' makes the pupil smaller; 'radial muscles contract' makes it larger.

Quick check

1. What two organs make up the central nervous system?
2. What carries the message across a synapse?
3. Name the three types of neurone in a reflex arc, in order.
4. Which part of the eye contains the light receptors?
5. In bright light, do the circular muscles of the iris contract or relax?

15 Hormones and temperature control Spec 2.86, 2.93-2.95B

Nervous and hormonal communication compared Spec 2.86

Both the nervous system and the **endocrine system** control responses in the body. The endocrine system is made of **glands** that secrete **hormones** directly into the **blood**. The blood carries the hormone to its **target organ**, where it causes an effect.

Nervous and hormonal communication compared		
	Nervous communication	Hormonal communication
Message carried by	Electrical impulses along neurones	Hormones (chemicals) in the blood
Speed of response	Very fast	Slower
Length of effect	Short-lived	Longer-lasting
Where it acts	Specific effectors (muscles or glands)	Target organs, which can be anywhere in the body

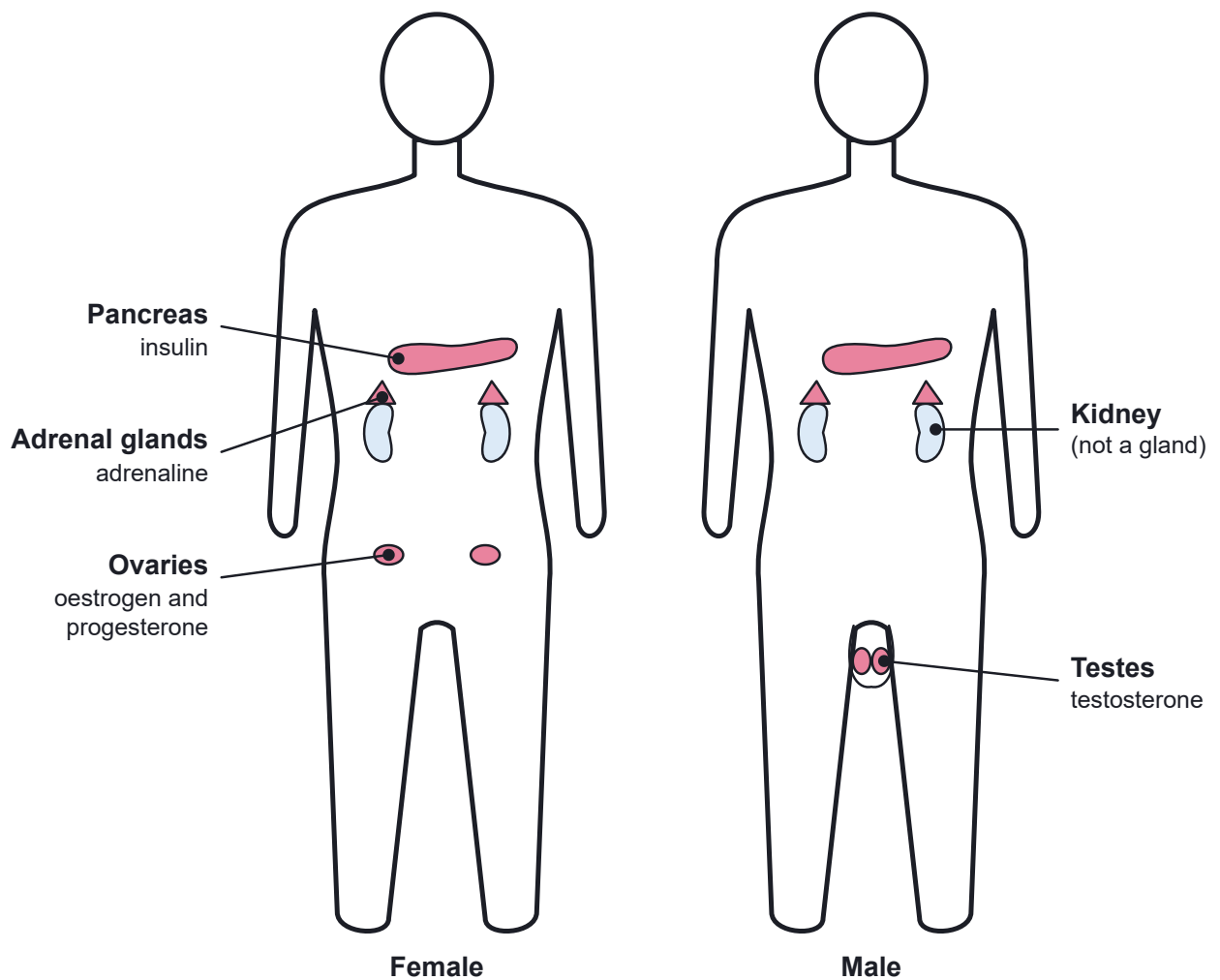
Exam tip: Compare in three words: slower, longer, chemical. Hormones travel in the blood, so they reach every part of the body but only affect their target organ.

Adrenaline, insulin and the sex hormones Spec 2.94

You need to know the source, role and effects of five hormones.

Five hormones: source, role and effects		
Hormone	Source	Role and effects
Adrenaline	Adrenal glands (on top of the kidneys)	Prepares the body for fight or flight . Increases heart rate, so more blood (with oxygen and glucose) reaches the muscles for respiration. Stimulates the liver to change glycogen into glucose, raising blood glucose
Insulin	Pancreas	Controls blood glucose concentration. When blood glucose is high, the pancreas secretes insulin. Insulin makes cells take up glucose from the blood and makes the liver convert glucose into glycogen for storage, so blood glucose falls
Testosterone	Testes	Main male sex hormone. Controls the development of male secondary sexual characteristics at puberty and stimulates sperm production
Oestrogen	Ovaries	Main female sex hormone. Controls the development of female secondary sexual characteristics at puberty and helps repair and build up the uterus lining in the menstrual cycle
Progesterone	Ovaries	Maintains the lining of the uterus in the second half of the menstrual cycle and during pregnancy

Common mistake: The pancreas makes insulin, but the liver stores glycogen. Do not write that the pancreas stores glucose.



Where the five hormones are made: **adrenal glands**, **pancreas**, **ovaries** and **testes**.

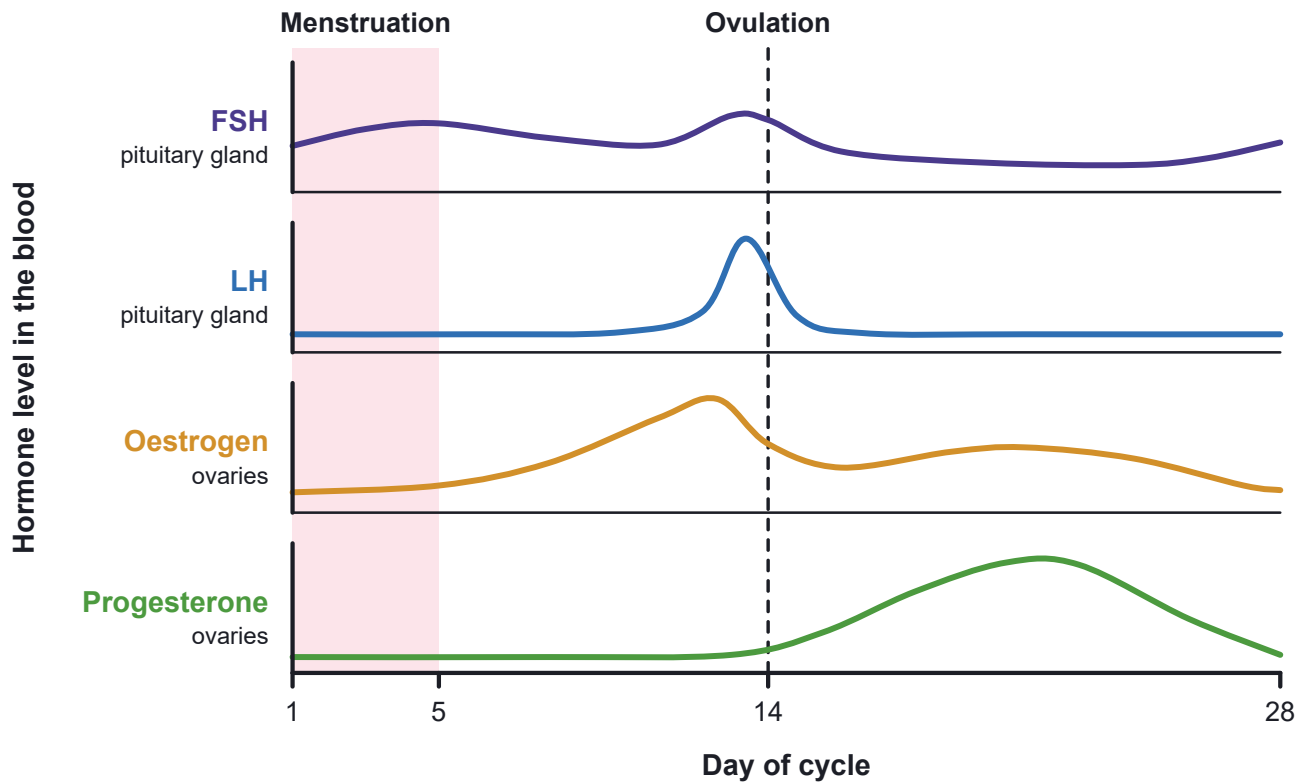
ADH, FSH and LH Spec 2.95B Biology only

Three more hormones are released by the **pituitary gland**, at the base of the brain.

ADH, FSH and LH		
Hormone	Source	Role and effects
ADH	Pituitary gland	Controls the water content of the blood. It makes the collecting ducts of the kidney more permeable to water, so more water is reabsorbed into the blood and less urine is made
FSH	Pituitary gland	Causes an egg to mature in an ovary. Stimulates the ovaries to produce oestrogen
LH	Pituitary gland	Stimulates the release of the egg (ovulation) from the ovary

ADH and the water content of the blood

	Blood water content too low	Blood water content too high
ADH released	More	Less
Collecting duct	More permeable to water	Less permeable to water
Water reabsorbed into blood	More	Less
Urine	Small volume, concentrated	Large volume, dilute

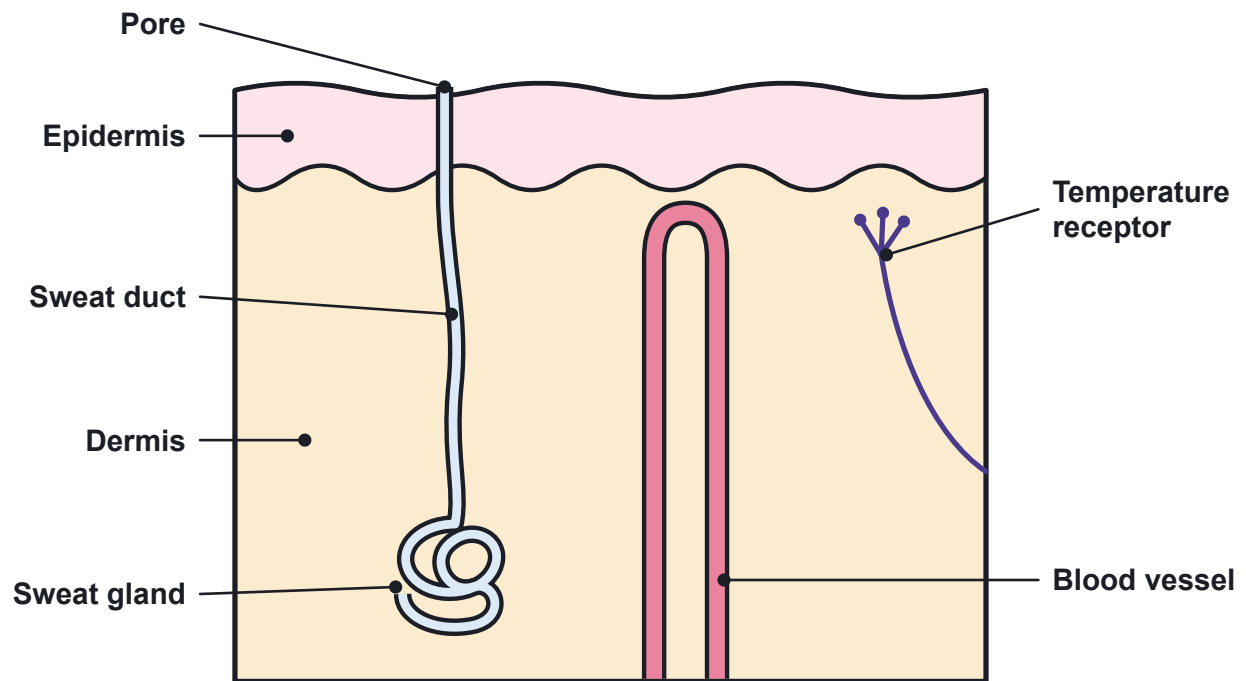


Levels of FSH, LH, oestrogen and progesterone. The **LH surge** triggers ovulation around day 14.

Common mistake: FSH is not the hormone that releases the egg. FSH makes the egg mature; LH stimulates its release.

The skin and temperature control Spec 2.93

The skin helps to keep the body temperature steady. It has two main layers, the **epidermis** (thin outer layer) and the **dermis** below it. The dermis contains sweat glands, blood vessels and temperature receptors.

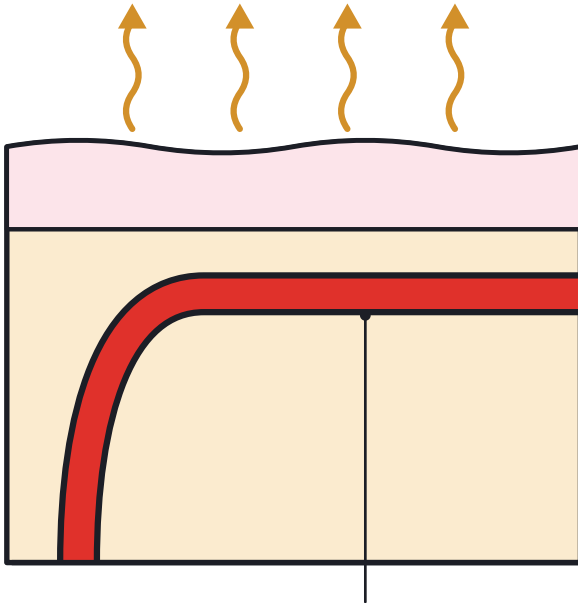


The structures in the skin involved in **temperature regulation**.

Skin responses to temperature change		
	Body too hot	Body too cold
Sweating	Sweat glands release sweat onto the skin. Sweat evaporates and takes heat from the skin, cooling the body	Little or no sweat is produced
Blood vessels in the dermis	Vasodilation : vessels widen, more blood flows near the surface, more heat is lost	Vasoconstriction : vessels narrow, less blood flows near the surface, less heat is lost
Overall effect	More heat is lost, so body temperature falls back to normal	Less heat is lost, so body temperature rises back to normal

Too hot: vasodilation

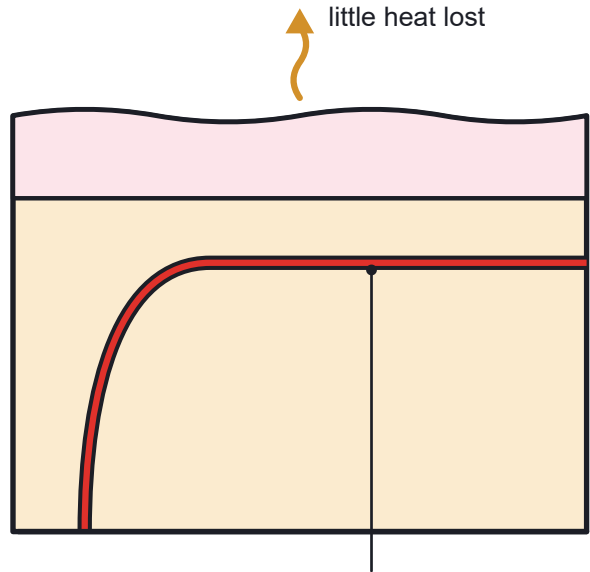
lots of heat lost



Blood vessel widens
more blood near surface

Too cold: vasoconstriction

little heat lost



Blood vessel narrows
less blood near surface

Vasodilation brings more blood near the surface to lose heat; **vasoconstriction** reduces heat loss.

Common mistake: Blood vessels do not move up or down in the skin. They get wider (vasodilation) or narrower (vasoconstriction).

Quick check

1. Name two differences between nervous and hormonal communication.
2. Which gland makes insulin?
3. Where is adrenaline produced?
4. **Biology only** What does ADH change in the kidney?
5. What happens to skin blood vessels when you are too hot?

Quick check answers

Cells and levels of organisation

1. Organelle, cell, tissue, organ, organ system.
2. They are where aerobic respiration takes place, releasing energy for the cell.
3. Cell wall, chloroplasts and a large permanent vacuole.
4. The process by which a cell becomes specialised for a particular job.
5. They can divide out of control and form a tumour (or viruses could be passed on, or the immune system may reject them).

Biological molecules and enzymes

1. Nitrogen (and sometimes sulfur).
2. Amino acids.
3. From blue to green, yellow, orange or brick-red.
4. An enzyme that speeds up a reaction in a living thing without being used up.
5. The shape of the active site changes, so the substrate no longer fits and the enzyme is denatured.

Movement of substances into and out of cells

1. The net movement of particles from an area of higher concentration to an area of lower concentration.
2. The diffusion of water from a dilute solution to a more concentrated solution through a partially permeable membrane.
3. Active transport.
4. It gets smaller.
5. Water moves out of the potato cells into the more concentrated solution by osmosis.

Nutrition in flowering plants

1. Carbon dioxide + water → glucose + oxygen (in the presence of light and chlorophyll).
2. Chemical energy, stored in glucose.
3. Carbon dioxide concentration, light intensity and temperature.
4. Magnesium ions are needed to make chlorophyll. Nitrate ions are needed to make amino acids.
5. Blue-black.

Human nutrition

1. Carbohydrate, protein, lipid, vitamins, minerals, water and dietary fibre.
2. Waves of muscle contraction that move food along the gut.
3. Amylase makes maltose from starch. Maltase makes glucose from maltose.
4. It neutralises stomach acid and emulsifies lipids.
5. Made in the liver and stored in the gall bladder.
3. Mass of water × 4.2 × temperature change.

Respiration

1. ATP (adenosine triphosphate).
2. glucose + oxygen → carbon dioxide + water.
3. Lactic acid.
4. Ethanol and carbon dioxide.
5. They are dead, so they show that any changes are caused by living seeds respiring.

Gas exchange in flowering plants

1. Diffusion.
2. They open and close the stoma.
3. Oxygen.
4. The rate of photosynthesis equals the rate of respiration, so there is no net gas exchange.
5. Yellow.

Gas exchange in humans

1. The intercostal muscles and the diaphragm.
2. It decreases, because the volume of the thorax increases.
3. To give a short diffusion distance so gases diffuse quickly.
4. Carbon monoxide.
5. It turns cloudy (milky).

The need for transport and transport in plants

1. It has a large surface area compared with its volume, so diffusion distances are short.
2. Xylem.
3. Sucrose and amino acids.
4. The evaporation of water from the surface of a plant.
5. It decreases the rate, because the concentration gradient of water vapour is smaller.

Blood and the immune system

1. Red blood cells, white blood cells, platelets and plasma.
2. Biconcave shape, no nucleus, contains haemoglobin.
3. They ingest (engulf) them.
4. Antibodies that are specific to the pathogen.
5. Antibody production that is sooner, faster and in greater quantity if the pathogen enters again.

The heart and circulation

1. It separates the left and right sides of the heart, so oxygenated and deoxygenated blood do not mix.
2. It pumps blood around the whole body, which needs higher pressure.
3. Muscles respire faster, so more oxygen and glucose must be delivered and more carbon dioxide removed.
4. Coronary arteries.
5. The hepatic portal vein.

Excretion

1. Carbon dioxide.
2. Water, salts (ions) and urea.
3. The Bowman's capsule (from the glomerulus).
4. The proximal convoluted tubule, by active transport.
5. It makes the collecting duct more permeable to water, so more water is reabsorbed.

Coordination, homeostasis and plant responses

1. A stimulus, a receptor and an effector.
2. The maintenance of a constant internal environment.
3. Control of body water content and control of body temperature.
4. Roots grow downwards: positive geotropism.
5. To the shaded side, where it makes cells elongate.

The nervous system and the eye

1. The brain and the spinal cord.
2. A neurotransmitter, which diffuses across the gap.
3. Sensory neurone, relay neurone, motor neurone.
4. The retina.
5. They contract, making the pupil smaller.

Hormones and temperature control

1. Nervous is fast and short-lived using electrical impulses; hormonal is slower and longer-lasting using chemicals in the blood.
2. The pancreas.
3. In the adrenal glands.
4. It makes the collecting ducts more permeable to water, so more water is reabsorbed.
5. They widen (vasodilation), so more heat is lost.