Course Companion

AQA · GCSE · Biology

Every topic handout in one volume

全部专题讲义合集

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1 · Cell biology

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Cell biology: the unit of life

Why it matters. In 1665 the English scientist Robert Hooke published *Micrographia*, a book of drawings made through his home-built microscope. When he looked at a thin slice of cork, he saw it was full of tiny empty boxes. They reminded him of the small rooms that monks lived in, so he called them "cells". Eleven years later, in 1676, the Dutch cloth merchant Antonie van Leeuwenhoek wrote to the Royal Society in London that he had seen "very little animalcules" swimming in a drop of water: the first record of bacteria. Every living thing is made of cells, and almost everything in biology, from how a muscle contracts to how an antibiotic works, starts with what happens inside them.

In this unit you will:

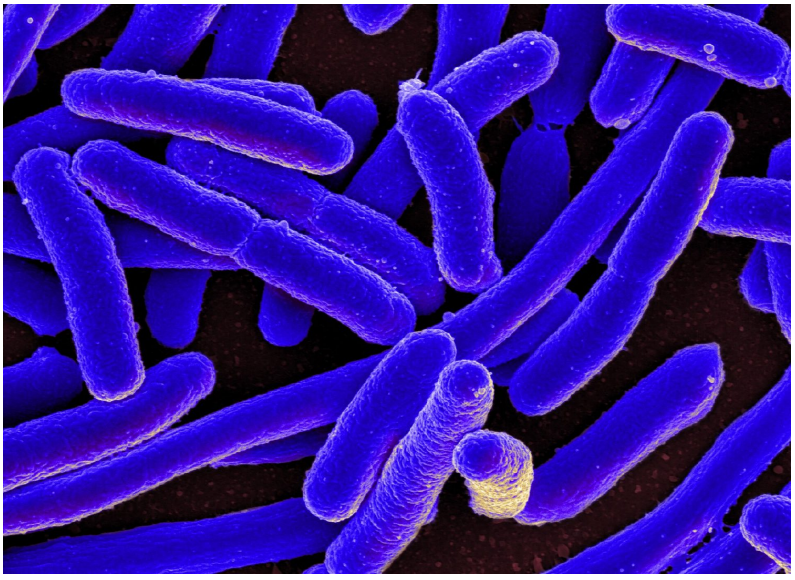
- compare animal, plant and bacterial cells, and link each cell part to its job;
- explain how cells become specialised, and calculate magnification;
- culture bacteria safely and test antibiotics (biology only);
- describe the cell cycle, mitosis and the uses of stem cells;
- explain diffusion, osmosis and active transport, and why large organisms need exchange surfaces.

AQA GCSE Biology (8461), topic 4.1 Cell biology, examined on Paper 1. It includes three required practicals: using a light microscope (RP1), testing antiseptics and antibiotics on bacteria (RP2, biology only) and osmosis in plant tissue (RP3). Culturing microorganisms is biology only; content marked (HT) is Higher tier only.

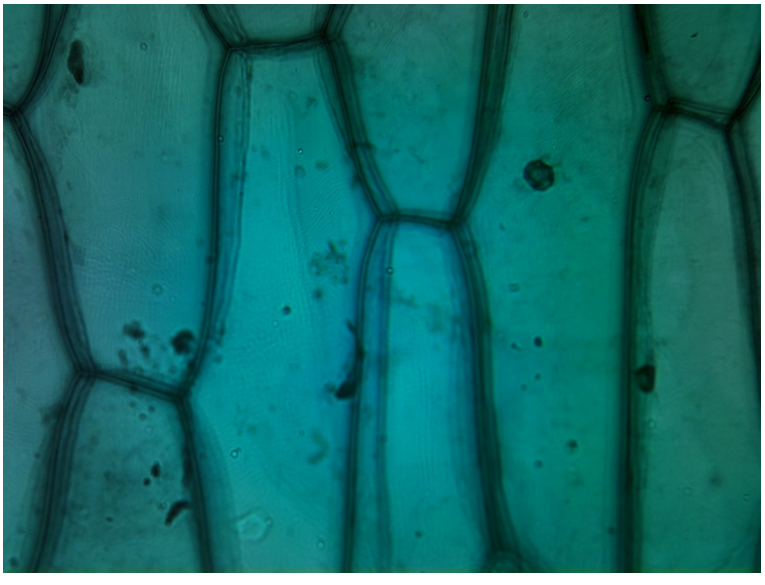
Cell structure

Eukaryotic 真核 cells, such as animal, plant and yeast cells, keep their genetic material inside a **nucleus** 细胞核. **Prokaryotic** 原核 cells, the bacteria, have no nucleus: their DNA is a single loop in the cytoplasm, and many also have small rings of DNA called plasmids. Bacterial cells are much smaller, typically 1 to 5 micrometres long, while most animal and plant cells are 10 to 100 micrometres.

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E. coli under an electron microscope: prokaryotic cells are much smaller and have no nucleus



Onion epidermis cells under a light microscope: each plant cell has a cell wall and a nucleus

Parts of animal and plant cells.

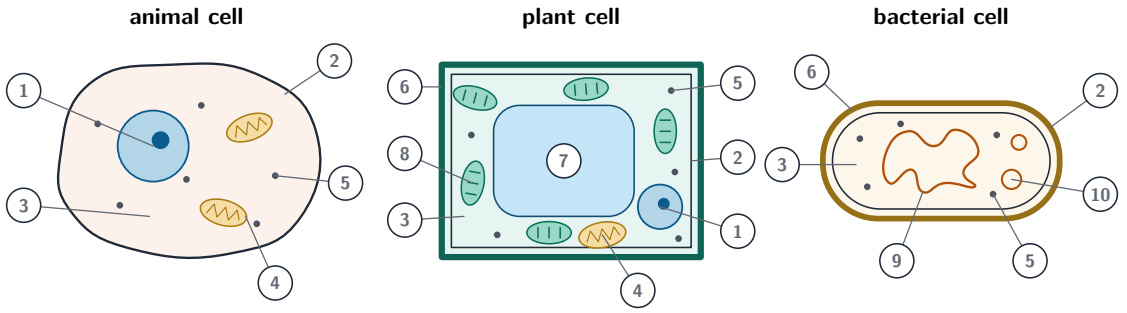
- The nucleus contains DNA and controls the cell's activities.
- The cell membrane controls what enters and leaves the cell.
- The **cytoplasm** 细胞质 is a jelly where many chemical reactions happen.
- Each **mitochondrion** 线粒体 is where aerobic respiration releases energy.
- Each **ribosome** 核糖体 is where proteins are made.

Plant cells also have:

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- a cell wall made of cellulose, which supports the cell;
- a permanent **vacuole** 液泡 filled with cell sap, which keeps the cell firm;
- in the green parts of the plant, a **chloroplast** 叶绿体 in which photosynthesis happens. Root cells are underground and have no chloroplasts.

Bacterial cells have a cell membrane, cytoplasm, ribosomes and a cell wall (not made of cellulose), but no nucleus, mitochondria or chloroplasts. A **plasmid** 质粒 is a small extra ring of DNA, which often carries genes such as those for antibiotic resistance.

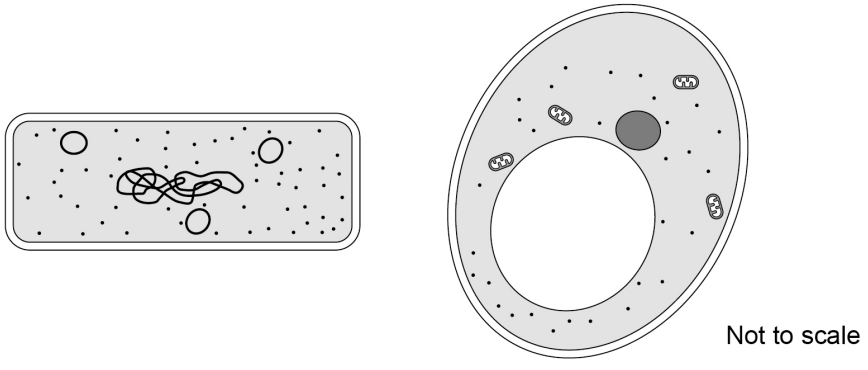


An animal cell, a plant cell and a bacterial cell, not to scale; the numbers are listed in the key below

Key to the numbers: 1 nucleus, 2 cell membrane, 3 cytoplasm, 4 mitochondrion, 5 ribosome, 6 cell wall, 7 permanent vacuole, 8 chloroplast, 9 DNA loop, 10 plasmid.

> **Worked example 1.** A question shows a bacterial cell and a yeast cell. Name two structures in the yeast cell that are not in the bacterial cell. Answer: a nucleus and mitochondria (a permanent vacuole also scores). "The yeast cell is more complicated" earns nothing: name the structures.

Figure 10



A bacterial cell and a yeast cell, not to scale (AQA GCSE Biology Paper 1H, June 2025, Figure 10)

Specialised cells and differentiation

Specialised cells 特化细胞 have features that suit their jobs. In an answer, give the feature and then explain how it helps.

Cell	Feature	How it helps
Sperm cell	tail; many mitochondria	swims to the egg; mitochondria release energy for swimming
Nerve cell	long axon; branched endings	carries impulses a long way; connects to many cells
Muscle cell	protein fibres; many mitochondria	the fibres contract; mitochondria release the energy needed
Root hair cell	long thin extension	large surface area to absorb water and mineral ions
Xylem cell	hollow tube; walls strengthened with lignin	water flows through; the walls do not collapse
Phloem cell	sieve plates; few cell contents	dissolved sugars flow from cell to cell

Differentiation 分化 is the process by which a cell gains the special structures it needs to do one job. Most animal cells differentiate early in development and then keep their type; cell division in adult animals is mainly for repair and replacement. Many plant cells can differentiate throughout the life of the plant.

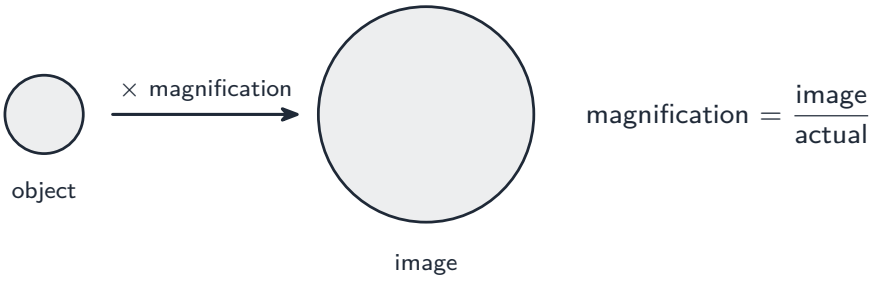
Microscopy and magnification

A **light microscope** 光学显微镜 uses light and lenses; it magnifies up to about 1500 times. An **electron microscope** 电子显微镜 uses a beam of electrons. Electron microscopes have a much greater magnification and **resolving power** 分辨能力 (resolution), the ability to show two points close together as separate. This is why they revealed ribosomes and the inside of mitochondria, which light microscopes cannot show. Making a blurred image bigger does not show more detail.

$$\text{magnification} = \frac{\text{image size}}{\text{real size}}$$

Magnification 放大倍数 has no unit. The image size and the real size must be in the same unit before you divide. Remember: 1 mm = 1000 µm (micrometres) and 1 µm = 1000 nm (nanometres).

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Magnification = image size ÷ actual size

Worked example 2. A cell's image is 4.8 cm long at a magnification of ×1200. Find its real length in micrometres. 4.8 cm = 48 mm = 48 000 μm, so real size = $\frac{48\,000}{1200} = 40$ μm.

Worked example 3 (HT). A cylindrical structure has volume 24 500 000 nm^3 and radius 125 nm. Its image is 4 mm long. Find the magnification, using $\pi = 3.14$. Real length = $\frac{V}{\pi r^2} = \frac{24\,500\,000}{3.14 \times 125^2} = 499.4$ nm. Image length = 4 mm = 4 000 000 nm. Magnification = $\frac{4\,000\,000}{499.4} = 8010$, written ×8010 with no unit. Keep the full value of the real length until the last step.

Required practical 1: using a light microscope. Place a thin specimen, such as onion skin stained with iodine, on a slide under a cover slip. Start with the lowest-power objective lens, focus with the coarse focus knob, then move to a higher power and use the fine focus. Draw what you actually see with clear, unshaded outlines, label the structures, and write the magnification (eyepiece × objective) or add a scale bar.

Culturing microorganisms (biology only)

Bacteria reproduce by **binary fission** 二分裂: one cell splits into two. In good conditions some bacteria divide as often as every 20 minutes. They can be grown in a liquid **nutrient broth** 营养肉汤 or as **colonies** 菌落 on **agar** 琼脂 gel.

$$\text{number of bacteria} = \text{starting number} \times 2^{\text{number of divisions}}$$

Worked example 4. One bacterium divides every 20 minutes. How many bacteria are there after 3 hours? Number of divisions = 180 ÷ 20 = 9, so the number is $1 \times 2^9 = 512$. (HT) In standard form, after 2 hours there are $2^6 = 64 = 6.4 \times 10^1$ bacteria. This assumes that the bacteria have enough food and space.

Aseptic technique. Aseptic technique 无菌操作 prevents **contamination** 污染 of the culture by unwanted **microorganisms** 微生物. Each step has a reason:

- **sterilise** 灭菌 the **Petri dishes** 培养皿 and **culture media** 培养基 before use, to kill microorganisms already on them;
- pass the **inoculating loop** 接种环 through a flame before use, to kill microorganisms on it;
- lift the lid only slightly, so that microorganisms from the air do not fall in;
- secure the lid with tape (but do not seal it all round), so that oxygen can still get in and harmful anaerobic bacteria do not grow;
- store the dish upside down, so that drops of condensation do not fall onto the agar.

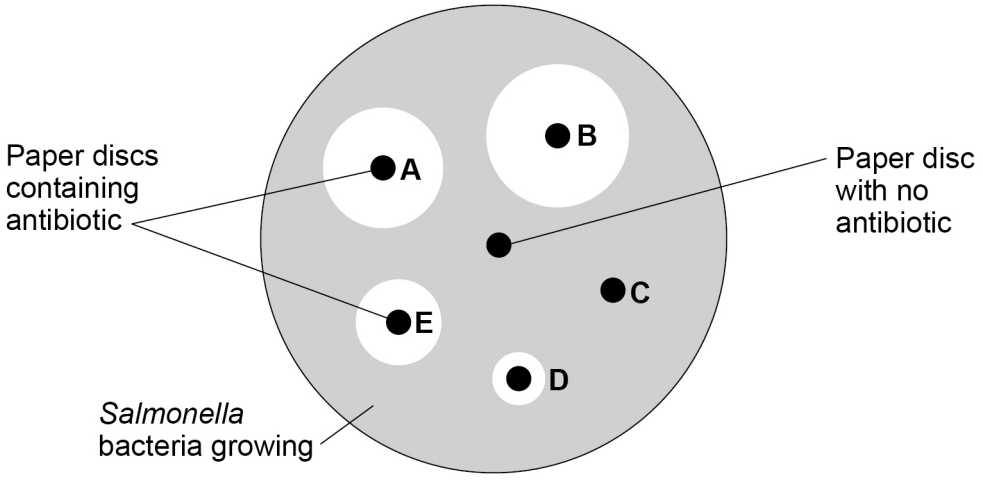
In school, cultures are kept at 25 °C or below, which reduces the growth of bacteria that could cause disease in humans. Hospital laboratories use 37 °C, body temperature, so cultures grow faster.



Antibiotic discs on a bacterial lawn: the bigger the clear zone, the more effective the antibiotic

Required practical 2: antiseptics and antibiotics. Spread bacteria evenly over agar to make a "lawn". Put paper discs soaked in different **antibiotics** 抗生素 or **antiseptics** 消毒剂 on the agar, and one disc soaked in sterile water as a **control** 对照. After incubation, a clear zone forms around a disc where bacteria have been killed or stopped from growing. A bigger **zone of inhibition** 抑菌圈 means a more effective substance against that bacterium. The control shows that the paper disc alone does not stop growth.

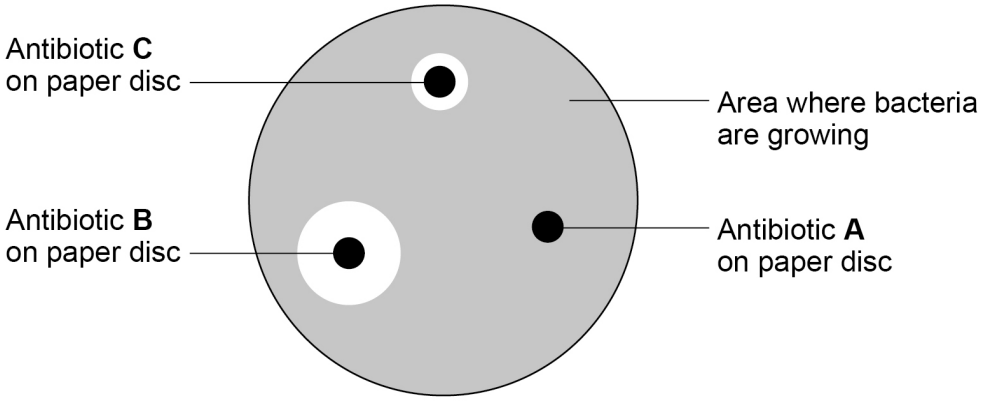
Figure 4



Five antibiotics, A to E, and a control disc with no antibiotic (AQA GCSE Biology Paper 1H, June 2023, Figure 4)

Worked example 5. In a test, antibiotic C has a small clear zone around it. A student says the bacteria are **resistant** 耐药 to antibiotic C. Explain why the student is wrong. A clear zone, even a small one, shows that antibiotic C killed some bacteria or stopped their growth. If the bacteria were resistant, they would grow right up to the edge of the disc.

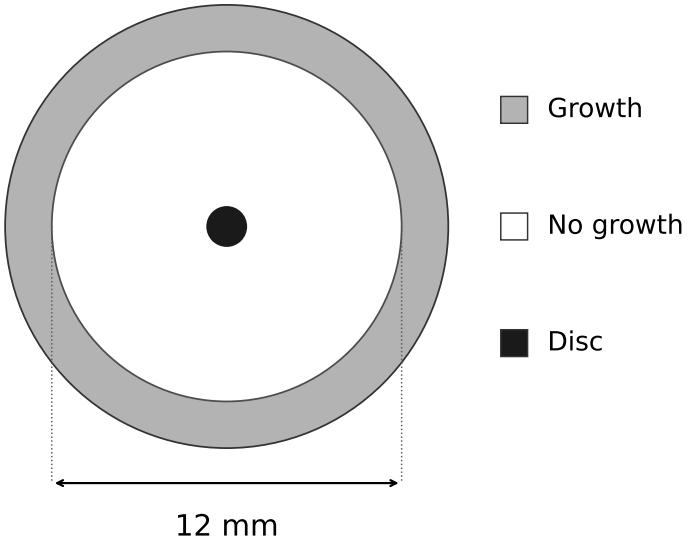
Figure 5



Antibiotic A has no clear zone, B a large one and C a small one (AQA GCSE Biology Paper 1H, June 2024, Figure 5)

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Worked example 6. A clear zone has a diameter of 12 mm. Find its area. The radius is $12 \div 2 = 6$ mm, so the area is $\pi r^2 = \pi \times 6^2 = 113$ mm^2 (3 s.f.). Using 12 mm as the radius would give an area four times too large.



A clear zone 12 mm across has a radius of 6 mm

Cell division

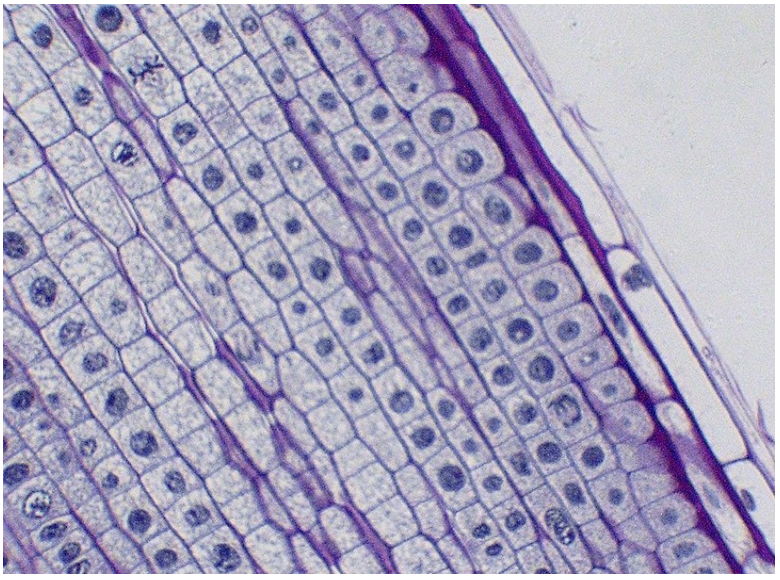
The nucleus contains **chromosomes** 染色体, long molecules of DNA. Each chromosome carries many **genes** 基因. In body cells chromosomes are found in pairs: human body cells have 23 pairs, 46 chromosomes in all.

The cell cycle. The **cell cycle** 细胞周期 has three stages:

1. The cell grows, makes more ribosomes and mitochondria, and copies its DNA, so that each chromosome becomes two identical copies.
2. **Mitosis** 有丝分裂: one set of chromosomes is pulled to each end of the cell, and the nucleus divides.
3. The cytoplasm and cell membrane divide, forming two genetically identical **daughter cells** 子细胞.

Mitosis is used for growth and development, for repairing damage, and for asexual reproduction.

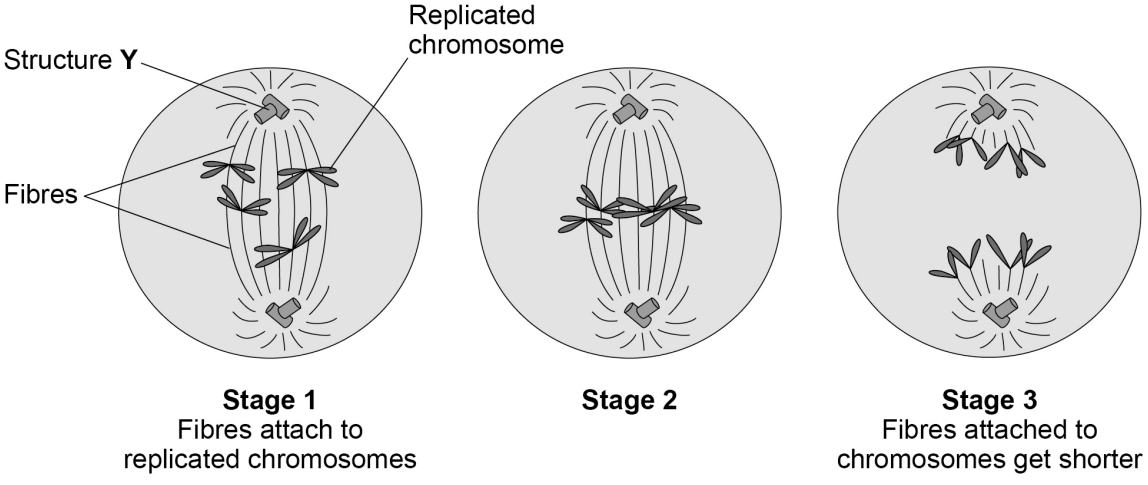
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A stained onion root tip: several cells are caught at different stages of mitosis

Worked example 7. A drug stops the fibres in a cell attaching to the chromosomes. Explain how this stops the cell dividing. Without the fibres, the chromosomes cannot be pulled to each end of the cell, so the nucleus cannot divide into two. Such a drug can slow the growth of a **tumour** 肿瘤, where cells divide out of control. But it also slows normal dividing cells, which is why some cancer treatments cause hair loss.

Figure 9

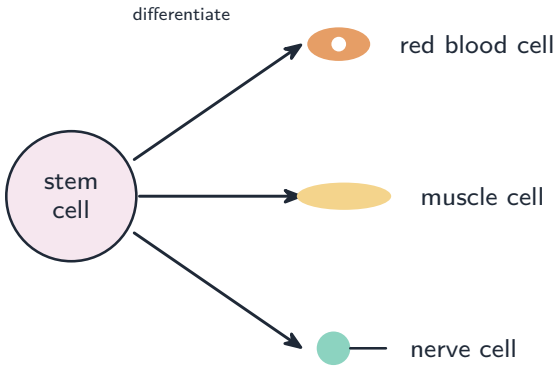


Fibres pull the copied chromosomes apart during mitosis (AQA GCSE Biology Paper 1H, June 2024, Figure 9)

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Stem cells

A **stem cell** 干细胞 is **undifferentiated** 未分化: it can divide to make more stem cells and can differentiate into other kinds of cell.



One unspecialised stem cell can differentiate into many specialised cell types

Source	What it can become
Human embryo	almost any type of human cell
Adult **bone marrow** 骨髓	many types, including blood cells, but fewer than embryonic cells
Plant **meristem** 分生组织 (root and shoot tips)	any type of plant cell, throughout the plant's life

Uses. **Embryonic stem cells** 胚胎干细胞 might one day replace faulty cells, for example insulin-making cells in diabetes or nerve cells in paralysis. In **therapeutic cloning** 治疗性克隆, an embryo is made with the same genes as the patient, so its stem cells are not **rejected** 排斥 by the patient's immune system. Meristem cells are used to clone plants quickly and cheaply, to save rare species from extinction, or to produce many identical crop plants with useful features such as disease resistance.

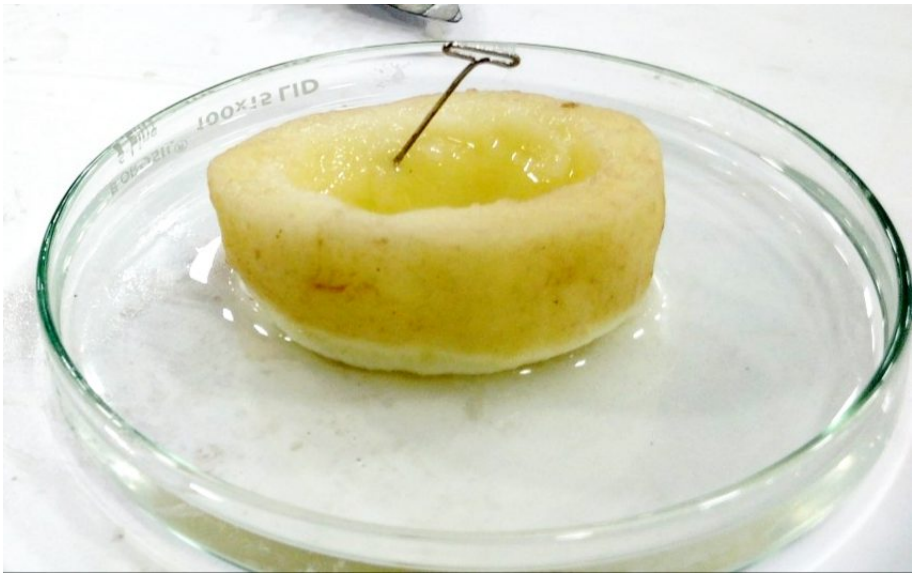
Risks and objections. Stem cells grown in a laboratory could carry viruses that pass to the patient. Some people have **ethical** 伦理 objections to using embryos: an embryo is destroyed when its stem cells are taken, and some believe an embryo has a right to life. For a full answer, give the reason, not just "religion".

Diffusion, osmosis and active transport

Diffusion 扩散 is the net movement of particles from an area of higher concentration to an area of lower concentration. Particles move in every direction, but more move down the **concentration gradient** 浓度梯度 than up it. Examples are oxygen and carbon dioxide in **gas exchange** 气体交换, and urea moving from cells into the **blood plasma** 血浆 to be taken to the kidneys. Diffusion is faster with a steeper

concentration gradient, a higher temperature and a larger membrane surface area.

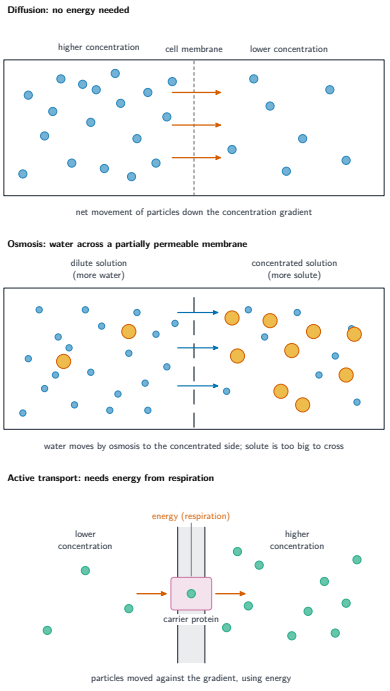
Osmosis 渗透 is the diffusion of water from a dilute solution to a more concentrated solution through a **partially permeable membrane** 部分透过性膜, which lets small water molecules through but not larger **solute** 溶质 molecules such as sugar.



A potato osmometer: sugar solution rises up the tube as water enters by osmosis

Active transport 主动运输 moves substances from a more dilute solution to a more concentrated solution, against the concentration gradient. It needs energy from respiration. **Root hair** 根毛 cells use it to absorb each **mineral ion** 矿物离子 from very dilute soil water, and the gut uses it to absorb sugar into the blood when the concentration in the gut is low.

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Diffusion, osmosis and active transport compared in three panels.

Process	What moves	Direction	Energy from respiration?
Diffusion	any dissolved or gas particles	high → low concentration	no
Osmosis	water	dilute → concentrated solution	no
Active transport	particles such as ions	low → high concentration	yes

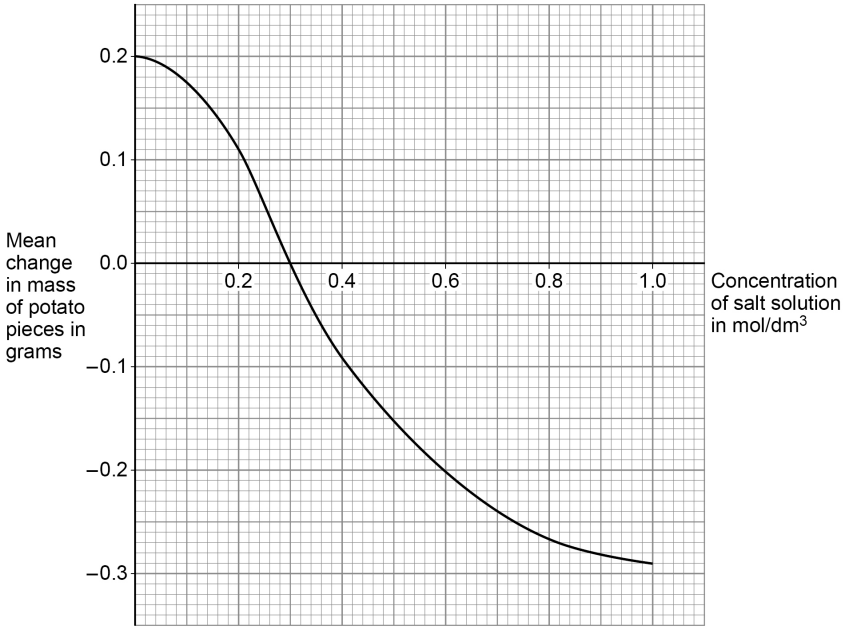
Required practical 3: osmosis in potato. Cut cylinders of potato of equal size from the same potato. Blot them dry, weigh each one, and put them in sugar or salt solutions of different concentrations, with the same volume of solution, for the same time and at the same temperature. Then blot and weigh again. Because the pieces start at slightly different masses, compare them using percentage change:

$$\text{percentage change} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100$$

Worked example 8. A piece of potato goes from 2.5 g to 2.9 g: percentage change $= \frac{0.4}{2.5} \times 100 = +16\%$. Another goes from 3.0 g to 2.55 g: $\frac{-0.45}{3.0} \times 100 = -15\%$. Keep the minus sign for a loss.

In distilled water the potato gains mass, because the solution inside its cells is more concentrated and water enters by osmosis. In a concentrated solution it loses mass, because water leaves. Where the graph crosses zero, there is no net movement of water: the solution outside has the same concentration as the cell sap. Water molecules still move both ways, but equally.

Figure 4



Mean change in mass of potato in grams against solution concentration (AQA GCSE Biology Paper 1H, June 2024, Figure 4)

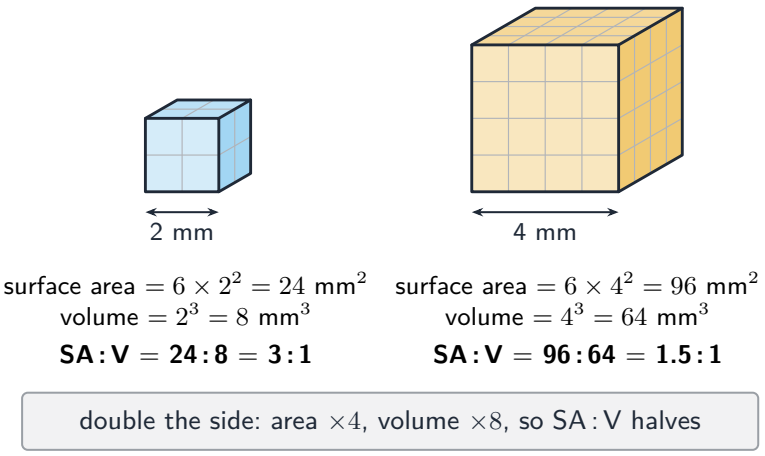
Worked example 9. Using the graph, explain why the mass of potato decreases in a 0.6 mol/dm^3 solution, and why it decreases more in a 1.0 mol/dm^3 solution. In 0.6 mol/dm^3 the solution outside is more concentrated than the cell sap, so water leaves the cells by osmosis. In 1.0 mol/dm^3 the concentration gradient is steeper, so more water leaves in the same time.

Exchange surfaces and surface area to volume ratio

A small single-celled organism can get all the oxygen it needs by diffusion through its surface. A large organism cannot, because it has much less surface for each unit of volume, and its inner cells are far from the surface. This is shown by the **surface area to volume ratio** 表面积与体积之比.

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Worked example 10. A cube of side 2 mm has surface area $6 \times 2^2 = 24$ mm^2 and volume $2^3 = 8$ mm^3, a ratio of $24 : 8 = 3 : 1$. A cube of side 4 mm has surface area 96 mm^2 and volume 64 mm^3, a ratio of $1.5 : 1$. Doubling the side multiplies the area by 4 but the volume by 8, so the ratio halves. The larger cube has more surface in total, but less surface for each mm^3 inside it.



Two cubes showing how doubling the side halves the surface-area-to-volume ratio.

So a **multicellular** 多细胞 organism needs **exchange surfaces** 交换表面 and a transport system, while a **single-celled** 单细胞 organism does not. Good exchange surfaces have:

- a large surface area, so more substance crosses at once;
- a thin membrane, so the diffusion path is short;
- (in animals) a good blood supply, which carries substances away and keeps the gradient steep;
- (for gas exchange) **ventilation** 通气, which brings in fresh air or water.

Examples are the **alveoli** 肺泡 in the lungs, surrounded by **capillaries** 毛细血管; the villi of the **small intestine** 小肠; fish **gills** 鳃; and plant roots and leaves.

Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.1 Cell biology, and the required practical handbook.
- R. Hooke, *Micrographia* (London, 1665), Observation XVIII, on cork.
- A. van Leeuwenhoek, letter to the Royal Society of 9 October 1676, *Philosophical Transactions* 12 (1677).
- AQA, *GCSE Biology* Paper 1 Higher (June 2023, 2024 and 2025), the antibiotic, cell division and osmosis questions, adapted.

Common errors

- Saying all plant cells have chloroplasts; root cells do not.
- Saying bacteria have no ribosomes or no cell wall; they have both.
- Dividing image size by real size without first changing to the same unit, or giving magnification a unit.
- Calling the water disc in RP2 a “control variable”; it is a control.
- Using the diameter instead of the radius in πr^2.
- Saying “water molecules stop moving” when there is no net osmosis.
- Writing that active transport moves substances down the concentration gradient.
- Saying a larger cube has a larger surface area to volume ratio.

Key terms

- **Eukaryotic cell**: a cell with its DNA inside a nucleus.
- **Prokaryotic cell**: a bacterial cell, with no nucleus.
- **Differentiation**: the process by which a cell becomes specialised.
- **Magnification**: how many times bigger the image is than the real object.
- **Aseptic technique**: methods that stop unwanted microorganisms contaminating a culture.
- **Mitosis**: the division of the nucleus that makes two identical nuclei.
- **Stem cell**: an undifferentiated cell that can make more stem cells and other cell types.
- **Diffusion**: the net movement of particles from higher to lower concentration.
- **Osmosis**: the diffusion of water across a partially permeable membrane from a dilute to a concentrated solution.
- **Active transport**: movement against a concentration gradient, using energy from respiration.

Check yourself

1. Name three structures found in plant cells but not in animal cells.
2. An image is 30 mm long and the magnification is $\times 500$. Find the real length in µm.
3. Give the reason for each of these steps: flaming the inoculating loop; storing the Petri dish upside down.
4. One bacterium divides every 30 minutes. How many bacteria are there after 4 hours?
5. Describe the three stages of the cell cycle.
6. Give one benefit and one objection to using embryonic stem cells.

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7. A potato piece goes from 4.0 g to 3.4 g. Calculate the percentage change in mass, and explain the change.

Answers: 1. Cell wall, permanent vacuole, chloroplasts. 2. 30 mm = 30 000 μm; $30\,000 \div 500 = 60$ μm. 3. Flaming kills microorganisms on the loop, so they do not contaminate the culture; storing upside down stops condensation dripping onto the agar. 4. 8 divisions, so $2^8 = 256$. 5. The cell grows, makes more organelles and copies its DNA; mitosis pulls one set of chromosomes to each end and the nucleus divides; the cytoplasm and membrane divide to make two identical cells. 6. Benefit: they can become almost any cell type, so they could treat diseases such as diabetes; objection: the embryo is destroyed. 7. $\frac{-0.6}{4.0} \times 100 = -15\%$; the solution was more concentrated than the cell sap, so water left the cells by osmosis.

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2 · Organisation

AQA · GCSE · Biology

Organisation: from cells to systems

Why it matters. On 3 December 1967, at Groote Schuur Hospital in Cape Town, the surgeon Christiaan Barnard and his team carried out the first human-to-human heart transplant. The patient, Louis Washkansky, was 53 and dying of heart failure; the donor was a young woman killed in a road accident. The new heart beat strongly, but Washkansky died 18 days later of pneumonia, because the drugs that stopped his body rejecting the heart had also weakened his defences against infection. Today thousands of heart transplants are carried out every year, alongside stents, statins and artificial valves. To understand any of them, you need to know how cells are organised into tissues, organs and organ systems, and how those systems work together.

In this unit you will:

- describe the levels of organisation from cells to organ systems;
- explain how enzymes digest food, and test foods for nutrients;
- describe the heart, blood vessels and blood, and how the lungs exchange gases;
- explain coronary heart disease and evaluate its treatments, and interpret data about risk factors;
- describe plant tissues, transpiration and translocation.

AQA GCSE Biology (8461), topic 4.2 Organisation, examined on Paper 1. It includes two required practicals: food tests (RP4) and the effect of pH on amylase (RP5). Content marked (HT) is Higher tier only.

Levels of organisation

Living things are organised in levels:

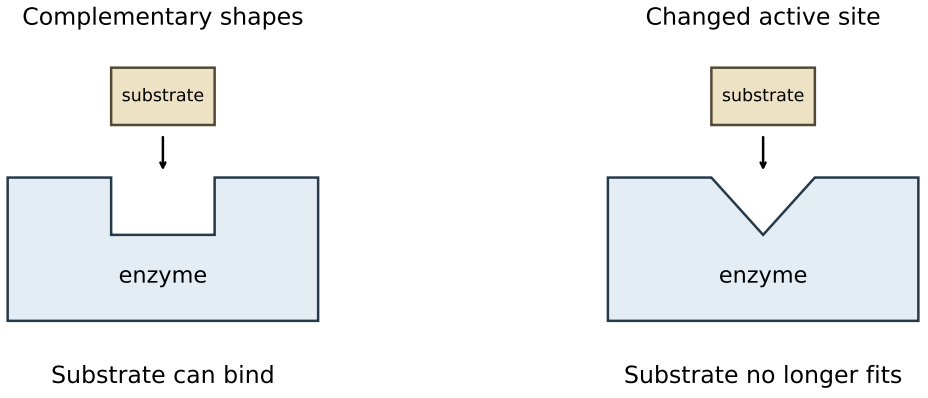
- a **tissue** 组织 is a group of cells with a similar structure and function, such as muscle tissue;
- an **organ** 器官 is a group of different tissues working together, such as the stomach;
- an **organ system** 器官系统 is a group of organs working together, such as the digestive system.

The stomach contains muscular tissue, which churns the food; glandular tissue, which makes digestive juices; and epithelial tissue, which covers the inside and outside. So the stomach is an organ, not a tissue.

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Enzymes and digestion

Enzymes 酶 are proteins that act as **biological catalysts** 生物催化剂: they speed up reactions without being used up. Each enzyme has an **active site** 活性位点 with a particular shape. In the **lock-and-key model** 锁钥模型, only a **substrate** 底物 with the matching shape fits the active site, as only one key fits a lock. The enzyme breaks the substrate (or joins substrates), the products leave, and the enzyme can be used again.



Lock and key: the substrate fits the active site; after denaturation the changed active site no longer fits

Temperature and pH. As temperature rises, the enzyme and substrate move faster and collide more often, so the reaction speeds up. Above the optimum temperature, the active site changes shape and the substrate no longer fits: this is **denaturation** 变性, and it is permanent. A pH far from the enzyme's optimum also changes the active site and slows the reaction. At low temperature the enzyme is not denatured; it is just slow.

Digestive enzymes. Digestion breaks large insoluble molecules into small soluble ones that can be absorbed into the blood through the wall of the small intestine.

Enzyme	Made in	Breaks down	Into
Amylase 淀粉酶	**salivary glands** 唾液腺, **pancreas** 胰腺, small intestine	starch	sugars
Protease 蛋白酶	stomach, pancreas, small intestine	proteins	amino acids
Lipase 脂肪酶	pancreas, small intestine	lipids (fats and oils)	fatty acids and glycerol

Amylase breaks starch into **simple sugars** 单糖 such as maltose. The products of digestion are used to build new carbohydrates, lipids and proteins, and some glucose

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is used in respiration.

Bile. **Bile** 胆汁 is made in the **liver** 肝脏 and stored in the **gall bladder** 胆囊. It is not an enzyme. It does two jobs:

- it is alkaline, so it neutralises the hydrochloric acid from the stomach, giving the alkaline conditions that enzymes in the small intestine work best in;
- it **emulsifies** 乳化 fat, breaking large drops into many small droplets. This gives a larger surface area for lipase to act on, so fat is digested faster.

Required practical 4: food tests. Grind the food with a little water and use a separate sample for each test.

Nutrient	Test	Positive result
Starch	add iodine solution	orange-brown turns blue-black
Reducing sugar 还原糖 (such as glucose)	add Benedict's solution and heat in a water bath at about 75 °C	blue turns green, yellow or brick red (more sugar gives a colour further along)
Protein	add **Biuret reagent** 双缩脲试剂	blue turns purple
Lipid	add Sudan III and shake	a red-stained oily layer floats on top

Heat Benedict's tests in a water bath, never over a flame, and wear eye protection.



Benedict's test: blue means no sugar; orange to brick-red means reducing sugar is present

Required practical 5: pH and the rate of amylase. Put one drop of iodine in each well of a spotting tile. Warm starch solution, amylase and a pH **buffer** 缓冲液

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(a solution that keeps the pH constant) in a water bath at the same temperature, then mix them and start a timer. Every 30 seconds, put a drop of the mixture into a new iodine drop. When the iodine stays orange-brown, all the starch has been digested. Record the time, and repeat at other pH values, keeping the temperature, volumes and concentrations the same.

> **Worked example 1.** The times for all the starch to be digested were 180 s at pH 5, 90 s at pH 6, 60 s at pH 7 and 120 s at pH 8. The rate can be found as $\frac{1}{\text{time}}$: at pH 7, rate $= \frac{1}{60} = 0.017\ \text{s}^{-1}$; at pH 6, rate $= \frac{1}{90} = 0.011\ \text{s}^{-1}$. The fastest of the tested values was pH 7, but the true optimum could be anywhere between pH 6 and pH 8. To find it more precisely, test more pH values in this range, such as 6.5 and 7.5.

> **Worked example 2.** Starch and amylase were left for 5 minutes at different temperatures. At 30 °C the iodine stayed orange-brown; at 90 °C it turned blue-black. Explain. At 30 °C the amylase broke down all the starch, so none was left. At 90 °C the amylase was denatured, so the starch was not digested.

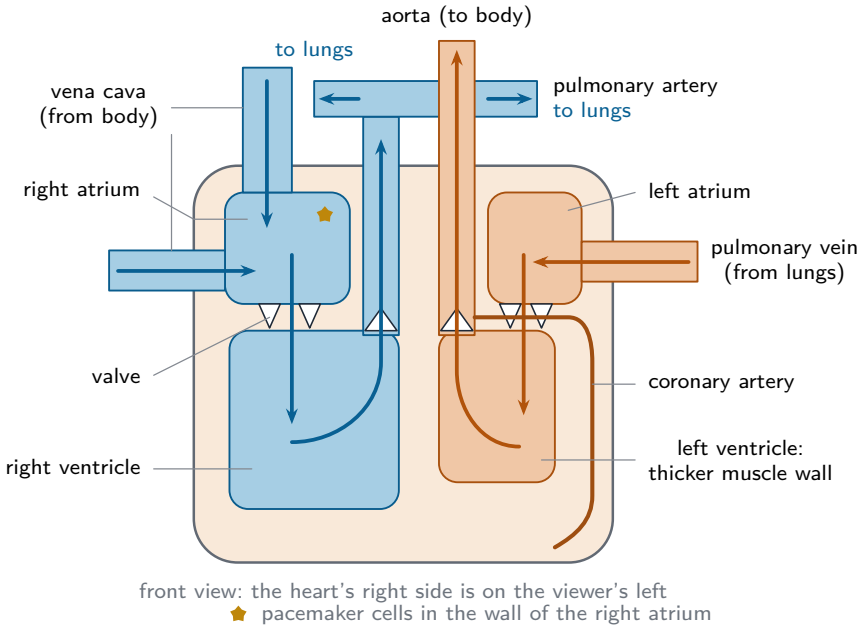
The heart and blood vessels

The heart pumps blood around the body. Humans have a **double circulation** 双循环: blood passes through the heart twice on each complete circuit. The right side pumps blood to the lungs to pick up oxygen; the left side pumps it to the rest of the body.

The route of blood through the heart:

1. Blood from the body enters the **right atrium** 右心房 through the **vena cava** 腔静脉.
2. It passes to the **right ventricle** 右心室, which pumps it through the **pulmonary artery** 肺动脉 to the lungs.
3. Oxygenated blood returns through the **pulmonary vein** 肺静脉 to the **left atrium** 左心房.
4. It passes to the **left ventricle** 左心室, which pumps it through the **aorta** 主动脉 to the body.

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The heart seen from the front, so its right side is on the left of the page: blue for deoxygenated blood, red for oxygenated

The left ventricle has a thicker muscle wall than the right, because it pumps blood at higher pressure all round the body. **Valves** 瓣膜 stop blood flowing backwards. The heart muscle gets its own oxygen from the **coronary arteries** 冠状动脉, which branch off the aorta. A group of cells in the right atrium acts as a natural **pacemaker** 起搏器, setting the heart rate; an artificial pacemaker is a small electrical device that corrects an irregular heartbeat.

Blood vessels. **Arteries** 动脉 carry blood away from the heart; **veins** 静脉 carry blood back to the heart. (The pulmonary artery is an artery carrying deoxygenated blood, because it carries blood away from the heart.)

Vessel	Structure	How this helps
Artery	thick layers of muscle and elastic fibres; narrow **lumen** 管腔	withstands high pressure; the elastic wall stretches and recoils with each heartbeat
Vein	thin wall; wide lumen; valves	blood at low pressure flows easily; valves stop it flowing backwards
Capillary 毛细血管	wall one cell thick	short distance for substances to diffuse between blood and cells

The lungs. Air passes down the **trachea** 气管 and **bronchi** 支气管 to millions of

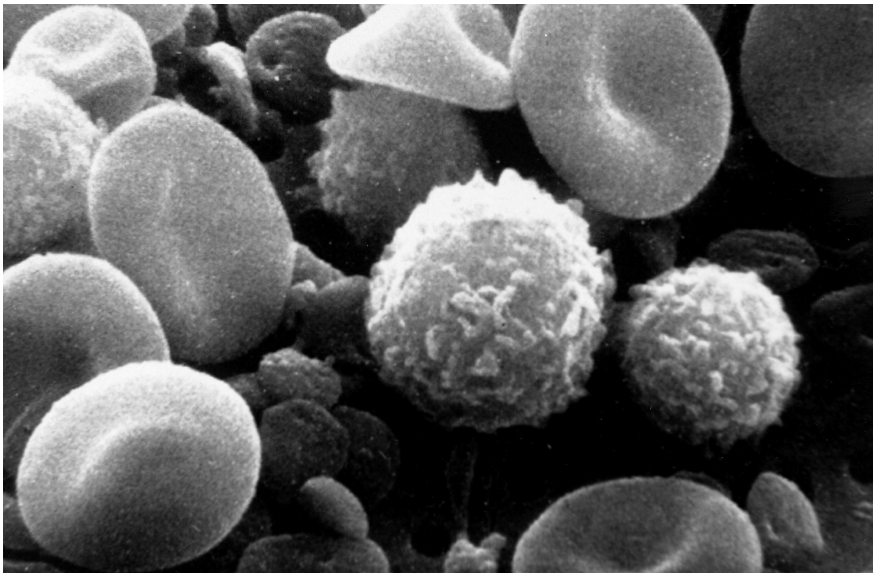
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tiny air sacs, the **alveoli** 肺泡. Oxygen diffuses from the air in the alveoli into the blood, and carbon dioxide diffuses the other way. The alveoli give a huge surface area, their walls and the capillary walls are very thin, and the blood flow and breathing keep the concentration gradients steep.

Blood

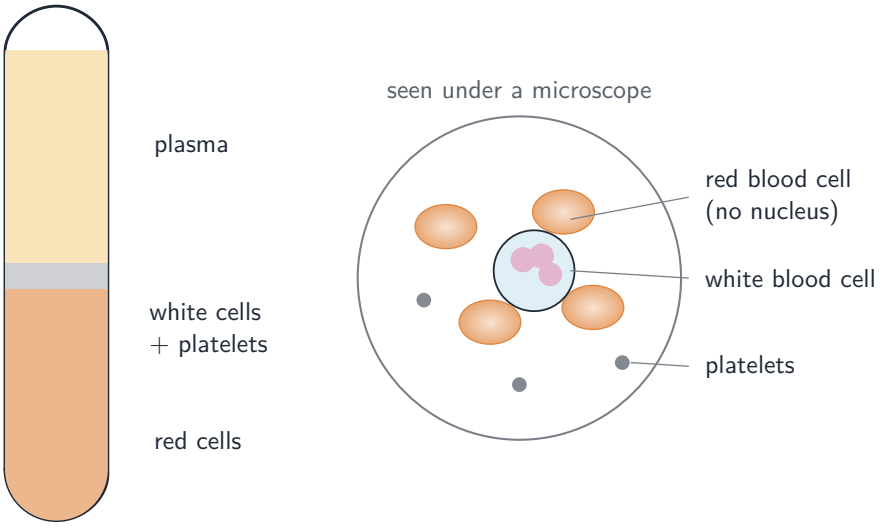
Blood is a tissue made of four parts.

- **Plasma** 血浆 is the pale yellow liquid. It carries dissolved glucose, amino acids, carbon dioxide, urea and hormones, and spreads heat around the body.
- **Red blood cells** 红细胞 carry oxygen. They contain **haemoglobin** 血红蛋白, which joins with oxygen in the lungs; they have no nucleus, leaving more room for haemoglobin; and their shape, a disc pushed in on both sides, gives a large surface area.
- **White blood cells** 白细胞 have a nucleus and defend the body: some engulf microorganisms and others make antibodies.
- **Platelets** 血小板 are small pieces of cells that help blood to clot at a wound, stopping blood loss and keeping microorganisms out.



Blood under a scanning electron microscope: red cells, white cells and small platelets

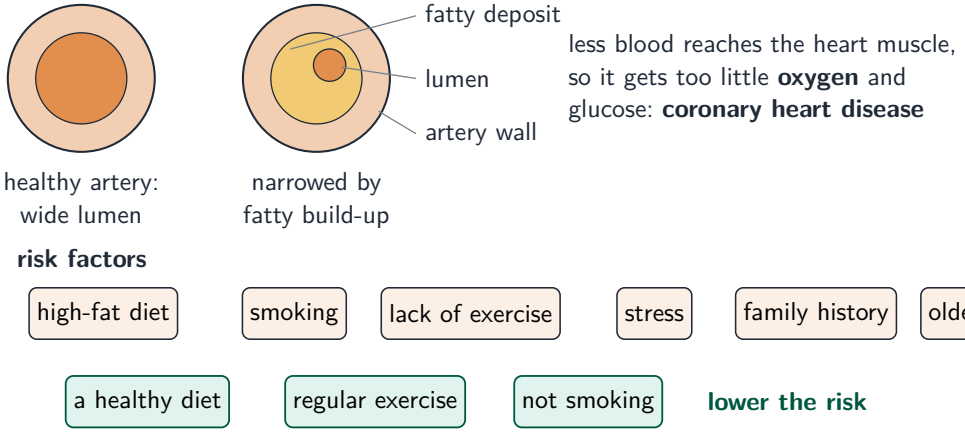
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The parts of blood: plasma, white cells and platelets, and red cells (not to scale)

Coronary heart disease

In **coronary heart disease** 冠心病, layers of fatty material build up inside the coronary arteries and narrow them. Less blood reaches the heart muscle, so it gets less oxygen and glucose. Its cells release less energy by aerobic respiration, so the muscle cannot contract properly, which can cause chest pain and, if an artery becomes blocked, a heart attack.



Coronary heart disease narrows the artery; several risk factors raise it and a healthy lifestyle lowers it

Treatments.

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Treatment	How it helps	Drawbacks
Stent 支架	a mesh tube that holds a narrowed artery open, so more blood flows to the heart muscle	risks of the operation; fatty material can build up again
Statin 他汀	a drug that lowers blood **cholesterol** 胆固醇, slowing the build-up of fatty material	must be taken for life; possible side effects such as muscle pain
Replacement valve	replaces a faulty valve that leaks or does not open fully	surgery; mechanical valves need drugs to stop clots
Heart transplant	replaces a failing heart with a donor heart	too few donors; the body may reject the heart, so drugs are needed for life
Artificial heart	keeps a patient alive while waiting for a transplant	risk of infection and blood clots

Worked example 3: evaluating treatments. Compare a stent with statins for a patient with narrowed coronary arteries. A stent improves blood flow straight away, but it needs a small operation and does not stop more fatty material forming. Statins slow the build-up of fatty material but take time to work, must be taken every day, and can have side effects. The two can be used together; the best choice depends on how severe and urgent the narrowing is. A good evaluation gives a benefit and a drawback of each, then a judgement.

Health, risk factors and cancer

Health 健康 is a state of physical and mental well-being. Diseases are either **communicable diseases** 传染性疾病, caused by pathogens that spread from person to person, or **non-communicable diseases** 非传染性疾病, which do not spread, such as heart disease and most cancers. Diseases can interact: a weak immune system makes infections more likely, and serious physical illness can lead to depression.

A **risk factor** 危险因素 is something that makes a disease more likely, but does not make it certain.

Risk factor	Linked disease
poor diet, smoking, lack of exercise	cardiovascular disease
obesity	Type 2 diabetes
alcohol	liver disease; damage to the brain
smoking	lung disease and lung cancer
smoking or alcohol in pregnancy	harm to the unborn baby
carcinogens, including ionising radiation	cancer

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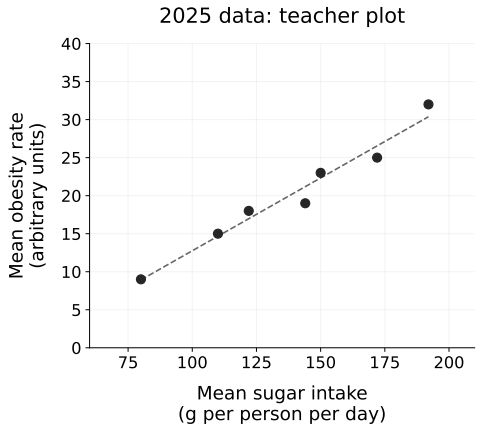


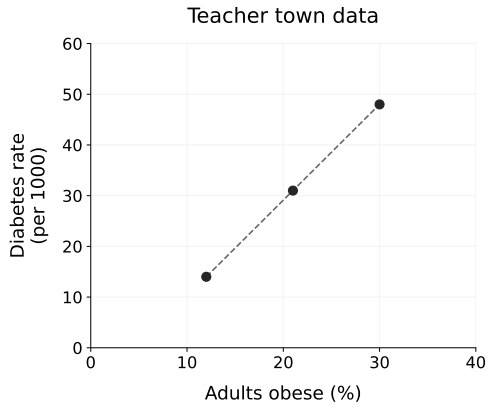
Smoking is a lifestyle risk factor for lung cancer and cardiovascular disease

Correlation and cause. A **positive correlation** 正相关 between two factors, such as obesity and diabetes, shows that they increase together. It does not by itself prove that one causes the other; a cause is accepted when there is also a mechanism that explains how one leads to the other.

> **Worked example 4.** In town A, 12% of adults are obese and the diabetes rate is 14 per 1000; in town B, 21% and 31 per 1000; in town C, 30% and 48 per 1000. As the percentage of obese people increases, the diabetes rate increases: a positive correlation. The rate in town C is $\frac{48}{14} = 3.4$ times the rate in town A. Obesity is a known risk factor for Type 2 diabetes, but three towns alone cannot prove that obesity caused the difference: age, diet and exercise could also differ between the towns.

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Left: sugar intake and obesity in seven countries (arbitrary units, AQA June 2025 data); right: obesity and diabetes rate in towns A, B and C; dashed lines are lines of best fit

Judging a study. Ask whether the sample was large and representative, whether other factors such as age and smoking were controlled, whether the results have been repeated by other scientists, and whether there is a known mechanism.

Cancer. Cancer 癌症 is the result of changes in cells that lead to uncontrolled growth and division, forming a tumour.

- A **benign tumour** 良性肿瘤 grows in one place, usually inside a membrane, and does not invade other parts of the body.
- A **malignant tumour** 恶性肿瘤 invades nearby tissue and its cells can spread in the blood to form secondary tumours elsewhere.

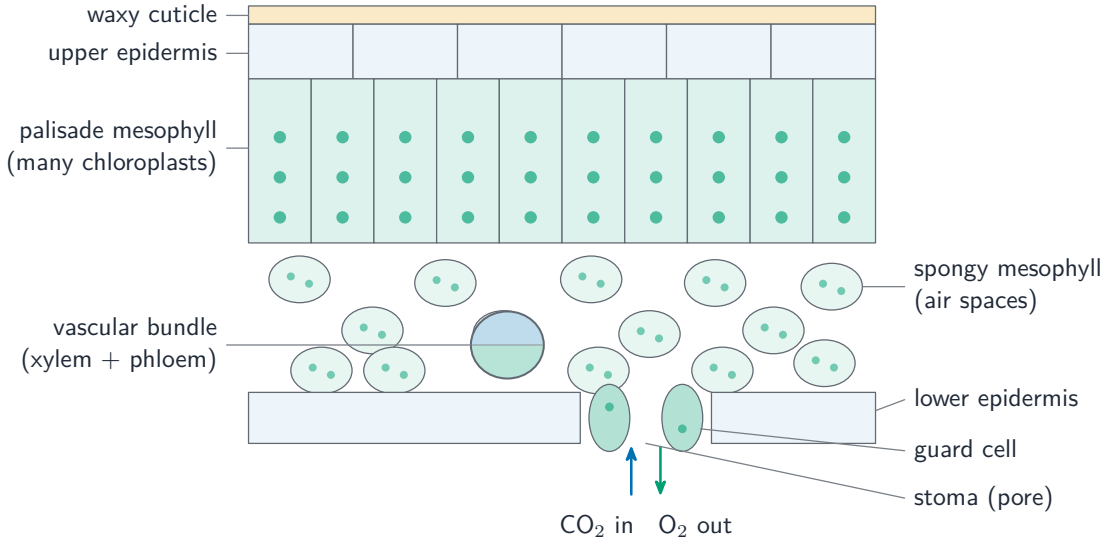
Tobacco smoke contains a **carcinogen** 致癌物 that can damage the DNA in lung cells. If the damage affects the genes that control cell division, the cells may divide out of control and form a malignant tumour. Some cancers also have genetic risk factors.

Plant tissues and organs

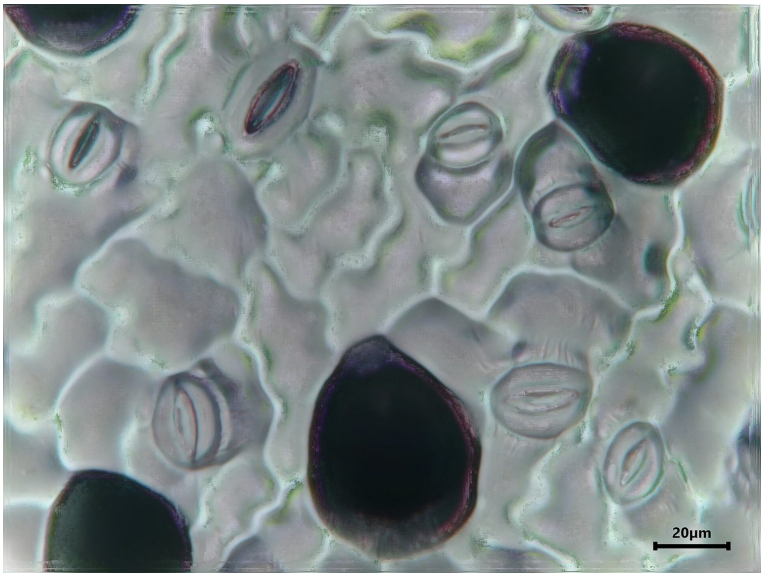
A leaf is an organ made of several tissues.

- The upper and lower **epidermis** 表皮 cover the leaf; the upper epidermis has a **waxy cuticle** 蜡质角质层 that reduces water loss.
- The **palisade mesophyll** 栅栏组织 has many chloroplasts, for photosynthesis.
- The **spongy mesophyll** 海绵组织 has air spaces, so gases can diffuse through the leaf.
- **Guard cells** 保卫细胞 open and close the **stomata** 气孔, the small pores that let carbon dioxide in and water vapour out.

- **Meristem** 分生组织 tissue at the tips of roots and shoots makes new cells for growth.



A section through a leaf, not to scale; the dots in the palisade cells are chloroplasts



Stomata on the lower surface of a leaf: guard cells open and close them to control water loss

Xylem and phloem.

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	Xylem 木质部	Phloem 韧皮部
Cells	dead, hollow tubes	living **sieve tubes** 筛管
Walls	strengthened with **lignin** 木质素	end walls with pores called **sieve plates** 筛板
Carries	water and mineral ions	dissolved sugars
Direction	up from roots to leaves	from leaves to growing or storage parts, up or down
Process	transpiration stream	**translocation** 转运

Root hairs. Each **root hair** 根毛 gives a large surface area. Water enters by **osmosis** 渗透 across a **partially permeable membrane** 部分透过性膜, and mineral ions enter by **active transport** 主动运输, using energy from respiration, because the soil water is more dilute than the cell.

Transpiration

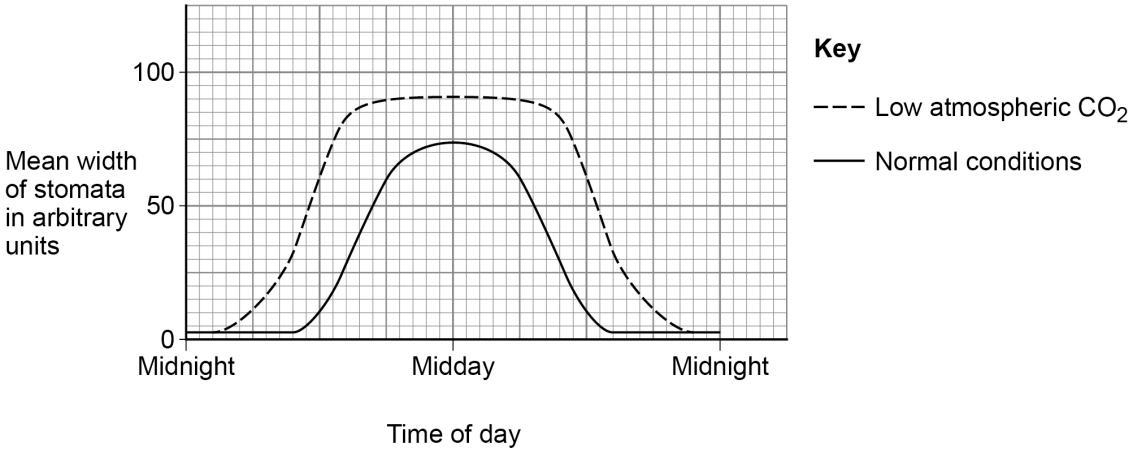
Transpiration 蒸腾作用 is the loss of water vapour from the leaves. Water evaporates from the surfaces of the mesophyll cells into the air spaces, and the vapour diffuses out through the stomata. As water is lost, more is pulled up the xylem from the roots: the transpiration stream.

Change	Effect on the rate of transpiration	Reason
higher temperature	increases	water evaporates and diffuses faster
more wind	increases	moist air is blown away from the leaf, so the gradient stays steep
brighter light	increases	stomata open wider for photosynthesis
higher humidity	decreases	the air outside is already moist, so the gradient is smaller

Measuring transpiration. A **potometer** 蒸腾计 measures how fast a leafy shoot takes up water, by timing how far an air bubble moves along a narrow tube. This is close to the rate of transpiration, though a little water is used by the plant. Cut the shoot under water so that no air enters the xylem, change one factor at a time, and repeat.

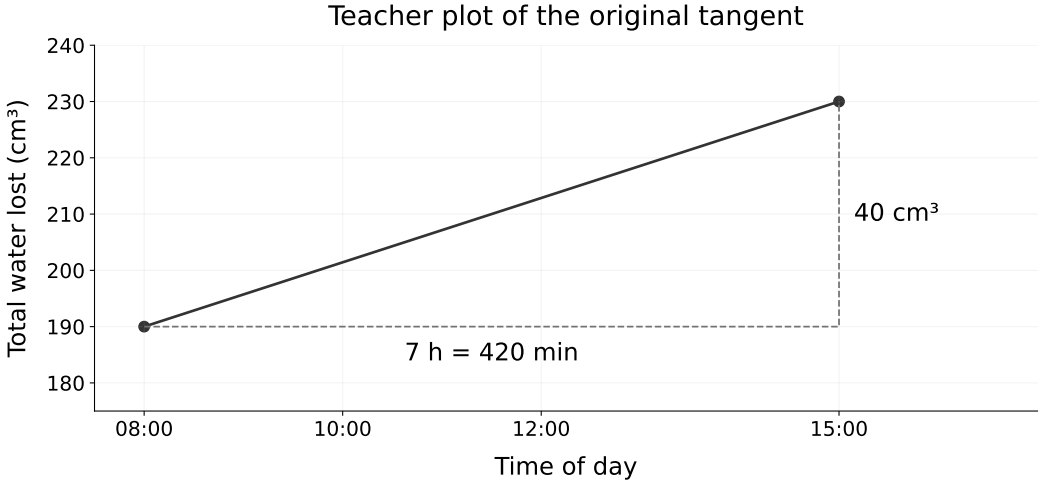
Stomata through the day. Stomata open in the light, letting in carbon dioxide for photosynthesis, and close in the dark, when photosynthesis cannot happen, to reduce water loss.

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Mean width of stomata through the day (arbitrary units): solid line in normal air, dashed line in low carbon dioxide (AQA GCSE Biology Paper 1H, June 2022, Figure 7)

Worked example 5 (HT): rate from a tangent. A graph shows the total volume of water lost by a plant against time of day. To find the rate at 12:00, draw a tangent to the curve at 12:00 and read two points far apart on it: 190 cm^3 at 08:00 and 230 cm^3 at 15:00. Rate $= \frac{230-190}{7\times60} = \frac{40}{420} = 0.0952$ cm^3/min, or 9.52×10^{-2} cm^3/min in standard form.



The tangent at 12:00 passes through 190 cm^3 at 08:00 and 230 cm^3 at 15:00, so its gradient is 40 cm^3 in 7 hours

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Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.2 Organisation, and the required practical handbook.
- C. N. Barnard, "The operation. A human cardiac transplant", *South African Medical Journal* 41 (30 December 1967), pages 1271 to 1274.
- AQA, *GCSE Biology* Paper 1 Higher (June 2021 to June 2025), the amylase, heart disease, stomata and transpiration questions, adapted.

Common errors

- Calling the stomach a tissue; it is an organ made of several tissues.
- Saying enzymes are "killed"; they are denatured.
- Saying bile is an enzyme or that it digests fat; it neutralises acid and emulsifies fat.
- Saying arteries carry oxygenated blood; they carry blood away from the heart.
- Writing that the left ventricle is thicker "because the body is further away"; it pumps at higher pressure.
- Saying a correlation proves cause.
- Mixing up benign and malignant tumours.
- Saying xylem carries sugar or that phloem carries water.
- Saying transpiration increases in humid air.

Key terms

- **Enzyme**: a protein that speeds up a reaction without being used up.
- **Active site**: the part of an enzyme that the substrate fits into.
- **Denaturation**: a permanent change in the shape of an enzyme's active site.
- **Double circulation**: blood passes through the heart twice in each complete circuit.
- **Coronary heart disease**: narrowing of the coronary arteries by fatty material.
- **Risk factor**: something linked to a higher chance of getting a disease.
- **Malignant tumour**: a tumour that invades tissues and spreads to form secondary tumours.
- **Transpiration**: the loss of water vapour from a plant's leaves.
- **Translocation**: the movement of dissolved sugars through the phloem.

Check yourself

1. Name the enzyme that digests protein, and the products.
2. Give the two functions of bile.
3. Describe the test for starch and the positive result.

4. Name the blood vessel that carries blood from the left ventricle, and explain why the left ventricle wall is thicker than the right.
5. Give two ways capillaries are adapted for exchange.
6. Give one benefit and one drawback of a heart transplant.
7. Explain why transpiration is faster on a windy day.

Answers: 1. Protease; amino acids. 2. It neutralises stomach acid, giving alkaline conditions for the enzymes in the small intestine; it emulsifies fats, giving a larger surface area for lipase. 3. Add iodine solution; it turns from orange-brown to blue-black. 4. The aorta; the left ventricle pumps blood at higher pressure all round the body. 5. Walls one cell thick, giving a short diffusion distance; a huge number of them, giving a large surface area. 6. Benefit: it replaces a heart that has failed; drawback: the body may reject it, so the patient needs drugs for life (or there are too few donors). 7. The wind blows away moist air near the leaf, keeping the water vapour concentration gradient steep, so water vapour diffuses out faster.

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3 · Infection and response

AQA · GCSE · Biology

Infection and response: the war inside

Why it matters. On 14 May 1796 the English doctor Edward Jenner took fluid from a cowpox blister on the hand of a milkmaid, Sarah Nelmes, and scratched it into the arm of an eight-year-old boy, James Phipps. Six weeks later he exposed the boy to smallpox, a disease that killed about three in every ten people it infected. James did not become ill. Jenner called his method vaccination, from *vacca*, the Latin word for cow. After a worldwide vaccination campaign, the World Health Organization declared on 8 May 1980 that smallpox had been eradicated: the only human disease ever wiped out. This topic explains how pathogens cause disease, how the body defends itself, and how vaccines, antibiotics and new drugs help.

In this unit you will:

- name the four types of pathogen and describe how diseases spread and can be controlled;
- describe named diseases of humans and plants;
- explain how the body's defences and white blood cells protect us, and how vaccination works;
- describe antibiotics, painkillers and how new drugs are tested;
- (biology only) explain how monoclonal antibodies are made and used, and how plants are affected by disease.

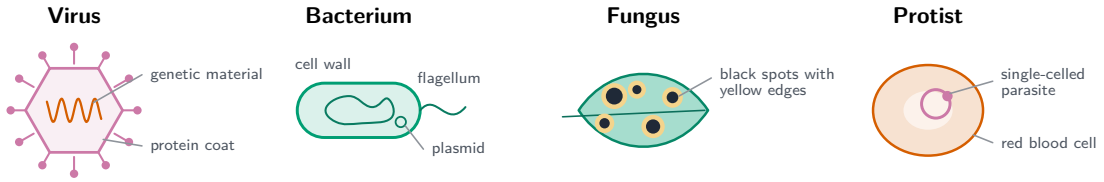
AQA GCSE Biology (8461), topic 4.3 Infection and response, examined on Paper 1. Monoclonal antibodies and plant disease are biology only; content marked (HT) is Higher tier only.

Pathogens and how diseases spread

Pathogens 病原体 are microorganisms that cause **infectious disease** 传染病. There are four types:

- **bacteria** 细菌, which reproduce quickly and may release **toxins** 毒素 (poisons) that damage tissues;
- **viruses** 病毒, which live and reproduce inside **host cells** 宿主细胞, damaging them when they burst out;
- **protists** 原生生物, single-celled organisms such as the one that causes malaria;
- **fungi** 真菌, some of which grow as threads or spread by spores.

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reproduces inside body cells and damages them

measles, HIV, tobacco mosaic virus

reproduces quickly; some make toxins that damage tissues

salmonella, gonorrhoea

spores spread in water or by wind; less photosynthesis

rose black spot

spread by mosquitoes (a vector); recurring fevers

malaria

not to scale: a virus is about a hundred times smaller than a bacterium

The four types of pathogen: virus, bacterium, protist and fungus (not to scale)

Pathogens spread in three main ways: through the air in droplets from coughs and sneezes, through water or food, and by direct contact, including body fluids. Some are carried by a **vector** 传播媒介, an animal that carries a pathogen from one host to another without being ill itself.

Reducing spread. Choose a method that blocks the route:

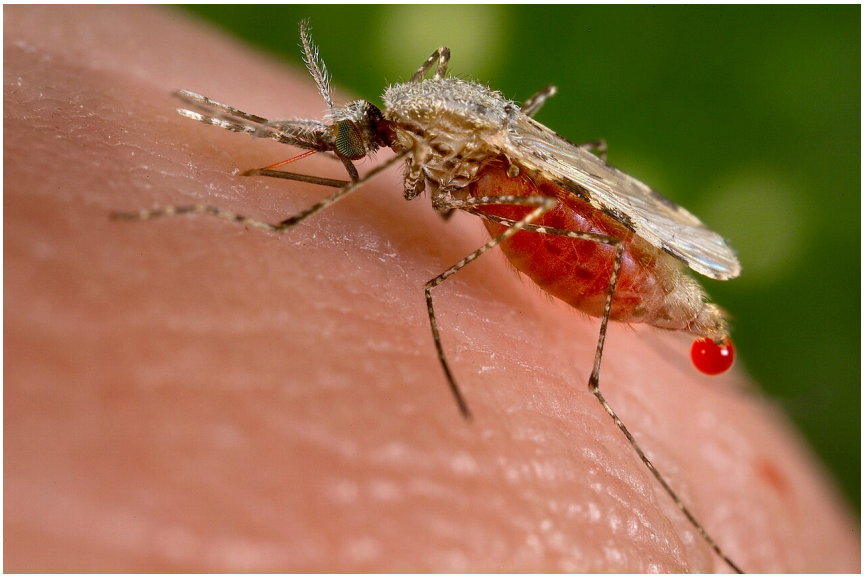
- hygiene, such as washing hands and covering coughs;
- isolating infected people, animals or plants;
- destroying or controlling vectors;
- vaccination.

Named diseases

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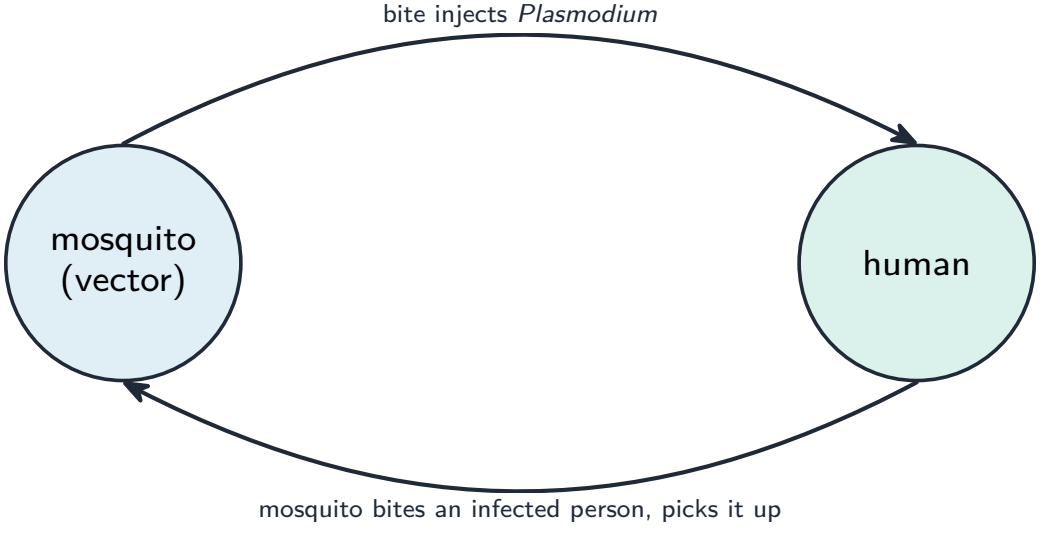
Disease	Pathogen	How it spreads	Symptoms	Control
Measles	virus	droplets from coughs and sneezes	fever and a red skin rash; can be fatal	vaccinating young children
HIV	virus	sexual contact; sharing needles	flu-like illness at first; it then attacks the immune system, leading to AIDS	antiretroviral drugs; condoms; clean needles
Tobacco mosaic virus (TMV)	virus (plants)	contact between plants	a mosaic of pale patches on the leaves, so less photosynthesis and growth	resistant varieties; removing infected plants
Salmonella food poisoning	bacterium	eating food prepared in unhygienic conditions	fever, stomach cramps, vomiting and diarrhoea, caused by the bacteria and their toxins	vaccinating poultry; cooking food thoroughly
Gonorrhoea	bacterium	sexual contact	thick yellow or green discharge; pain when urinating	antibiotics (many strains are now resistant); condoms
Rose black spot	fungus (plants)	spores carried by wind and water	purple or black spots on leaves, which turn yellow and fall early	fungicides; removing and burning infected leaves
Malaria	protist	mosquito bites	repeated bouts of fever; can be fatal	mosquito nets; insecticide; draining standing water where mosquitoes breed

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A female Anopheles mosquito: the vector that carries the malaria protist from person to person

In malaria, the mosquito is the vector and the protist is the pathogen. A mosquito that bites an infected person takes in the protist and can pass it on with its next bite.



Malaria needs a mosquito vector: the parasite passes from human to mosquito to human with each bite – which is why control targets the mosquito

Worked example 1. TMV makes parts of the leaves pale. Explain why infected plants grow less. The pale parts have less chlorophyll, so less light is absorbed and less photosynthesis happens. The plant makes less glucose for respiration and for building new cells, so it grows less.

Worked example 2. In the UK, poultry are vaccinated against Salmonella. Explain how this reduces food poisoning in humans. The vaccinated birds make antibodies, so if they are infected later they destroy the bacteria quickly. Fewer bacteria get into eggs and meat, so fewer people swallow them.

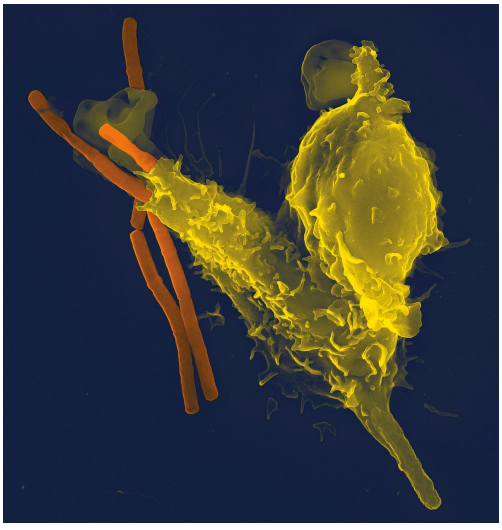
The body's defences

Non-specific defences stop pathogens getting in.

- The skin is a barrier, and scabs seal cuts.
- Hairs and **mucus** 黏液 in the nose trap particles.
- In the trachea and bronchi, mucus traps pathogens and tiny hairs called **cilia** 纤毛 sweep it up to the throat, where it is swallowed.
- **Hydrochloric acid** 盐酸 in the stomach kills most pathogens in food and drink.

White blood cells. If pathogens get in, **white blood cells** 白细胞 attack them in three ways:

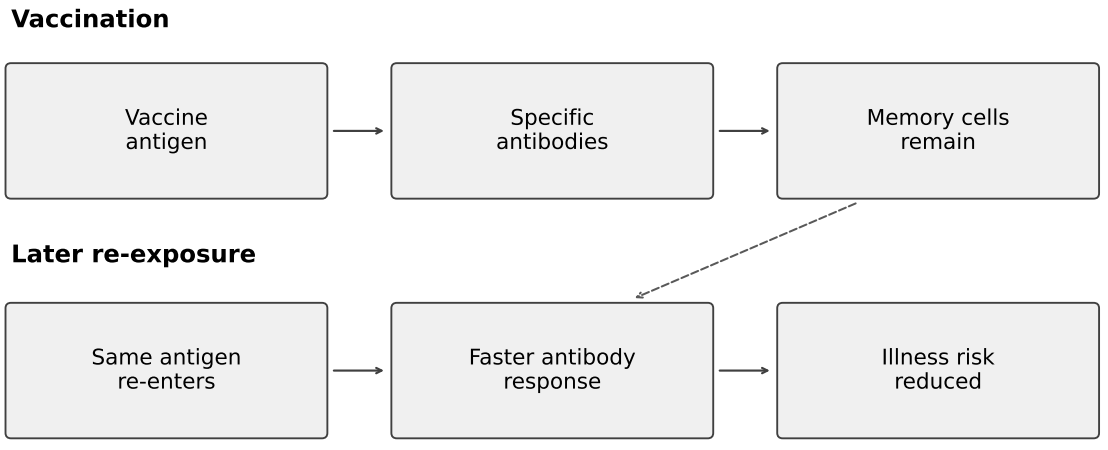
- **phagocytosis** 吞噬: some white blood cells engulf pathogens and digest them;
- **antibody production** 产生抗体: some make antibodies, proteins that fit a particular **antigen** 抗原 on the pathogen's surface, sticking pathogens together and marking them for destruction;
- **antitoxin production** 产生抗毒素: some make antitoxins, which neutralise the toxins released by bacteria.



A phagocyte (yellow) engulfing bacteria: white blood cells ingest pathogens

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Vaccination. Vaccination 疫苗接种 puts a small amount of a dead or inactive form of a pathogen into the body. Its antigens make white blood cells produce the matching antibodies, and **memory cells** 记忆细胞 stay in the blood. If the real pathogen enters later, the memory cells make the right antibodies quickly and in large amounts, so the pathogen is destroyed before it causes illness.

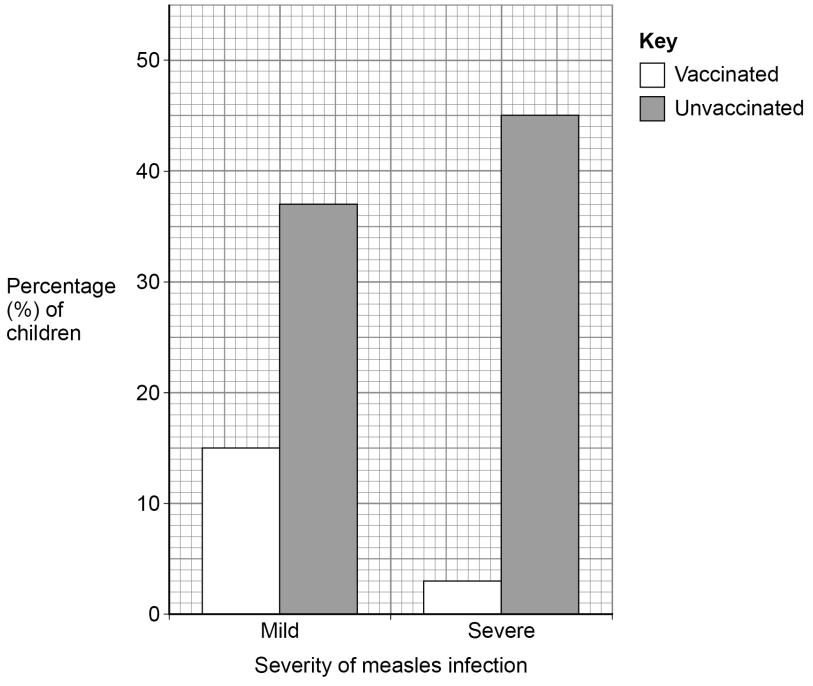


After vaccination, memory cells make antibodies faster and in larger amounts when the pathogen returns

When most people in a population are vaccinated, a pathogen has few people it can infect and pass on from, so even the unvaccinated are less likely to meet it. This is called herd immunity.

Worked example 3. A survey of 240 children with measles recorded whether each had been vaccinated and how ill they became. Of all the children, 3% were vaccinated with severe illness and 45% were unvaccinated with severe illness. How many children were unvaccinated with severe illness? $\frac{45}{100} \times 240 = 108$ children. The data support the idea that vaccination reduces severe illness, although some vaccinated children still caught measles.

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Measles severity in vaccinated and unvaccinated children, as percentages of all 240 children surveyed (AQA GCSE Biology Paper 1H, June 2025, Figure 1)

Antibiotics, painkillers and new drugs

Antibiotics 抗生素, such as penicillin, kill bacteria inside the body. Each one works on particular bacteria, so doctors must choose the right one. Antibiotics do not affect viruses, which live inside our cells, so they cannot cure a cold or flu. **Painkillers** 止痛药 such as paracetamol relieve symptoms but do not kill pathogens.

Antibiotic resistance. A random **mutation** 突变 can make one bacterium resistant to an antibiotic. When the antibiotic is used, the bacteria that are not resistant die, but the resistant ones survive and reproduce, so the resistant strain spreads. To slow this, doctors should not prescribe antibiotics for viral infections, and patients should finish the course.

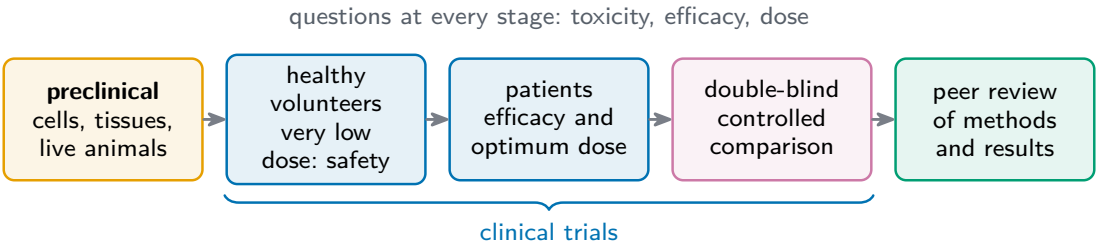
Where drugs come from. Many drugs were first found in living things: digitalis, a heart drug, from foxgloves; aspirin, a painkiller, from willow bark; and penicillin, discovered by Alexander Fleming in 1928, from *Penicillium* mould. Most new drugs are now made by chemists in laboratories.

Testing new drugs. A new drug is tested for three things: **toxicity** 毒性 (is it harmful?), **efficacy** 疗效 (does it work?) and **dose** 剂量 (how much should be given?).

1. **Preclinical** 临床前 testing: on cells, tissues and live animals in the laboratory.
2. Clinical trials on healthy volunteers, starting with a very low dose, to check that it is safe.

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3. Trials on patients, to find out whether it works and the best dose.
4. Results are checked by other scientists through **peer review** 同行评审 before they are published.



Each stage asks about toxicity, efficacy and dose before the next begins.

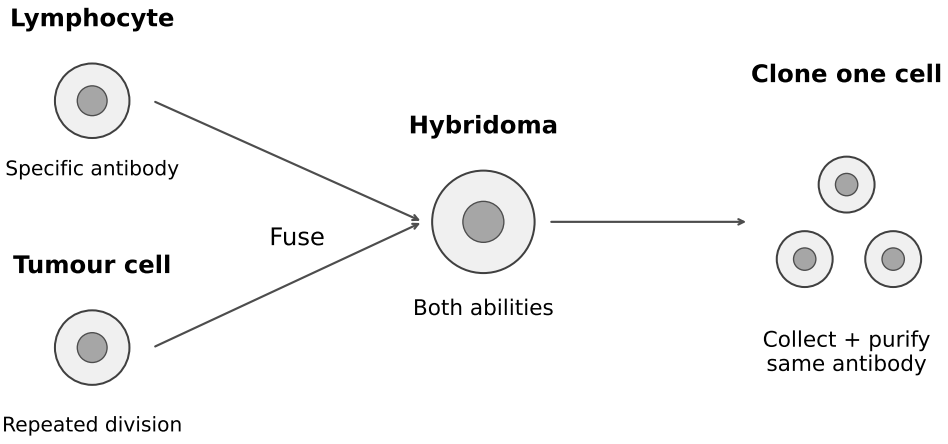
In a clinical trial, some patients get the drug and others get a **placebo** 安慰剂, a dummy with no drug in it, so that the effect of the drug can be compared with the effect of simply expecting to get better. In a **double-blind** 双盲 trial neither the patients nor the doctors know who has the drug, so their expectations cannot affect the results.

Monoclonal antibodies (biology only, HT)

Monoclonal antibodies 单克隆抗体 are identical antibodies made by a **clone** 克隆 of identical cells. They all bind to one particular antigen, so they can find one chemical or one type of cell.

How they are made.

1. A mouse is injected with the chosen antigen, so that its **lymphocytes** 淋巴细胞 (a kind of white blood cell) make the matching antibody.
2. A lymphocyte is fused with a tumour cell, which divides again and again. The fused cell is a **hybridoma** 杂交瘤: it makes the antibody and keeps dividing.
3. One hybridoma is cloned to make many identical cells, all making the same antibody.
4. The antibodies are collected and purified.

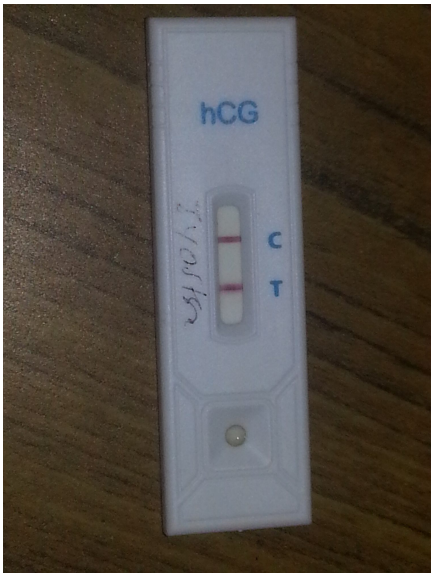


Making monoclonal antibodies: a lymphocyte fuses with a tumour cell, and the hybridoma is cloned

Uses.

- **Diagnosis**: pregnancy tests detect the hormone HCG in urine; other tests detect pathogens or measure hormone levels in blood.
- **Research**: antibodies with a fluorescent dye attached show where a particular molecule is in a cell or tissue.
- **Treatment**: an antibody carrying a drug or radioactive substance binds to cancer cells, delivering it to them and less to normal cells.

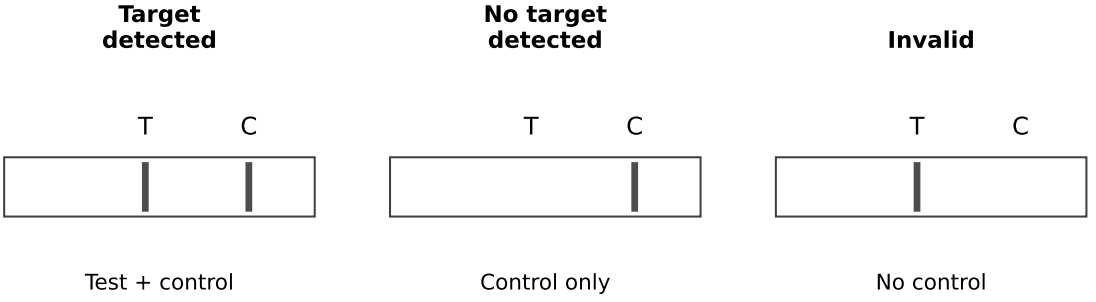
Monoclonal antibodies have caused more side effects than expected, so they are not yet as widely used as was first hoped.



A pregnancy test: monoclonal antibodies bind the hormone HCG, so a line appears

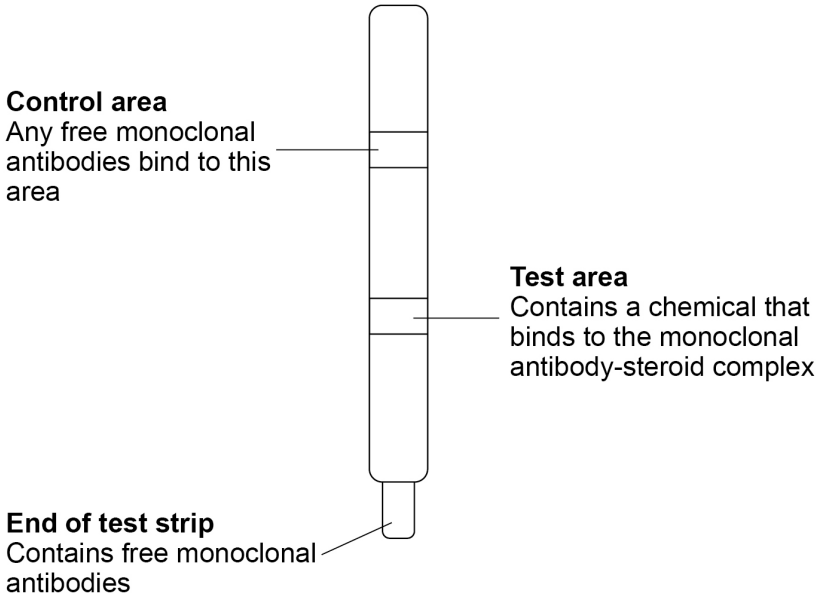
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How a pregnancy test works. The tip of the stick holds antibodies, attached to a coloured bead, that bind HCG. Urine carries them along the strip. At the test line (T), fixed antibodies catch the HCG with its coloured antibodies attached, so a line appears only if HCG is present. At the control line (C), other fixed antibodies catch the free coloured antibodies, so a line always appears if the test has worked.



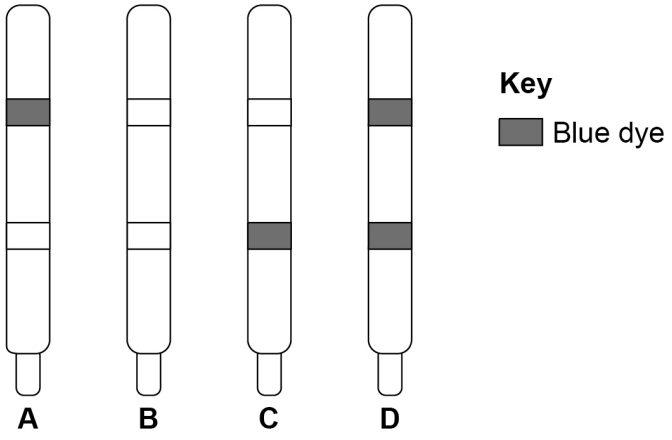
A test strip: a line at T means the target was found; the line at C shows the test worked

Worked example 4. Four drug tests on athletes give these results: A has only the control line; B has no lines; C has only the test line; D has both lines. D is positive. A is negative. B and C are not valid, because their control lines did not appear, so the liquid did not flow properly or the antibodies were missing; these tests must be repeated.



A steroid test: the test area catches antibody bound to steroid; the control area catches free antibody (AQA GCSE Biology Paper 1H, June 2023, Figure 5)

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Test results for athletes A to D; grey shows blue dye (AQA GCSE Biology Paper 1H, June 2023, Figure 6)

Plant diseases and defences (biology only)

Signs of disease. Signs that a plant is unhealthy include stunted growth, spots on leaves, areas of decay, growths, a malformed stem or leaves, discolouration and visible pests. To identify the cause you can use a gardening book or website, send a sample to a laboratory, or (HT) use a test kit containing monoclonal antibodies against a particular pathogen.

Plants can be infected by **TMV** 烟草花叶病毒 and **rose black spot** 玫瑰黑斑病, and attacked by insects such as **aphids** 蚜虫, which suck sap from the phloem.

Mineral deficiencies. A **deficiency** 缺乏症 of a mineral ion also causes symptoms.

Missing ion	Why the plant needs it	Effect
nitrate	to make amino acids and proteins	stunted growth
magnesium	to make chlorophyll	yellow leaves, called **chlorosis** 缺绿, and less photosynthesis

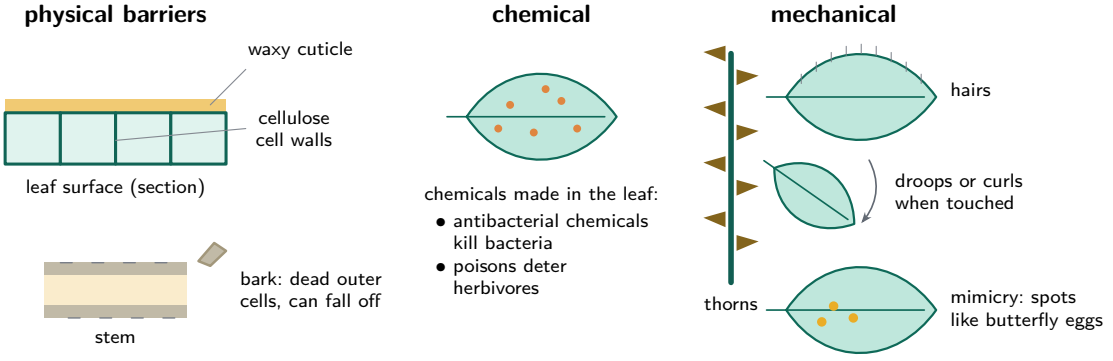
Worked example 5. A rose has purple spots and is losing leaves, while a second plant has yellow leaves with no spots. The first probably has rose black spot. The second may lack magnesium, which is needed for chlorophyll, or it may not be getting enough light. More evidence, such as a soil test, is needed to be sure.

Plant defences.

- Physical: cellulose cell walls, a tough **waxy cuticle** 蜡质角质层 on leaves, and a layer of dead cells (bark) on stems, which falls off with any pathogens on it.
- Chemical: antibacterial chemicals, and poisons that put off **herbivores** 食草动物.

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- Mechanical: thorns and hairs that stop animals eating the plant, leaves that droop or curl when touched, and mimicry, looking like something an animal will avoid.



Physical, chemical and mechanical plant defences; schematic, not to scale.

Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.3 Infection and response.
- E. Jenner, *An Inquiry into the Causes and Effects of the Variolae Vaccinae* (London, 1798), Case XVII (James Phipps).
- World Health Organization, *Declaration of global eradication of smallpox*, World Health Assembly resolution WHA33.3 (8 May 1980).
- AQA, *GCSE Biology* Paper 1 Higher (June 2023 to June 2025), the measles, Salmonella and steroid-test questions, adapted.

Common errors

- Saying antibiotics kill viruses.
- Saying the mosquito causes malaria; it is the vector, and the protist is the pathogen.
- Writing “toxins cause the symptoms” without saying that the bacteria release them.
- Saying antibodies “kill” pathogens directly; they bind to antigens, and other white blood cells then destroy the pathogens.
- Saying bacteria “become resistant because they need to”; resistance arises by random mutation and natural selection.
- Reading a test strip as positive without checking that the control line appeared.
- Saying monoclonal antibody treatments harm no normal cells at all.

Key terms

- **Pathogen**: a microorganism that causes infectious disease.
- **Vector**: an organism that carries a pathogen from one host to another.
- **Antigen**: a molecule on the surface of a pathogen that an antibody binds to.
- **Antibody**: a protein made by white blood cells that binds to a particular antigen.
- **Vaccination**: giving a dead or inactive pathogen to make the body produce memory cells.
- **Placebo**: a dummy treatment with no active drug.
- **Double-blind trial**: a trial in which neither patients nor doctors know who receives the drug.
- **Monoclonal antibodies**: identical antibodies made by a clone of one hybridoma cell.

Check yourself

1. Name the type of pathogen that causes each of these: measles, malaria, gonorrhoea, rose black spot.
2. Explain how cilia and mucus protect the lungs.
3. Describe three ways white blood cells defend the body.
4. Explain why a vaccinated person does not become ill when the pathogen enters their body.
5. Explain why doctors should not give antibiotics for a cold.
6. Why do drug trials give some patients a placebo?
7. (HT) Why is a lymphocyte fused with a tumour cell when making monoclonal antibodies?

Answers: 1. Virus; protist; bacterium; fungus. 2. Mucus traps pathogens and cilia sweep the mucus up to the throat, where it is swallowed. 3. Engulfing pathogens (phagocytosis); making antibodies; making antitoxins. 4. Memory cells make the matching antibodies quickly, so the pathogen is destroyed before it can cause illness. 5. A cold is caused by a virus, which antibiotics do not affect, and unnecessary use helps resistant bacteria spread. 6. To compare the drug's effect with the effect of expecting to get better. 7. The lymphocyte makes the antibody but does not keep dividing; the tumour cell divides again and again, so the hybridoma does both.

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4 · Bioenergetics

AQA · GCSE · Biology

Bioenergetics: photosynthesis and respiration

Why it matters. On 17 August 1771 the English chemist Joseph Priestley put a sprig of mint into a sealed glass jar in which a candle had burned until it went out. Air that had "been injured" by the candle, he wrote, could not keep a candle alight or a mouse alive. Ten days later he lit a candle in the jar again, and it burned perfectly well. The plant had "restored" the air. In 1779 the Dutch doctor Jan Ingenhousz showed that plants do this only in the light. We now know the plant was making oxygen by photosynthesis, the process that supplies almost all the food and oxygen on Earth, while every living cell, plant or animal, uses that oxygen to release energy by respiration.

In this unit you will:

- write the equations for photosynthesis and respiration, and explain where the energy comes from;
- explain how light, carbon dioxide and temperature limit the rate of photosynthesis;
- describe how plants use the glucose they make;
- compare aerobic and anaerobic respiration, and explain how the body responds to exercise;
- describe metabolism as the sum of all the reactions in a cell.

AQA GCSE Biology (8461), topic 4.4 Bioenergetics, examined on Paper 1. It includes required practical 6: the effect of light intensity on the rate of photosynthesis. Content marked (HT) is Higher tier only, including graphs with more than one limiting factor, the inverse square law and the cost of greenhouse heating and lighting.

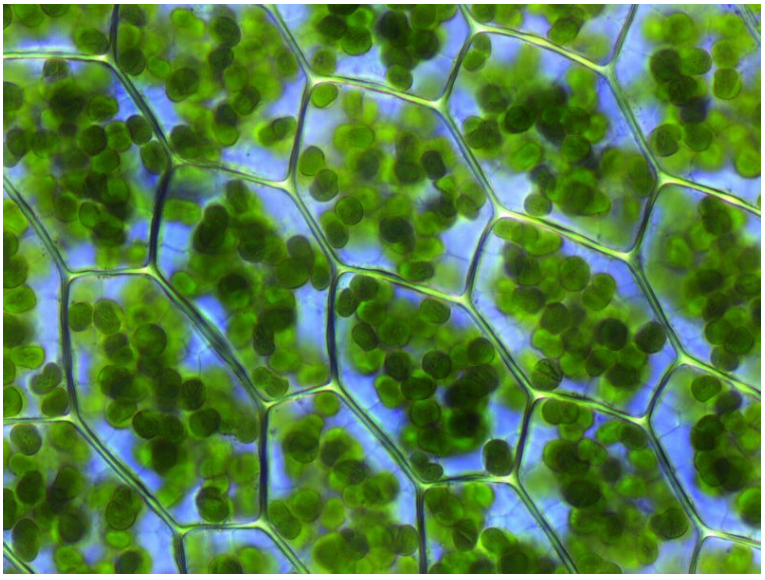
Photosynthesis

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

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

Photosynthesis 光合作用 happens in the **chloroplasts** 叶绿体 of plant cells and algae. Green **chlorophyll** 叶绿素 absorbs light energy, which is used to turn carbon dioxide and water into **glucose** 葡萄糖, with oxygen as a by-product. Photosynthesis is an **endothermic** 吸热 reaction: energy is transferred from the surroundings, as light, to the chloroplasts.

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Chloroplasts packed inside moss leaf cells: the green chlorophyll absorbs light for photosynthesis

Worked example 1. Three leaves on a plant were treated for two days: leaf A was covered with black paper, leaf B was sealed in a clear plastic bag with a chemical that absorbs carbon dioxide, and leaf C was left uncovered. Only leaf C then contained **starch** 淀粉 when tested with iodine. Explain. Leaf A had no light and leaf B had no carbon dioxide, so neither could photosynthesise. They made no glucose, so none was turned into starch. Leaf C had both, so it made glucose and stored some as starch.

The rate of photosynthesis

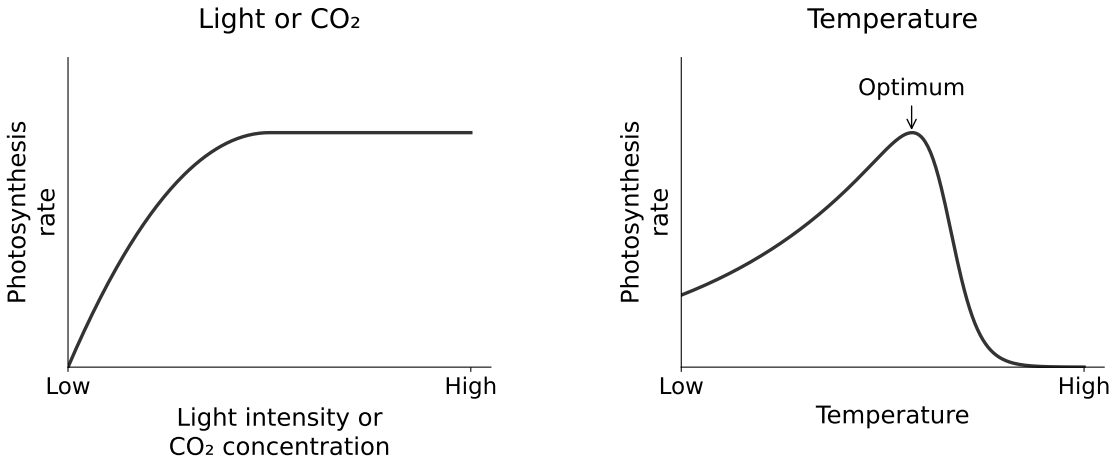
Four factors can affect the rate of photosynthesis:

- **light intensity** 光照强度, because light supplies the energy;
- carbon dioxide concentration, because carbon dioxide is a reactant;
- temperature, because photosynthesis is controlled by enzymes;
- the amount of chlorophyll, because chlorophyll absorbs the light.

A **limiting factor** 限制因素 is the one in short supply that stops the rate going any higher. On a graph of rate against light intensity, the rate rises at first, so light is limiting. Then the line levels off: more light makes no difference, because something else, such as carbon dioxide or temperature, is now limiting.

Temperature is different. The rate increases up to an **optimum** 最适温度 temperature, then falls quickly, because the enzymes **denature** 变性.

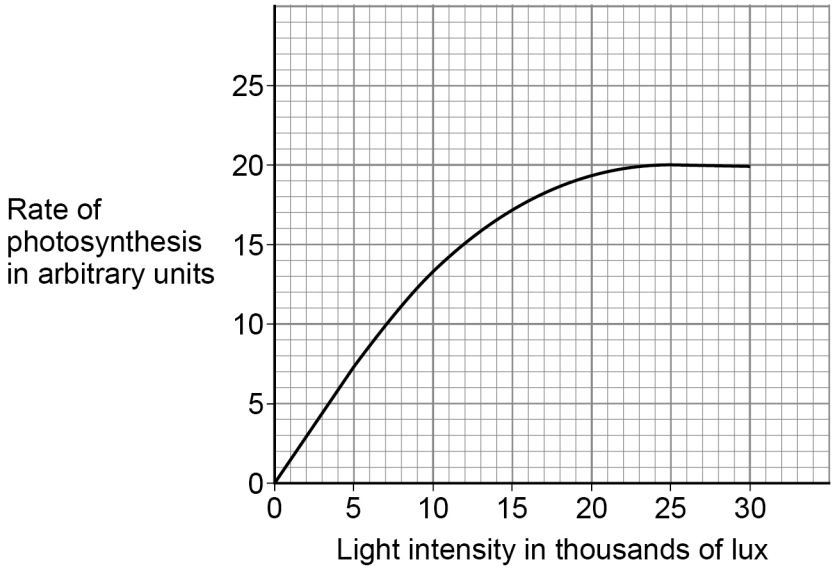
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Rate rises with light intensity or carbon dioxide until another factor limits it; with temperature it rises to an optimum, then falls as enzymes denature

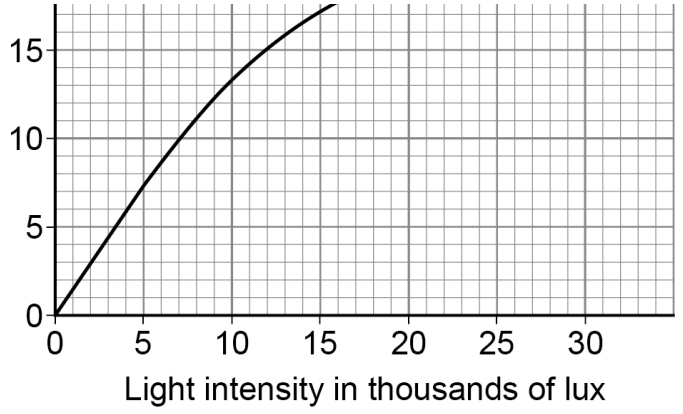
Reading the graph. On the graph below, the rate increases steadily with light intensity up to about 5000 lux: the straight part is the region where light limits the rate. Above that, the rate levels off. Check the axis labels: here the light intensity is in thousands of lux.

Figure 8



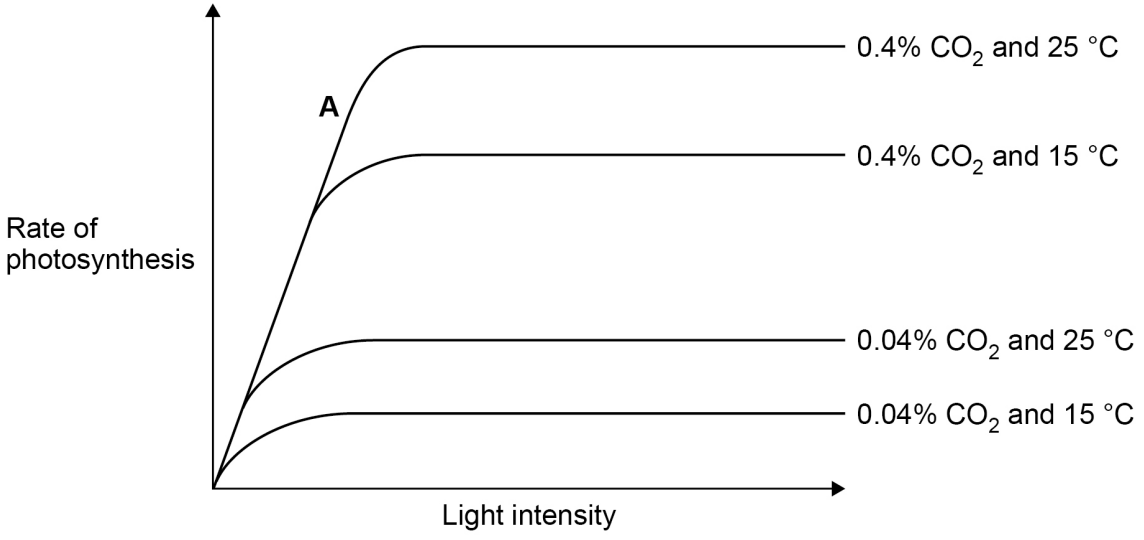
Rate of photosynthesis against light intensity in thousands of lux (AQA GCSE Biology Paper 1H, June 2023, Figure 8)

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The straight part of the same graph, enlarged

Several limiting factors (HT). When a graph shows several curves, compare two at a time, changing only one condition. If raising the carbon dioxide concentration from 0.04% to 0.4%, at the same temperature, raises the level of the plateau, then carbon dioxide was limiting at the lower concentration. If raising the temperature from 15 °C to 25 °C, at the same carbon dioxide concentration, also raises it, then temperature was limiting.



Rate of photosynthesis against light intensity at two temperatures and two carbon dioxide concentrations (AQA GCSE Biology Paper 1H, June 2024, Figure 7)

The inverse square law (HT). Light intensity falls with distance from a lamp according to the **inverse square law** 平方反比定律:

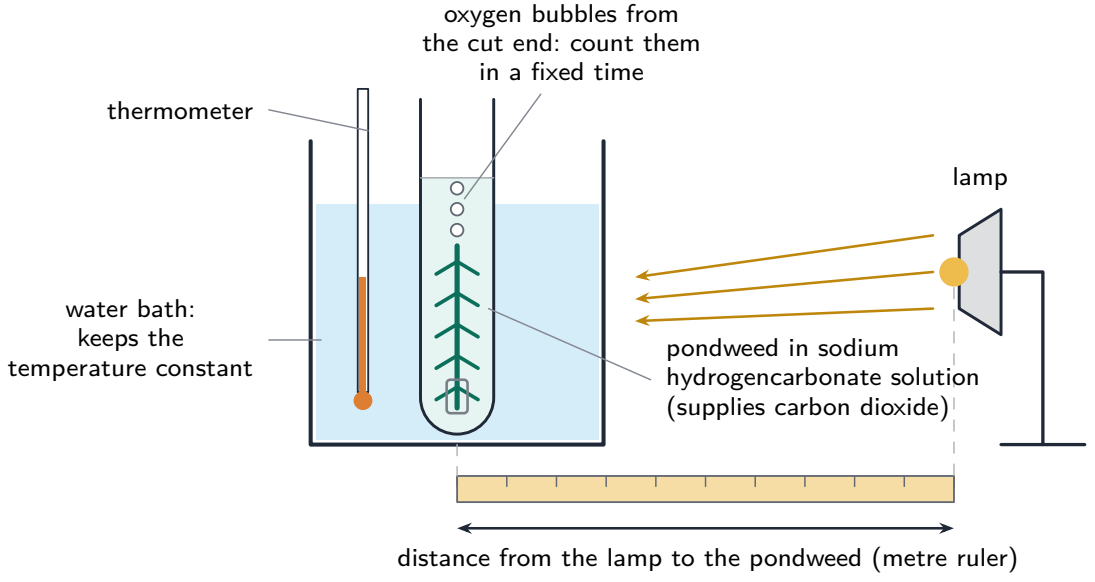
$$\text{light intensity} \propto \frac{1}{\text{distance}^2}$$

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Worked example 2 (HT). A lamp is moved from 15 cm to 45 cm from a plant. The distance is 3 times greater, so the light intensity becomes $\frac{1}{3^2} = \frac{1}{9}$ of what it was.

Greenhouses (HT). Growers can add artificial light, heating or extra carbon dioxide, for example from paraffin heaters. Each costs money, and it pays only if the extra crop is worth more than the extra cost. It is wasted if a different factor is limiting.

Required practical 6: light intensity and photosynthesis. Put a piece of **pondweed** 水草 in a boiling tube of **sodium hydrogencarbonate** 碳酸氢钠 solution, which supplies carbon dioxide. Place a lamp at a measured distance, wait a few minutes, then count the oxygen bubbles released in one minute. Repeat at several distances. Keep the temperature constant (a beaker of water between the lamp and the tube helps), and use the same piece of pondweed. Repeat each distance and calculate a mean. Collecting the gas in a measuring cylinder or gas syringe and measuring its volume is more accurate than counting bubbles, which may be different sizes.



Counting oxygen bubbles from pondweed at a measured distance from a lamp (not to scale)

Worked example 3. A student investigated temperature, the **independent variable** 自变量. The **dependent variable** 因变量 was the time for the pondweed to produce 10 bubbles.

Temperature / °C	**10**	**20**	**30**	**40**	**50**
Time for 10 bubbles / s	84	43	27	25	33

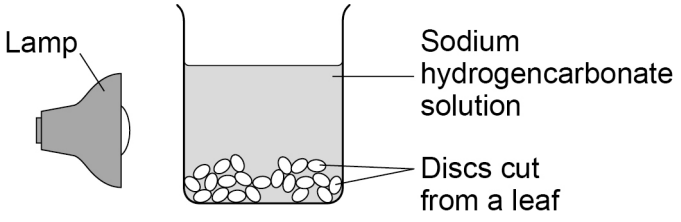
At 20 °C, the rate $= \frac{10}{43} = 0.233$ bubbles per second. A shorter time means a faster

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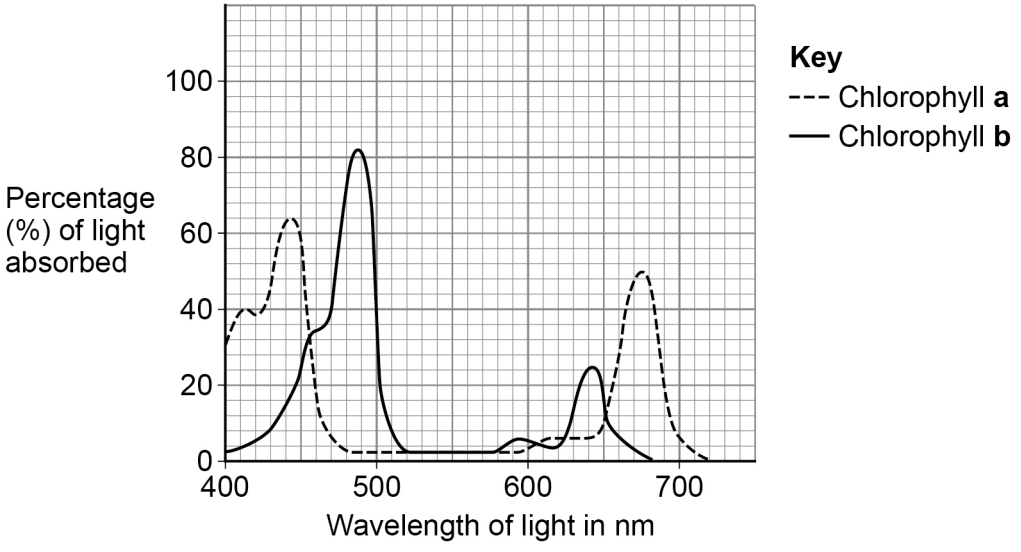
rate, so the rate was fastest at 40 °C. Between 10 °C and 40 °C the rate rises because the molecules move faster and the enzymes work faster; at 50 °C it falls as the enzymes begin to denature. The true optimum lies somewhere between 30 °C and 50 °C.

Light colour. In a related experiment, small discs cut from leaves sink in sodium hydrogencarbonate solution, then float as they photosynthesise, because oxygen collects in them. Discs in blue light rose in 115 s, in red light in 397 s and in green light in 831 s. Chlorophyll absorbs blue and red light well but reflects most green light, which is why leaves look green, so little photosynthesis happens in green light. Light colour is set by its **wavelength** 波长.

Figure 9



Leaf discs in sodium hydrogencarbonate solution under coloured light (AQA GCSE Biology Paper 1H, June 2023, Figure 9)



Light absorbed by chlorophyll a and chlorophyll b at different wavelengths (AQA GCSE Biology Paper 1H, June 2023, Figure 10)

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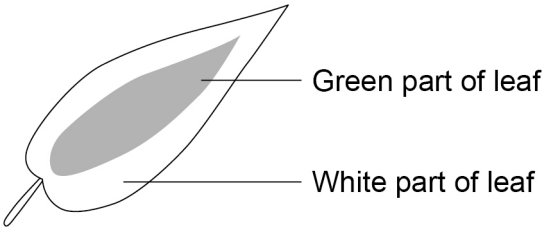
How plants use glucose

The glucose made in photosynthesis is used:

- for respiration, to release energy;
- to make starch, which is insoluble, for storage;
- to make fats and oils for storage, especially in seeds;
- to make **cellulose** 纤维素, which strengthens cell walls;
- to make **amino acids** 氨基酸, which are built into proteins. This also needs **nitrate ions** 硝酸根离子 absorbed from the soil.

Worked example 4. A variegated leaf has green parts and white parts. After two days in the light it is tested with iodine. Predict and explain the result. The green parts turn blue-black, showing starch; the white parts stay orange-brown. The white parts have no chlorophyll, so they cannot photosynthesise and make no glucose to store as starch.

Figure 6



A variegated leaf: the grey part is green and the white part has no chlorophyll (AQA GCSE Biology Paper 1H, June 2024, Figure 6)

Respiration

Respiration 呼吸作用 is a chemical reaction that happens all the time in every living cell, in plants and animals, day and night. It is **exothermic** 放热: it transfers energy that the organism uses for movement, for keeping warm and for building large molecules. Breathing, which moves air in and out of the lungs, is not the same thing as respiration.

Aerobic respiration. **Aerobic respiration** 有氧呼吸 uses oxygen and happens mainly in the **mitochondria** 线粒体.

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

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

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Anaerobic respiration. **Anaerobic respiration** 无氧呼吸 happens without oxygen, in the **cytoplasm** 细胞质. It transfers much less energy, because the glucose is only partly broken down.

- In muscles: glucose → **lactic acid** 乳酸.
- In plant cells and **yeast** 酵母: glucose → **ethanol** 乙醇 + carbon dioxide.

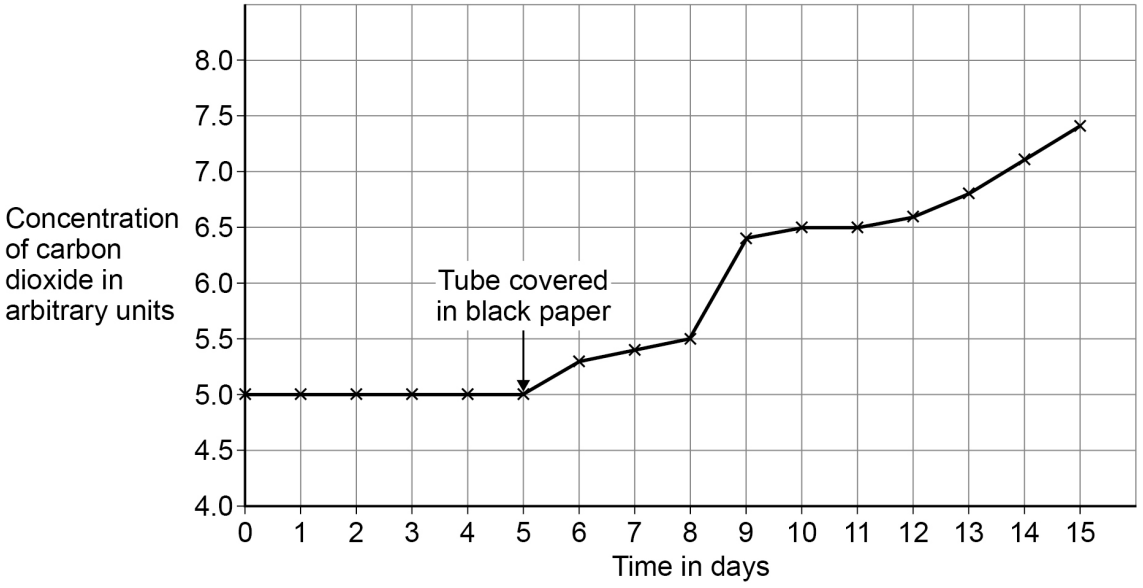
Anaerobic respiration in yeast is called **fermentation** 发酵. It is used to make bread, where the carbon dioxide makes the dough rise, and alcoholic drinks, where ethanol is the product wanted.

	Aerobic	**Anaerobic (muscle)**	**Anaerobic (yeast and plants)**
Needs oxygen?	yes	no	no
Products	carbon dioxide and water	lactic acid	ethanol and carbon dioxide
Energy transferred per glucose	a lot	much less	much less

Worked example 5. A sealed tube contains pondweed, a water snail and a carbon dioxide sensor. It is lit for five days, then covered in black paper; the snail dies on day 10. Explain the readings.

- Days 0 to 5: the carbon dioxide level stays steady. The pondweed takes in carbon dioxide for photosynthesis as fast as both organisms release it by respiration.
- Days 5 to 10: the level rises. In the dark there is no photosynthesis, but both organisms keep respiring.
- After day 10: the level keeps rising, because **decomposers** 分解者 such as bacteria feed on the dead snail and respire.

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Carbon dioxide concentration in the sealed tube over 15 days (AQA GCSE Biology Paper 1H, June 2021, Figure 7)

Response to exercise

During exercise, muscles need more energy, so they respire faster and need more oxygen and glucose. To supply them, the **heart rate** 心率, the **breathing rate** 呼吸频率 and the **breath volume** 呼吸量 all increase.

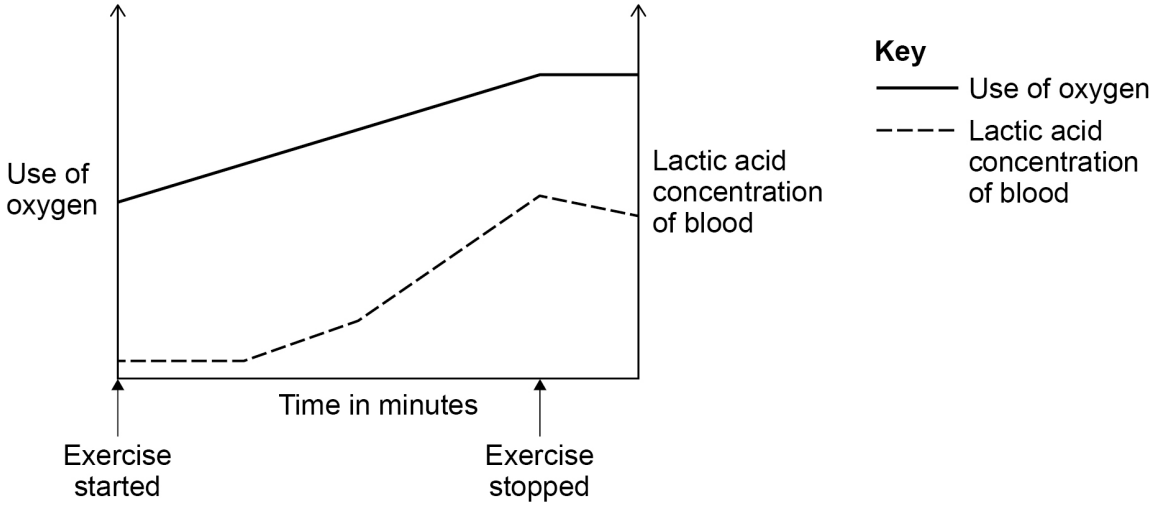
During hard exercise the muscles may not get enough oxygen, so they respire anaerobically as well. Lactic acid builds up, and the muscles become **fatigued** 疲劳: they stop contracting efficiently.



A hard sprint outruns the oxygen supply, so muscles respire anaerobically and build up an oxygen debt

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Oxygen debt (HT). After exercise you keep breathing hard. The **oxygen debt** 氧债 is the extra oxygen needed to react with the lactic acid and remove it from the cells. Blood carries the lactic acid to the **liver** 肝脏, where it is turned back into glucose.



Oxygen use and blood lactic acid during and after exercise; each line has its own vertical scale (AQA GCSE Biology Paper 1H, June 2025, Figure 7)

Worked example 6. Three athletes did exercise A and exercise B on different days, resting until their heart rate returned to normal before each test. Their increases in heart rate were 40, 50 and 30 beats per minute for A, and 60, 70 and 50 beats per minute for B. Mean increase for A $= \frac{40+50+30}{3} = 40$ beats per minute; for B $= \frac{60+70+50}{3} = 60$ beats per minute. Exercise B raised the heart rate more. A fair test uses the same athletes, the same length of exercise and the same way of measuring.

More red blood cells. Training at high altitude increases the number of red blood cells. More red blood cells contain more **haemoglobin** 血红蛋白, so the blood carries more oxygen to the muscles for aerobic respiration.

Metabolism

Metabolism 代谢 is the sum of all the reactions in a cell or in the body. The energy released by respiration is used to build new molecules, in reactions controlled by enzymes:

- glucose is joined into starch, **glycogen** 糖原 (in animals) or cellulose;
- one molecule of **glycerol** 甘油 and three **fatty acids** 脂肪酸 make a **lipid** 脂质 molecule;
- glucose and nitrate ions make amino acids, which are joined into proteins;
- respiration breaks down glucose;

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- excess proteins are broken down to make **urea** 尿素, which is removed from the body by **excretion** 排泄 in urine.

Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.4 Bioenergetics, and the required practical handbook.
- J. Priestley, "Observations on different kinds of air", *Philosophical Transactions of the Royal Society* 62 (1772), pages 147 to 264.
- J. Ingenhousz, *Experiments upon Vegetables* (London, 1779).
- AQA, *GCSE Biology* Paper 1 Higher (June 2021 to June 2025), the limiting-factor, leaf-disc, variegated-leaf and exercise questions, adapted.

Common errors

- Writing light as a reactant in the photosynthesis equation; it is the energy source.
- Saying photosynthesis makes starch directly; it makes glucose, which is then turned into starch.
- Saying the level part of a graph is still limited by light.
- Saying plants photosynthesise instead of respiring; they do both, and respire all the time.
- Saying respiration "makes" energy; it transfers energy.
- Writing that anaerobic respiration in muscles makes carbon dioxide or ethanol.
- (HT) Saying oxygen is used in the liver to turn lactic acid into glucose.

Key terms

- **Photosynthesis**: an endothermic reaction in which light energy is used to make glucose from carbon dioxide and water.
- **Limiting factor**: the factor in shortest supply, which stops the rate increasing.
- **Respiration**: an exothermic reaction in cells that transfers energy from glucose.
- **Aerobic respiration**: respiration using oxygen, making carbon dioxide and water.
- **Anaerobic respiration**: respiration without oxygen, making lactic acid in muscles or ethanol and carbon dioxide in yeast.
- **Oxygen debt**: the extra oxygen needed after exercise to remove lactic acid.
- **Metabolism**: the sum of all the reactions in a cell or body.

Check yourself

1. Write the word equation for photosynthesis.
2. Give four factors that affect the rate of photosynthesis.
3. In RP6, why is a beaker of water placed between the lamp and the pondweed?
4. Give three uses of the glucose made by a plant.
5. Write the word equation for anaerobic respiration in yeast, and give one use.
6. Give three changes in the body during exercise and say why they happen.
7. (HT) A lamp is moved from 20 cm to 10 cm away. By what factor does the light intensity change?

Answers: 1. Carbon dioxide + water → glucose + oxygen (using light energy). 2. Light intensity, carbon dioxide concentration, temperature, amount of chlorophyll. 3. To absorb heat from the lamp, so that the temperature stays constant. 4. Any three of: respiration; starch for storage; fats and oils; cellulose; amino acids. 5. Glucose → ethanol + carbon dioxide; making bread or alcoholic drinks. 6. Heart rate, breathing rate and breath volume increase, to supply more oxygen and glucose to the muscles and remove carbon dioxide. 7. Half the distance, so the intensity is $2^2 = 4$ times greater.

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5 · Homeostasis and response

AQA · GCSE · Biology

Homeostasis and response: keeping conditions steady

Why it matters. On 11 January 1922, at Toronto General Hospital, a 14-year-old boy called Leonard Thompson was given the first injection of insulin ever tried on a human patient. He had Type 1 diabetes and weighed only 30 kg; at that time the disease was always fatal, usually within a year or two. The extract, prepared by Frederick Banting and Charles Best from dog and cattle pancreases, was impure and caused an abscess. Twelve days later the biochemist James Collip had a purer extract ready, and Leonard's blood glucose fell to normal. He lived another 13 years. Insulin is one of the body's chemical messengers that keep conditions inside us steady. This topic is about how the nervous system and hormones detect changes and respond to them, in humans and in plants.

In this unit you will:

- describe how control systems use receptors, coordination centres and effectors;
- explain how the nervous system and reflex arcs work, and measure reaction time;
- (biology only) describe the brain and the eye, and how body temperature is controlled;
- explain how hormones control blood glucose, water balance and the menstrual cycle, and how fertility can be controlled;
- (biology only) explain how plant hormones control growth, and their uses.

AQA GCSE Biology (8461), topic 4.5 Homeostasis and response, examined on Paper 2. It includes required practicals 7 (reaction time) and 8 (the effect of light or gravity on the growth of seedlings, biology only). Content marked (HT) is Higher tier only.

Control systems and the nervous system

Homeostasis 稳态 is the regulation of the conditions inside a cell or organism to keep them at the best level for enzymes and cells to work, whatever changes happen inside or outside. In humans it controls blood glucose concentration, body temperature and water levels.

Every automatic control system has three parts:

- **receptors** 感受器, which detect changes, called **stimuli** 刺激;
- **coordination centres** 协调中枢, such as the brain, the **spinal cord** 脊髓 and the **pancreas** 胰腺, which receive and process the information;
- **effectors** 效应器, muscles or glands, which bring about responses that restore the best conditions.

The nervous system. Information travels along nerve cells, each called a **neurone**

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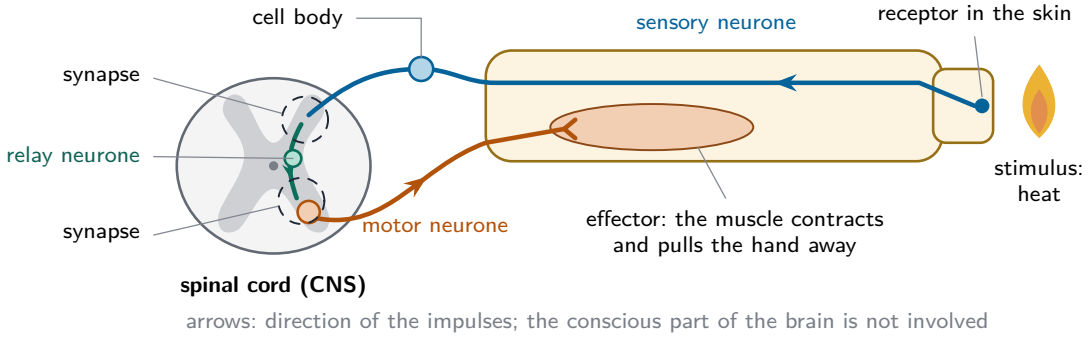
神经元, as **electrical impulses** 电冲动. The central nervous system (CNS), the brain and spinal cord, coordinates the response. The route is:

stimulus → receptor → sensory neurone → CNS → motor neurone → effector → response

Nervous responses are very fast and short-lived. Hormonal responses are usually slower and last longer.

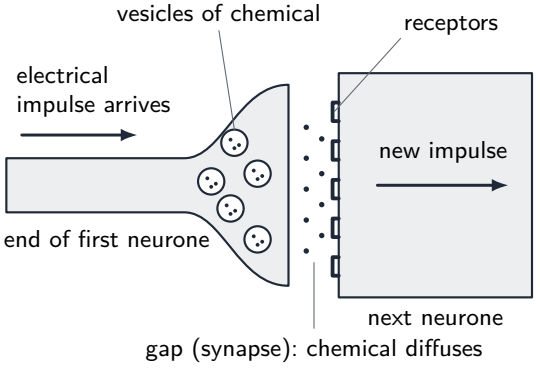
Reflexes. A reflex is an automatic, rapid response that does not involve the conscious part of the brain. It protects the body, for example by pulling a hand away from a hot object. The pathway is called a **reflex arc** 反射弧:

stimulus → receptor → **sensory neurone** 感觉神经元 → **relay neurone** 中间神经元 (in the spinal cord) → **motor neurone** 运动神经元 → effector (a muscle) → response



Spinal withdrawal reflex: impulses pass from the receptor to the effector through the spinal cord; the conscious part of the brain is not involved.

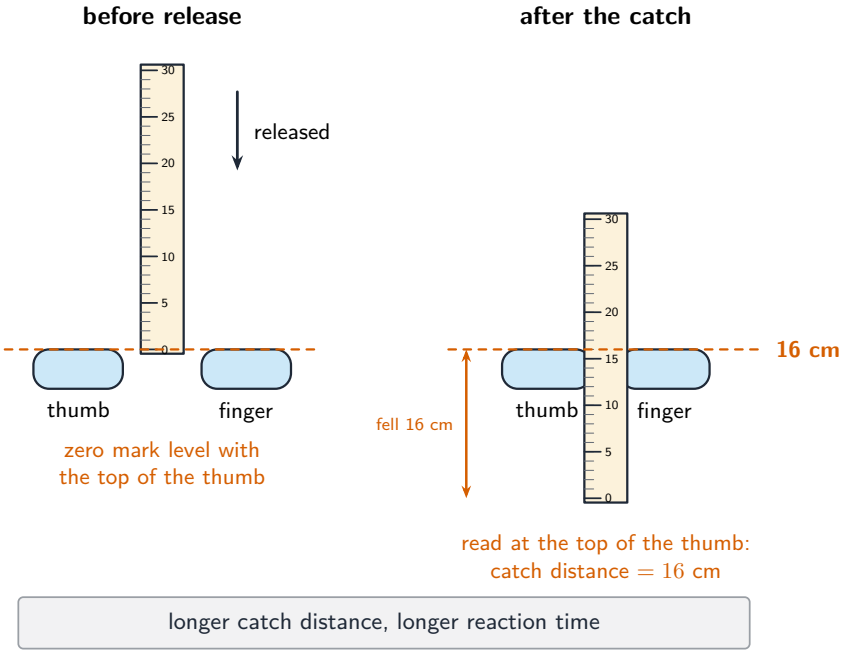
Synapses. Where two neurones meet there is a tiny gap, a **synapse** 突触. When an impulse reaches the end of a neurone, a chemical is released. It diffuses across the gap and starts an impulse in the next neurone.



A chemical crosses the gap and triggers a new electrical impulse in the next neurone.

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Required practical 7: reaction time. One person holds a ruler vertically, with the zero mark level with the top of the other person's thumb. Without warning, they drop it, and the other person catches it as quickly as possible. Record the distance the ruler fell. Repeat several times, always using the same hand and the same starting gap, then test a factor such as listening to music or drinking caffeine. Practice trials first reduce the effect of getting better with practice.



The zero mark starts at thumb level; catch distance is read at the thumb.

Worked example 1. Catch distances were 18, 15, 12, 16, 14, 23 and 14 cm. In order, 12, 14, 14, 15, 16, 18, 23, so the **median** 中位数 is 15 cm. The mean is $112 \div 7 = 16$ cm. Using the equation given, $t = \sqrt{\frac{2d}{980}}$ with d in cm, the mean reaction time is $\sqrt{\frac{2\times16}{980}} = 0.181$ s, or 181 ms.

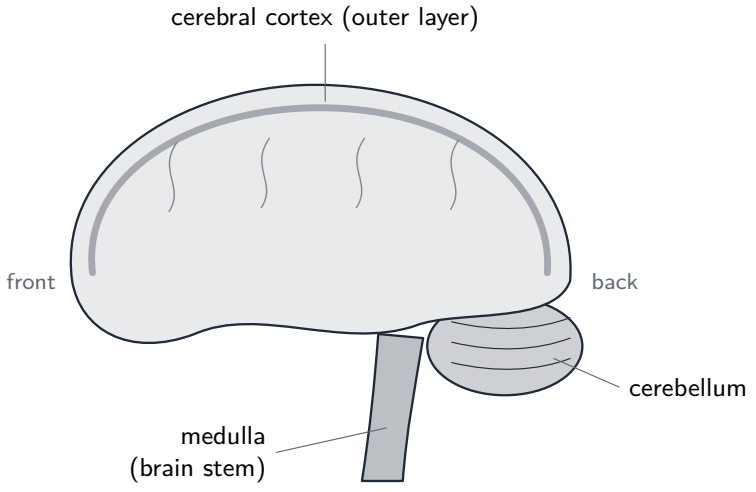
Catching a ruler is not a reflex. The stimulus is detected by the eyes, impulses travel along the optic nerve to the brain, and the brain sends impulses along motor neurones to the hand muscles.

The brain (biology only)

The brain controls complex behaviour. It is made of billions of connected neurones, and different regions do different jobs:

- the **cerebral cortex** 大脑皮层: consciousness, intelligence, memory and language;
- the **cerebellum** 小脑: balance and muscle coordination;

- the **medulla** 延髓: unconscious activities such as the heartbeat and breathing.



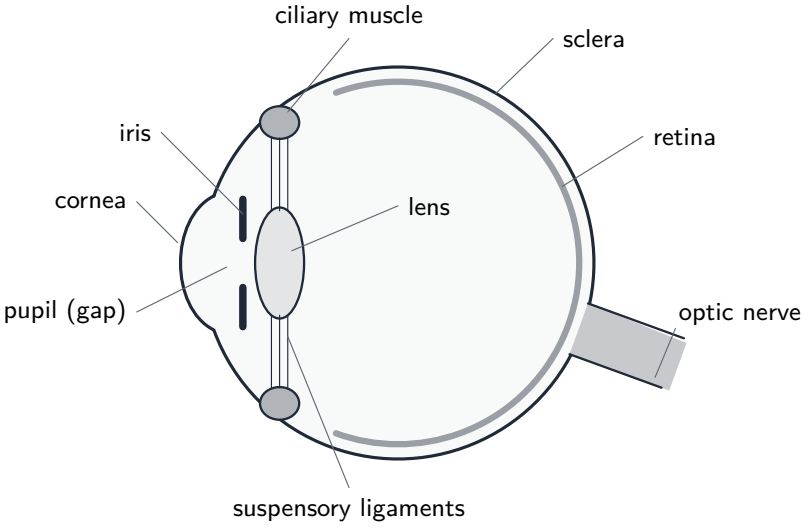
The brain from the side: cerebral cortex, cerebellum and medulla

Studying the brain (HT). Scientists map the brain by studying people with damage to one area, by stimulating areas electrically and watching the response, and by MRI scanning, which shows which areas are active. Treating brain damage is difficult, because the brain is delicate and easily harmed, and it is hard to reach some areas without damaging others.

The eye (biology only)

The eye is a sense organ with receptors that respond to light.

- The **retina** 视网膜 contains receptor cells sensitive to light intensity and colour.
- The **optic nerve** 视神经 carries impulses from the retina to the brain.
- The **sclera** 巩膜 is the tough white outer layer.
- The **cornea** 角膜 is the transparent front, which refracts light into the eye.
- The **iris** 虹膜 controls the size of the **pupil** 瞳孔, the hole that lets light in.
- Ciliary muscles and suspensory ligaments change the shape of the **lens** 晶状体.



Eye section: the pupil is an opening; ligaments connect ciliary muscles to the lens.

The pupil reflex. In bright light, the circular muscles of the iris contract and the radial muscles relax, so the pupil gets smaller and less light enters, protecting the retina. In dim light, the radial muscles contract and the circular muscles relax, so the pupil widens.

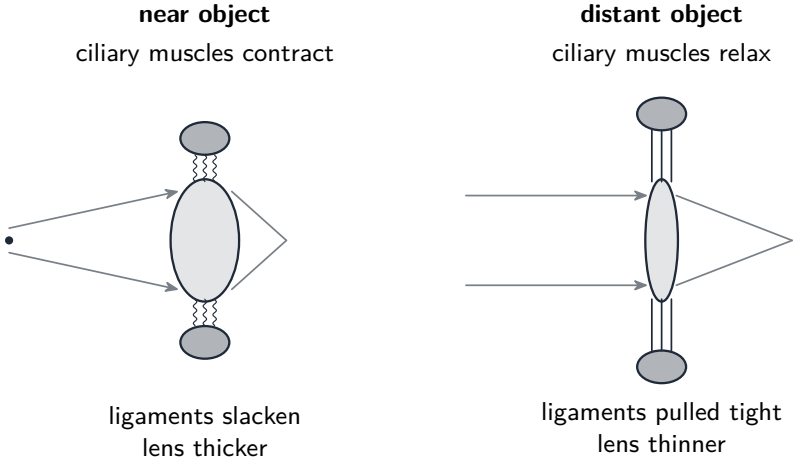


The human eye: the iris changes the size of the pupil to control how much light enters

Accommodation. **Accommodation** 视觉调节 is the change in lens shape that focuses light on the retina.

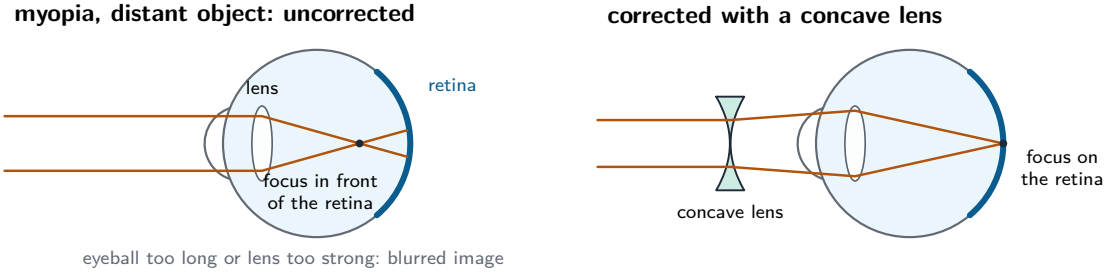
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Looking at	Ciliary muscles	Suspensory ligaments	Lens	Refraction
a near object	contract	slacken	thicker	more
a distant object	relax	pulled tight	thinner	less



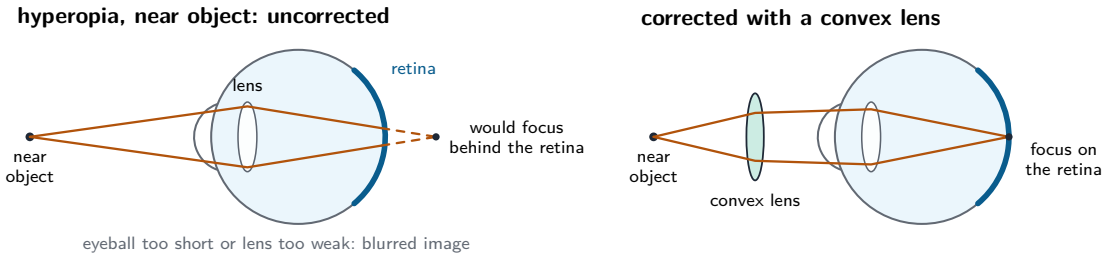
Near and distant focusing: muscle contraction changes ligament tension and lens shape.

Defects of vision. In **myopia** 近视 (short sight), light from distant objects focuses in front of the retina, because the eyeball is too long or the lens too strong. A **concave lens** 凹透镜 spreads the rays out so they focus on the retina.



Myopia: light from a distant object focuses in front of the retina; a concave lens corrects it

In **hyperopia** 远视 (long sight), light from near objects would focus behind the retina, because the eyeball is too short or the lens cannot thicken enough. A **convex lens** 凸透镜 brings the rays together before they enter the eye.



Hyperopia: light from a near object would focus behind the retina; a convex lens corrects it

Vision can also be corrected with contact lenses, laser surgery that reshapes the cornea, or an operation to replace the lens.

Controlling body temperature (biology only)

The **thermoregulatory centre** 体温调节中枢 in the brain contains receptors that monitor the temperature of the blood. It also receives impulses from temperature receptors in the skin.

If you are too hot:

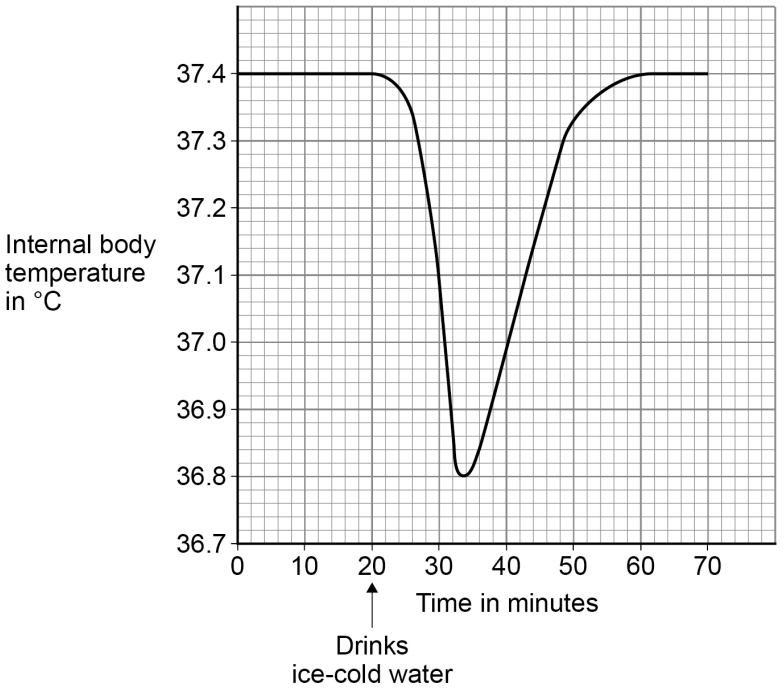
- the blood vessels supplying the skin capillaries widen (**vasodilation** 血管舒张), so more blood flows near the surface and more energy is transferred to the surroundings;
- **sweat glands** 汗腺 release more **sweat** 汗液, which transfers energy away from the skin as it evaporates.

If you are too cold:

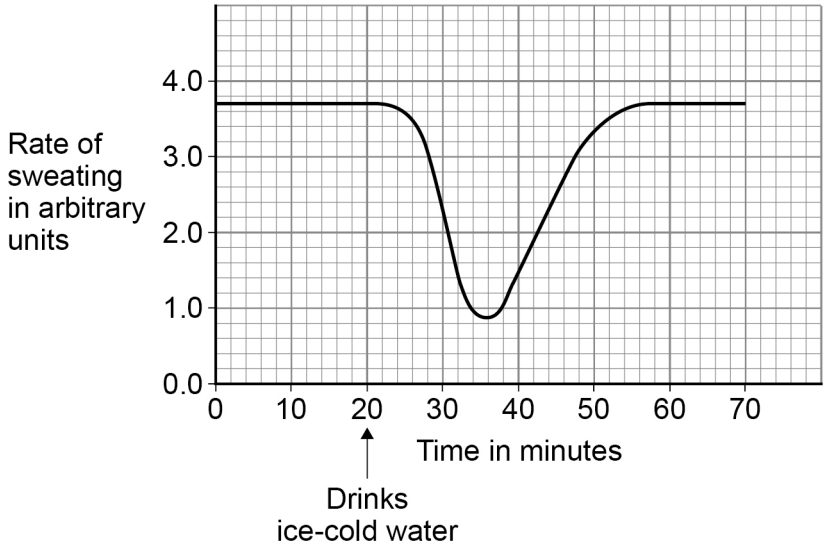
- the blood vessels supplying the skin capillaries narrow (**vasoconstriction** 血管收缩), so less blood flows near the surface and less energy is lost;
- sweating stops;
- skeletal muscles contract and relax rapidly (shivering), and the extra respiration releases energy that warms the body.

Each response reverses the change, which is an example of negative feedback.

> **Worked example 2 (HT).** A person at rest drinks ice-cold water after 20 minutes. Their core temperature rises slightly over the next few minutes, while their sweating rate falls. Explain. The cold water cools the blood, and the thermoregulatory centre in the brain detects this. It sends impulses to the sweat glands to produce less sweat. Less sweat evaporates, so less energy is lost from the skin, and the core temperature rises back up.



Core body temperature before and after drinking ice-cold water at 20 minutes (AQA GCSE Biology Paper 2H, June 2021, Figure 5)



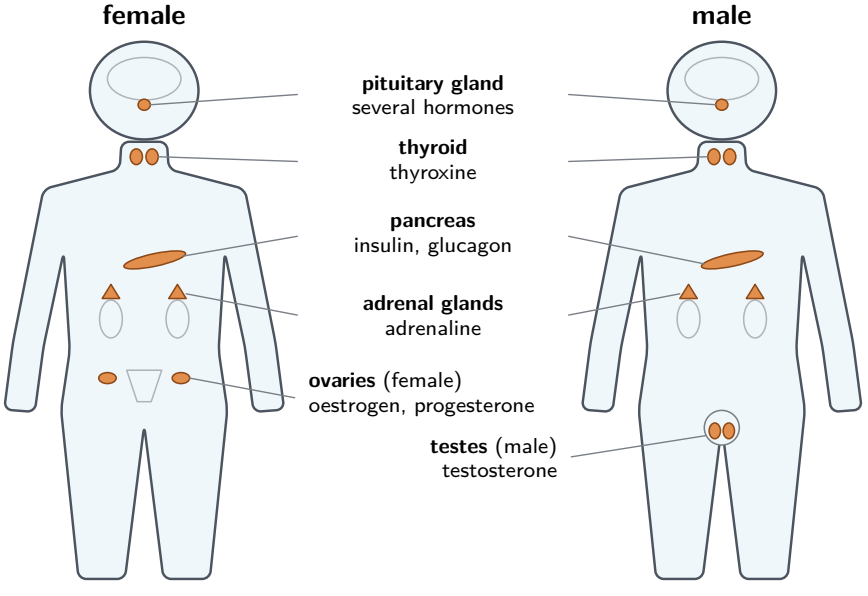
Rate of sweating before and after drinking ice-cold water (AQA GCSE Biology Paper 2H, June 2021, Figure 6)

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Hormones and blood glucose

The **endocrine system** 内分泌系统 is made of glands that release each **hormone** 激素 directly into the blood. The blood carries hormones to **target organs** 靶器官, where they have an effect.

Gland	Main hormones
Pituitary gland 垂体, at the base of the brain	several, including ADH, FSH, LH and TSH; it is called the "master gland" because many of its hormones act on other glands
Thyroid 甲状腺	thyroxine
Adrenal glands 肾上腺	adrenaline
Pancreas	insulin and glucagon
Ovaries 卵巢	oestrogen and progesterone
Testes 睾丸	testosterone



schematic positions, not to scale; kidneys drawn faintly below the adrenal glands

Where the endocrine glands are, in a female and a male body

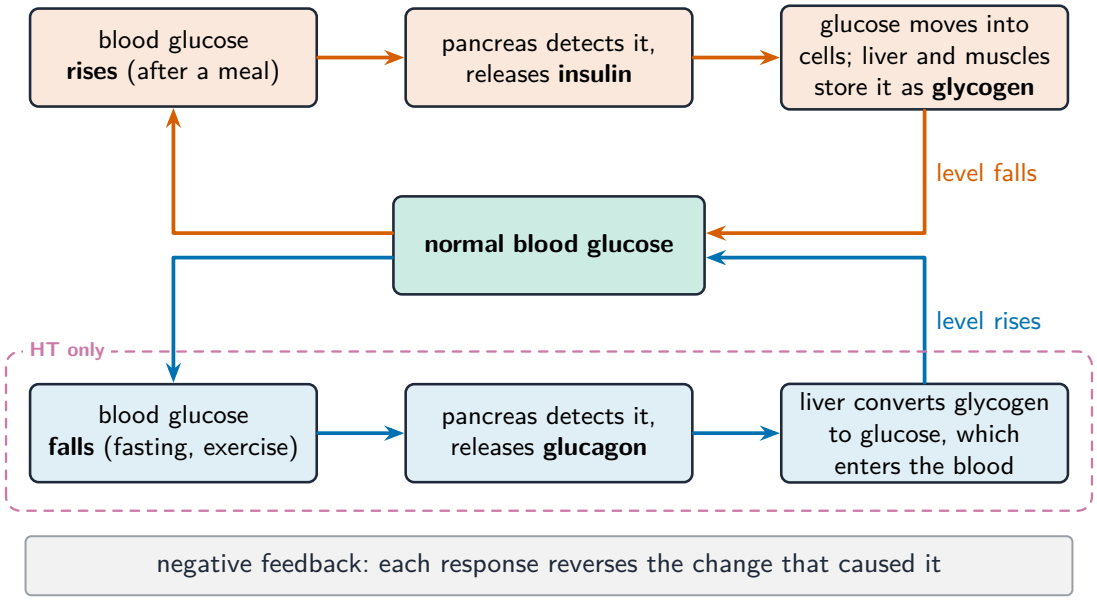
Controlling blood glucose. The pancreas monitors the blood glucose concentration.

- If it is too high, the pancreas releases **insulin** 胰岛素. Insulin makes glucose move from the blood into cells. In the liver and muscles, extra glucose is turned into **glycogen** 糖原 for storage. Blood glucose falls.

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- (HT) If it is too low, the pancreas releases **glucagon** 胰高血糖素. Glucagon makes the liver turn glycogen back into glucose and release it into the blood. Blood glucose rises.

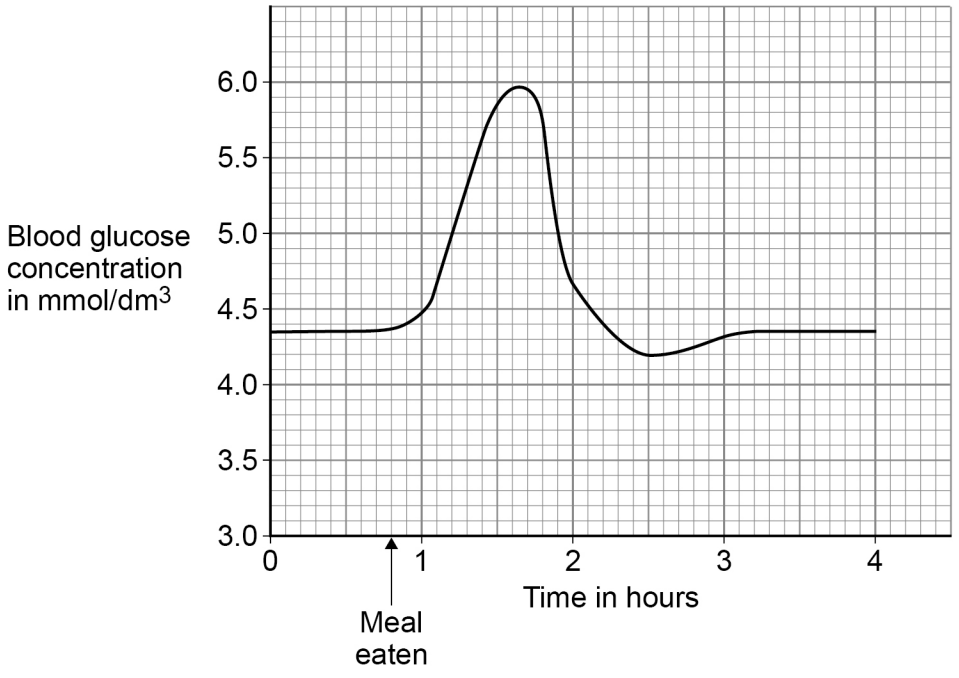
(HT) Insulin and glucagon work against each other. As the blood glucose returns to normal, less of the hormone is released. A response that reverses a change in this way is called **negative feedback** 负反馈.



Insulin lowers high blood glucose; the HT glucagon branch raises low blood glucose.

Worked example 3. A graph shows a person's blood glucose for four hours after a meal. It peaks about 1.5 hours after eating. Insulin release would be highest at about this time, because the high glucose concentration makes the pancreas release insulin, which then lowers the glucose by moving it into cells and storing it as glycogen.

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Blood glucose concentration for four hours after a meal (AQA GCSE Biology Paper 2H, June 2022, Figure 2)

Diabetes

	Type 1 diabetes 1型糖尿病	**Type 2 diabetes 2型糖尿病**
Cause	the pancreas produces too little insulin	body cells no longer respond properly to insulin
Result	blood glucose can rise dangerously high	blood glucose can rise dangerously high
Treatment	insulin injections	a carbohydrate-controlled diet and exercise, often with medicines
Risk factor	usually begins in childhood	obesity is a major risk factor

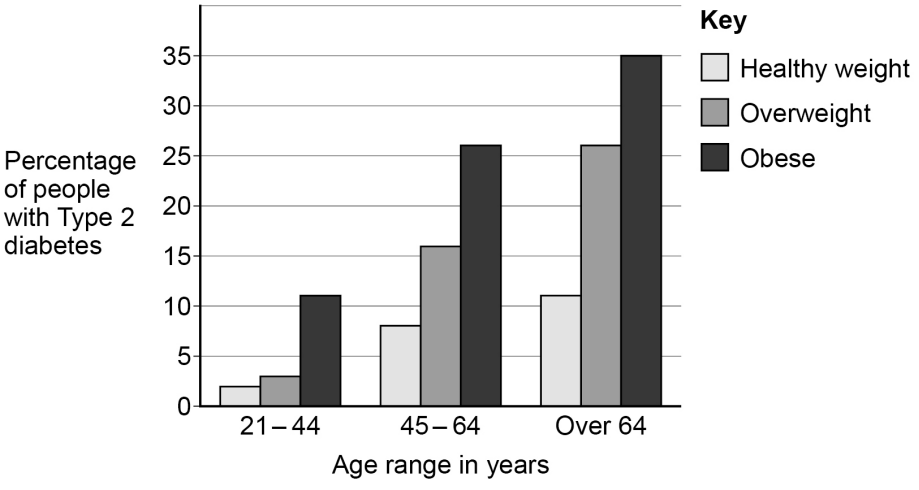
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A blood glucose meter: people with diabetes check their blood glucose because insulin control has failed

Worked example 4. Person C has a blood glucose concentration of 9.56 mmol/dm^3 (normal mean 4.51) and an insulin level of 24.32 arbitrary units (normal mean 14.83). Both are higher than normal. High glucose despite plenty of insulin suggests that C's cells are not responding to insulin, so C might have Type 2 diabetes. Further tests would be needed to be sure.

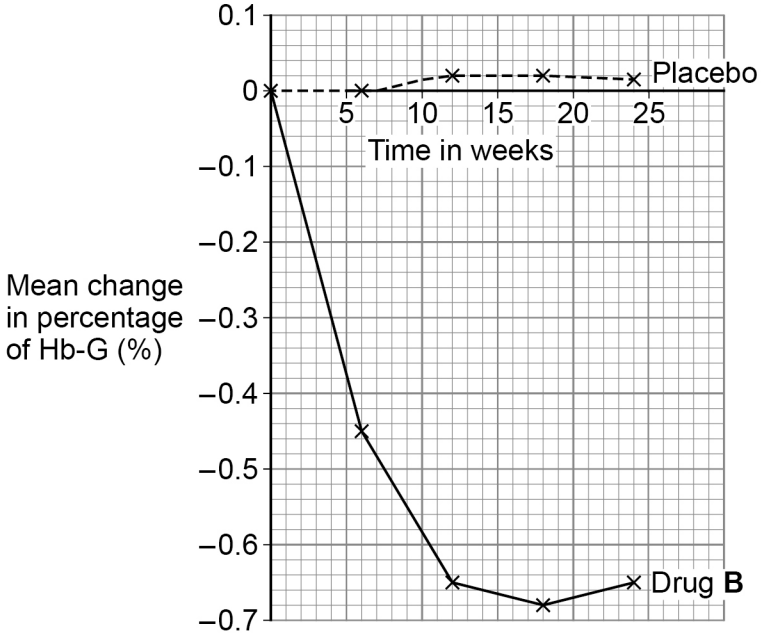
Worked example 5. A graph shows that the percentage of people with Type 2 diabetes increases with age and with body weight. This is a correlation in a population: it does not mean that every older or heavier person will develop diabetes.



Percentage of people with Type 2 diabetes by age and weight category (AQA GCSE Biology Paper 2H, June 2025, Figure 10)

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Worked example 6. A drug for Type 2 diabetes is tested against a placebo. Hb-G is the percentage of haemoglobin with glucose attached, which shows blood glucose control over several weeks. One patient group starts at 8.3%, and after 12 weeks the graph shows a change of -0.65. The new value is $8.3 - 0.65 = 7.65\%$. The graph shows the change, not the final value, so read the axis label carefully.

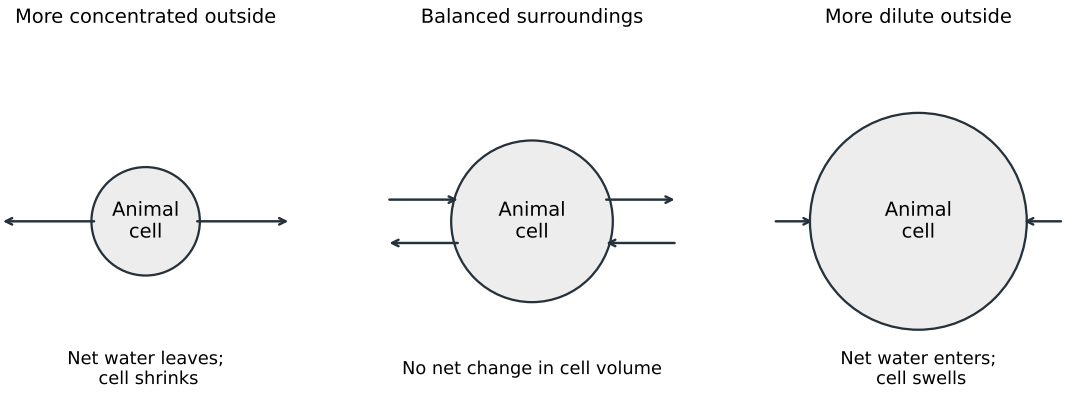


Change in Hb-G for drug B and a placebo over 24 weeks (AQA GCSE Biology Paper 2H, June 2025, Figure 11)

Water and nitrogen balance (biology only)

Why water balance matters. If the fluid around cells becomes more concentrated than the cytoplasm, the cells lose water by osmosis and shrink; if it becomes more dilute, they gain water and swell. Either way, they stop working properly.

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Arrows show net movement, except the balanced case: water moves both ways.

Animal-cell volume responds to net osmotic water movement.

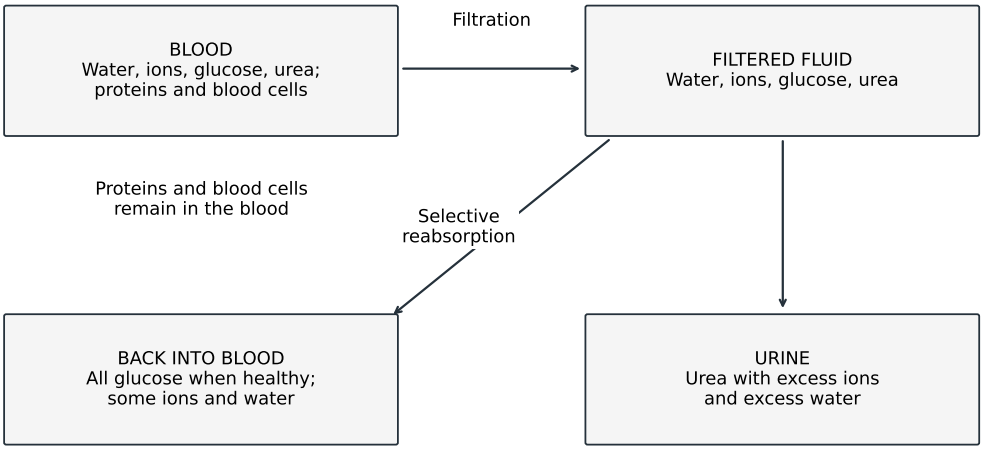
Water leaves the body from the lungs in exhaled air, from the skin in sweat (with ions and a little urea), and from the kidneys in urine. We cannot control the losses from the lungs and skin, so the kidneys adjust the volume and concentration of urine.

Urea (HT). Amino acids that the body does not need are **deaminated** 脱氨 in the **liver** 肝脏: the part containing nitrogen is removed, forming **ammonia** 氨. Ammonia is toxic, so the liver immediately turns it into **urea** 尿素, which is carried in the blood to the kidneys and excreted in urine.

How the kidneys work.

1. **Filtration** 滤过: small molecules such as water, glucose, ions and urea are filtered out of the blood. Proteins and blood cells are too large and stay in the blood.
2. **Selective reabsorption** 选择性重吸收: useful substances are taken back into the blood. All the glucose is reabsorbed, and as much water and as many ions as the body needs.
3. Urea, and any extra water and ions, pass out in the urine.

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Functional process, not anatomy.

Functional filtration and selective reabsorption, not anatomical structures.

ADH (HT). When the blood is too concentrated, the pituitary gland releases more **ADH** 抗利尿激素. ADH makes the kidney tubules more permeable to water, so more water is reabsorbed into the blood, and a small volume of concentrated urine is produced. When the blood is too dilute, less ADH is released, less water is reabsorbed and a large volume of dilute urine is produced. This is negative feedback.

> **Worked example 7 (HT).** After a person drank a lot of water, their ADH level fell from 3.75 to 1.25 ng/dm^3, their urine production rose from 1.8 to 8.8 cm^3 per minute, and the concentration of their urine fell from 1110 to 700 arbitrary units. Explain. With less ADH, the tubules were less permeable, so less water was reabsorbed into the blood. More water stayed in the urine, so more urine was made, and it was more dilute. At 8.8 cm^3 per minute, 10 minutes would produce $8.8 \times 10 = 88$ cm^3.

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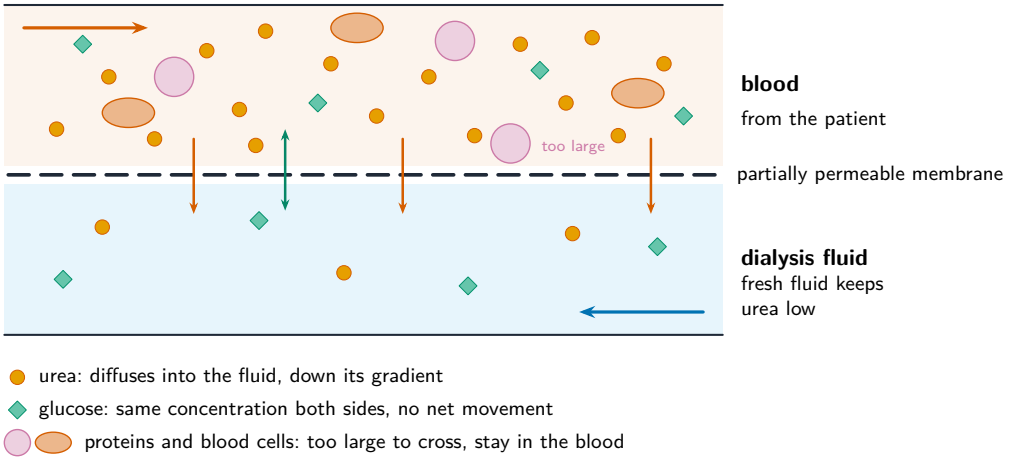
Table 2

Concentration of ADH in the blood in nanograms/dm^3	Concentration of dissolved substances in urine in arbitrary units	Rate of urine production in cm^3/minute
0.0	50	20.0
1.25	700	8.8
2.50	980	3.9
3.75	1110	1.8
5.00	1170	0.9

ADH concentration, urine concentration and urine production rate before and after drinking water (AQA GCSE Biology Paper 2H, June 2023, Table 2)

Kidney failure. People whose kidneys fail can be treated by dialysis or a kidney transplant.

In **dialysis** 透析, the patient's blood flows past dialysis fluid, separated by a partially permeable membrane. The fluid contains no urea, so urea diffuses out of the blood. It contains the same concentration of glucose and useful ions as normal blood, so these are not lost. Proteins and blood cells are too large to cross the membrane. Fresh fluid keeps the urea gradient steep.



A urea gradient, matched glucose concentrations and a partially permeable membrane.

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	Dialysis	Transplant 移植
Benefits	available without a donor; no major surgery	one operation gives working kidneys; more freedom and a normal diet
Drawbacks	several long sessions a week; strict diet; expensive over time	needs a matching donor; surgery; risk of rejection, so drugs that suppress the immune system are needed, increasing the risk of infection

Hormones in human reproduction

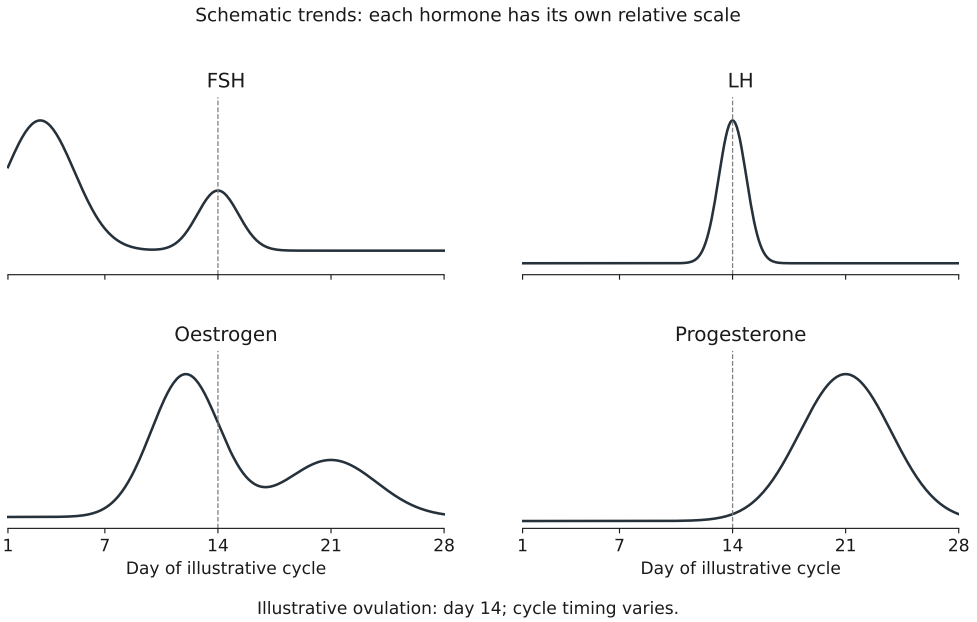
During puberty, reproductive hormones cause secondary sexual characteristics to develop. **Oestrogen** 雌激素, made by the ovaries, is the main female reproductive hormone; eggs begin to mature, and about every 28 days one is released by **ovulation** 排卵. **Testosterone** 睾酮, made by the testes, is the main male reproductive hormone and stimulates sperm production.

The menstrual cycle.

Hormone	Made in	Job
FSH 卵泡刺激素 (follicle stimulating hormone)	pituitary	makes an egg mature in the ovary
LH 黄体生成素 (luteinising hormone)	pituitary	stimulates the release of the egg
Oestrogen	ovaries	makes the lining of the uterus grow
Progesterone 孕激素	ovaries	keeps the lining of the uterus in place

How the hormones interact (HT). FSH makes an egg mature and stimulates the ovary to produce oestrogen. Oestrogen inhibits FSH and, at high levels, stimulates a surge of LH, which causes ovulation on about day 14. After ovulation, progesterone keeps the uterus lining thick and inhibits FSH and LH. If the egg is not fertilised, progesterone falls, the lining breaks down (menstruation) and the cycle begins again.

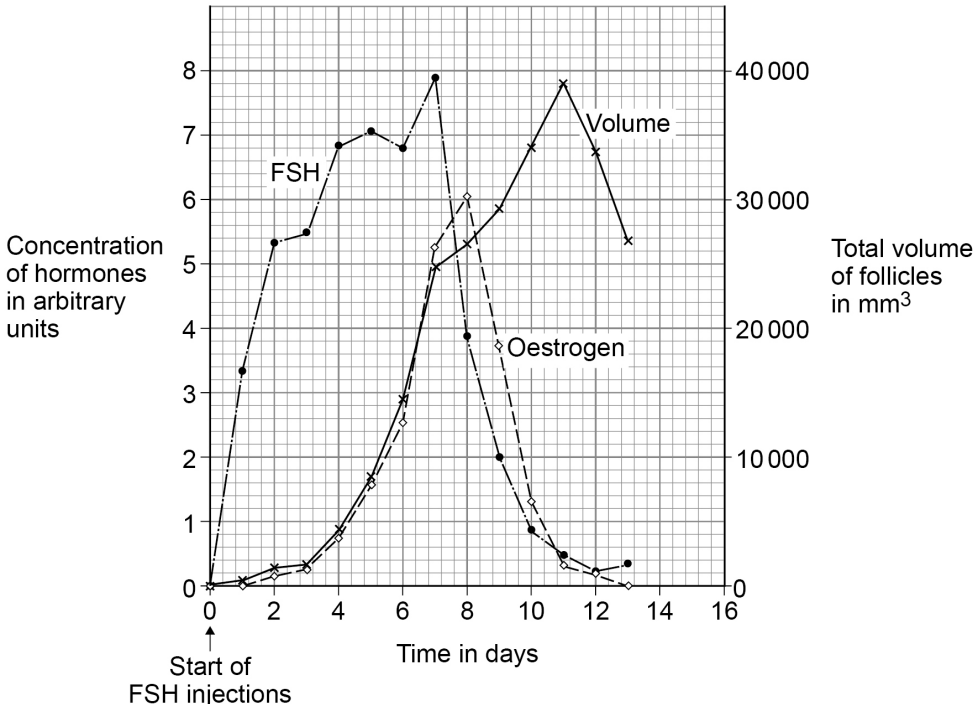
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The four hormones of the menstrual cycle, each on its own scale; ovulation happens at about day 14

Worked example 8 (HT). A woman whose body makes no FSH is given daily FSH injections. On day 11 the total volume of her follicles is 39 000 mm^3 and their mean diameter is 22 mm. Assuming they are spheres, how many follicles are there? Radius = 11 mm, so one follicle has volume $\frac{4}{3}\pi r^3 = \frac{4}{3} \times 3.14 \times 11^3 = 5572$ mm^3. Number $= \frac{39\,000}{5572} = 7$ follicles. Because she makes no FSH, her follicles do not develop and make oestrogen, so she does not develop the female secondary sexual characteristics that oestrogen controls.

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Hormone concentration (left axis) and total follicle volume (right axis) after daily FSH injections (AQA GCSE Biology Paper 2H, June 2023, Figure 12)

Controlling fertility

Contraception. Hormonal methods include the oral contraceptive pill, injections, implants and skin patches. They contain oestrogen or progesterone (or both), which inhibit FSH so that no eggs mature; some also stop ovulation or make the mucus at the entrance to the uterus too thick for sperm.

Non-hormonal methods:

- barrier methods, such as **condoms** 避孕套 and **diaphragms** 子宫帽, stop sperm reaching an egg;
- spermicides kill or disable sperm;
- intrauterine devices (coils) prevent the implantation of an embryo or release a hormone;
- surgical sterilisation is permanent;
- avoiding sex at the time when an egg may be in the oviduct is the least reliable.

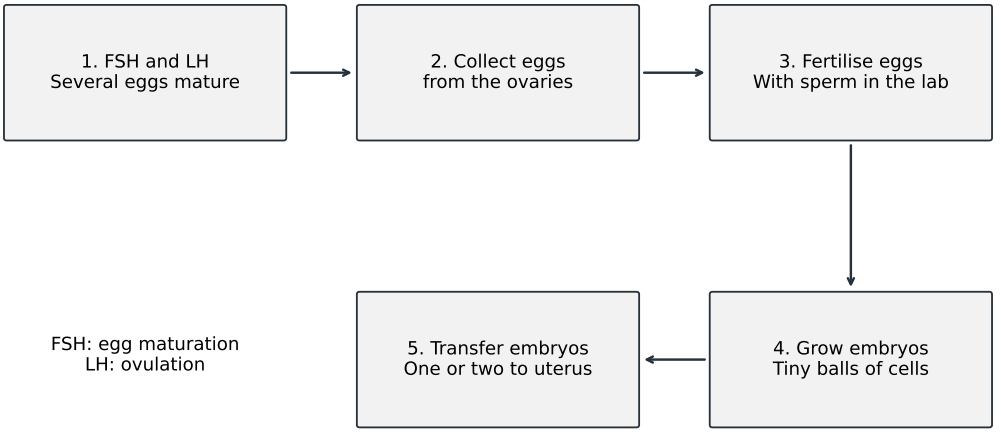
To choose, people weigh up how reliable a method is, whether it uses hormones, whether it can be reversed, whether it protects against sexually transmitted infections (only condoms do), and their own beliefs.

Treating infertility (HT). FSH and LH can be given as a fertility drug, so that eggs mature and are released. In IVF (in vitro fertilisation):

1. the woman is given FSH and LH to make several eggs mature;

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2. the eggs are collected and fertilised by sperm in a laboratory;
3. the fertilised eggs develop into embryos;
4. when they are tiny balls of cells, one or two embryos are put into the uterus.



Fertilisation happens in the laboratory; embryos are transferred.

IVF stages from hormone treatment to embryo transfer.

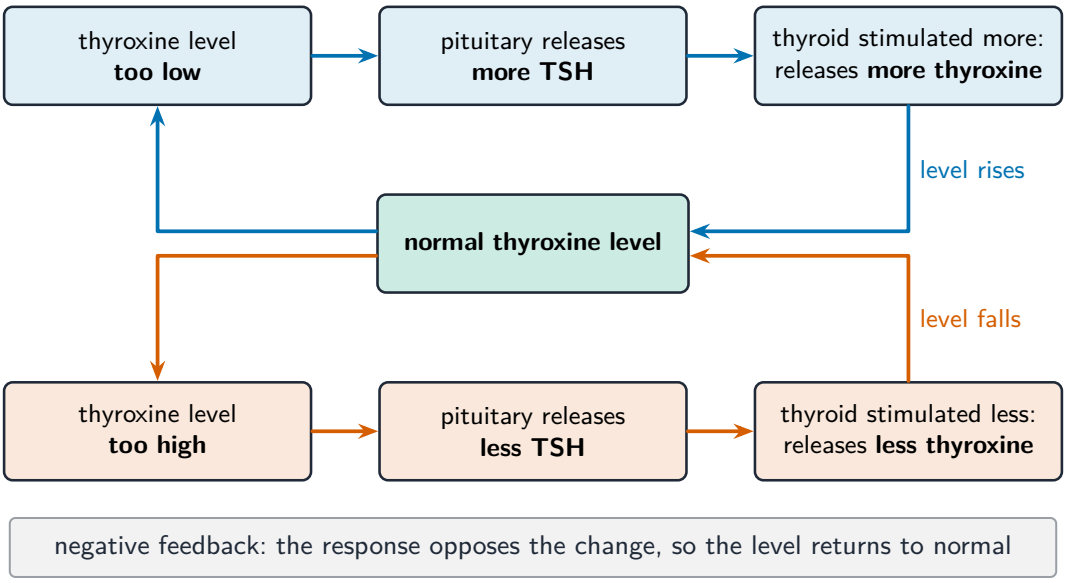
IVF can give infertile couples a child, but it is emotionally and physically stressful, success rates are not high, and it can lead to multiple births, which are a risk to both the babies and the mother.

Adrenaline and thyroxine (HT)

Adrenaline is made by the adrenal glands in times of fear or stress. It increases the heart rate, which delivers more oxygen and glucose to the brain and muscles, preparing the body for "fight or flight".

Thyroxine is made by the thyroid gland. It increases the basal metabolic rate, the speed of the chemical reactions in the body, and is important for growth and development. When thyroxine falls, the pituitary releases more TSH, which stimulates the thyroid to release more thyroxine. When thyroxine rises, less TSH is released. This is another example of negative feedback.

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The pituitary's TSH stimulates the thyroid; each response opposes the change, so thyroxine returns to normal.

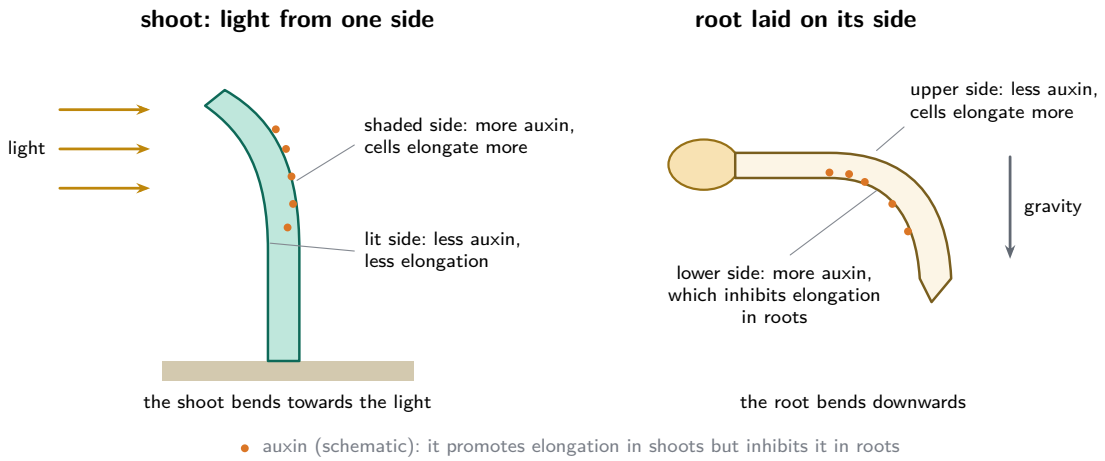
Worked example 9 (HT). Explain how more thyroxine helps a person in a cold place keep warm. Thyroxine increases the metabolic rate, so more respiration takes place in cells. Respiration releases energy, some as heat, which warms the body.

Plant hormones (biology only)

Plants respond to light and gravity by growing in a particular direction. **Phototropism** 向光性 is a growth response to light; **gravitropism** 向地性 (or geotropism) is a growth response to gravity. Shoots grow towards light and away from gravity; roots grow towards gravity.

Auxin. These responses are controlled by the plant hormone **auxin** 生长素, made in the tips of shoots and roots.

- In a shoot lit from one side, auxin collects on the shaded side. Auxin makes shoot cells elongate (grow longer), so the shaded side grows faster and the shoot bends towards the light.
- In a root lying on its side, auxin collects on the lower side. In roots, auxin slows elongation, so the upper side grows faster and the root bends downwards.



Different shoot/root elongation responses to unequal auxin distribution.

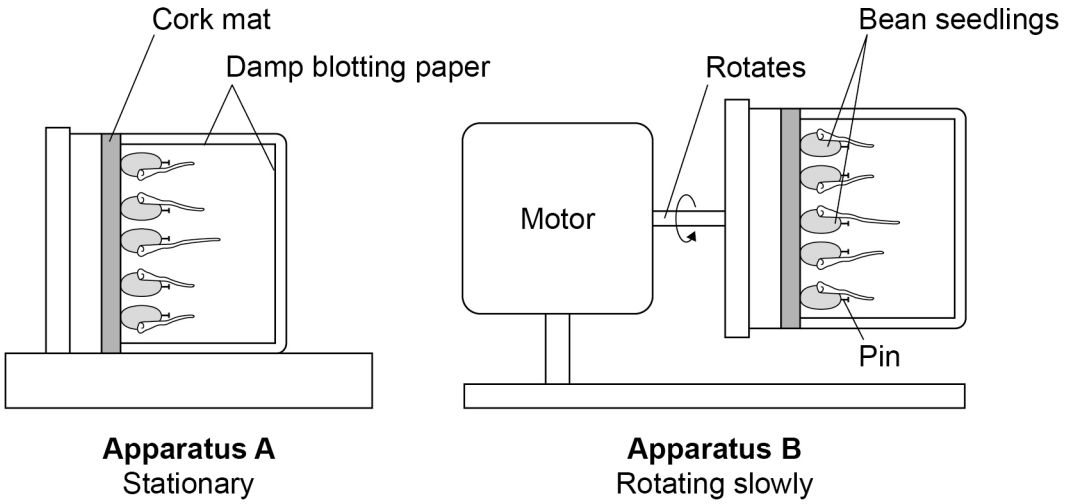
Required practical 8: light or gravity and seedling growth. Grow seedlings of the same type and age in the same conditions, except for the factor tested: for example, some with light from one side through a slit in a box, and some with light from all around. After several days, measure each shoot's length (a thread laid along a curved shoot, then measured on a ruler, gives the true length) and record the direction of growth with labelled drawings. Use several seedlings for each condition and calculate a mean.

Worked example 10. Three shoots each started at 20 mm and finished at 32, 34 and 33 mm. The increases were 12, 14 and 13 mm, so the mean increase was $\frac{12+14+13}{3} = 13$ mm.

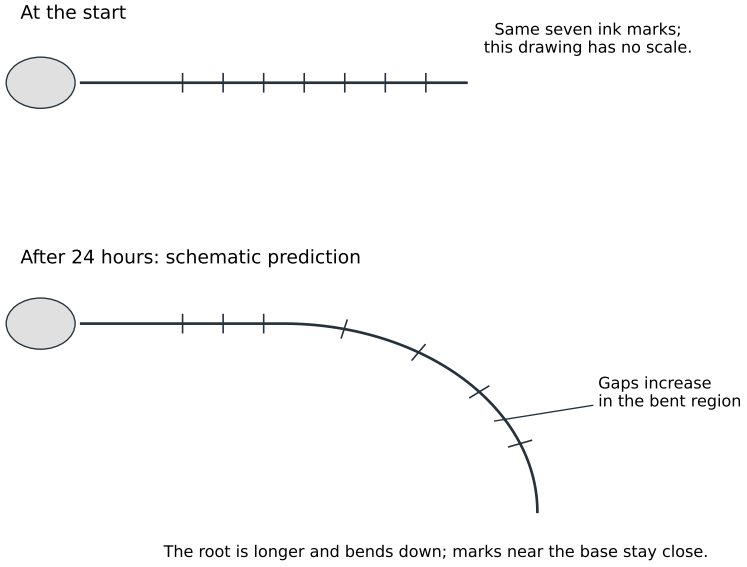
Worked example 11. Bean seedlings were kept in the dark on damp paper for 24 hours. Seedling A was in a stationary dish; dish B rotated slowly. Explain the setup and the results. The dark stops light affecting the direction of growth; the damp paper supplies the water needed for growth. Rotating B means gravity does not act on the same side of the root for long, so its root grows straight; A's root bends downwards. Ink marks on A's root spread further apart near the tip, where the cells grew longest.

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Figure 6



Seedling A in a stationary dish and seedling B in a slowly rotating dish (AQA GCSE Biology Paper 2H, June 2024, Figure 6)



The predicted root: longer, bent downwards, with the ink marks further apart near the tip

Uses of plant hormones (HT).

- Auxins: rooting powders that make cuttings grow roots; weed killers that make broad-leaved weeds grow out of control; promoting growth in tissue culture.
- Ethene: controls ripening, so fruit can be picked unripe and ripened when it reaches the shops.

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- Gibberellins: end seed dormancy so seeds germinate, make plants flower, and increase fruit size.

Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.5 Homeostasis and response, and the required practical handbook.
- F. G. Banting, C. H. Best, J. B. Collip, W. R. Campbell and A. A. Fletcher, "Pancreatic extracts in the treatment of diabetes mellitus", *Canadian Medical Association Journal* 12 (March 1922), pages 141 to 146.
- AQA, *GCSE Biology* Paper 2 Higher (June 2021 to June 2025), the reaction-time, temperature, diabetes, ADH, follicle and root-growth questions, adapted.

Common errors

- Saying reflexes involve the conscious brain, or that catching a ruler is a reflex.
- Saying the pupil is a muscle; it is a hole controlled by the iris.
- Mixing up which lens corrects myopia (concave) and hyperopia (convex).
- Saying capillaries move closer to the skin; the blood vessels supplying them widen or narrow.
- Saying sweat cools you when it is produced; it cools you as it evaporates.
- Confusing glycogen (the store), glucagon (the hormone) and glucose (the sugar).
- Saying the kidneys make urea; the liver makes it.
- Saying ADH makes more urine; it makes less, more concentrated urine.
- Saying light destroys auxin, or applying the shoot rule to roots.

Key terms

- **Homeostasis**: keeping the conditions inside the body steady.
- **Reflex arc**: the pathway of a reflex, from receptor to effector through the spinal cord.
- **Synapse**: the gap between two neurones, crossed by a chemical.
- **Accommodation**: changing the shape of the lens to focus on near or distant objects.
- **Hormone**: a chemical messenger carried in the blood to a target organ.
- **Negative feedback**: a response that reverses a change and returns conditions to normal.
- **Selective reabsorption**: taking useful substances back into the blood in the kidney.
- **Ovulation**: the release of an egg from an ovary.
- **Phototropism**: a growth response to the direction of light.

Check yourself

1. Name the three parts of a control system and give an example of each.
2. Describe the pathway of a reflex arc.
3. (Biology only) Describe how the eye focuses on a near object.
4. Explain what happens when blood glucose rises after a meal.
5. Give one difference between Type 1 and Type 2 diabetes.
6. (Biology only, HT) Explain how ADH reduces water loss.
7. Explain how the contraceptive pill prevents pregnancy.
8. (Biology only) Explain why a shoot lit from one side bends towards the light.

Answers: 1. Receptors (such as temperature receptors in the skin); coordination centres (brain, spinal cord or pancreas); effectors (muscles or glands). 2. Stimulus → receptor → sensory neurone → relay neurone → motor neurone → effector → response, crossing synapses between neurones. 3. The ciliary muscles contract, the suspensory ligaments slacken and the lens becomes thicker, refracting light more. 4. The pancreas releases insulin, which makes glucose move into cells and be stored as glycogen in the liver and muscles, so blood glucose falls. 5. In Type 1 the pancreas makes too little insulin; in Type 2 the cells no longer respond to insulin. 6. ADH makes the kidney tubules more permeable to water, so more water is reabsorbed into the blood and less is lost in urine. 7. Its hormones inhibit FSH, so no eggs mature and none are released. 8. Auxin collects on the shaded side and makes those cells elongate more, so that side grows faster and the shoot bends towards the light.

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6 · Inheritance, variation and evolution

AQA · GCSE · Biology

Inheritance, variation and evolution: passing it on

Why it matters. On 8 February and 8 March 1865, a monk called Gregor Mendel read a paper to the Natural History Society in Brünn (now Brno, in the Czech Republic). For eight years he had grown pea plants in the monastery garden, about 28 000 of them, and counted their features: tall or short, round or wrinkled seeds, purple or white flowers. He found that features were passed on as separate "units" in simple number patterns, such as 3 : 1. Hardly anyone understood him, and he died in 1884 with his work almost unknown. In 1900 three other scientists found the same patterns, and then found his paper. Mendel's units are what we now call genes. This topic explains how genes are passed on, why individuals vary, and how variation and natural selection lead to evolution.

In this unit you will:

- compare sexual and asexual reproduction, and describe meiosis;
- describe DNA, genes and the genome, and (HT) how proteins are made;
- use genetic terms and Punnett squares to predict inheritance, including inherited disorders and sex;
- explain variation, natural selection, selective breeding, genetic engineering and (biology only) cloning;
- (biology only) describe the history of evolutionary theory, the evidence for evolution, and how living things are classified.

AQA GCSE Biology (8461), topic 4.6 Inheritance, variation and evolution, examined on Paper 2. Content marked (HT) is Higher tier only.

Reproduction and meiosis

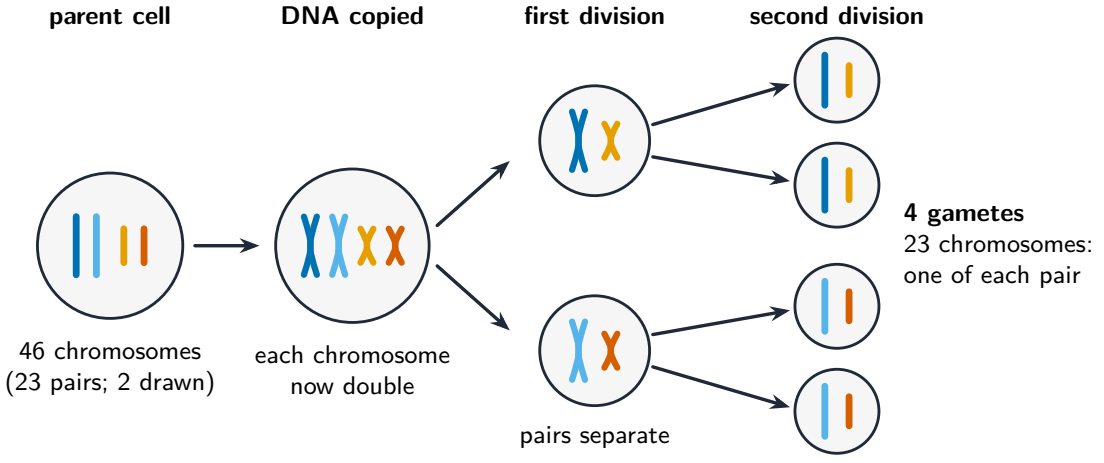
Sexual reproduction 有性生殖 involves the joining of male and female sex cells, each called a **gamete** 配子: sperm and egg cells in animals, pollen and egg cells in flowering plants. It mixes genetic information from two parents, so the offspring vary. **Asexual reproduction** 无性生殖 involves only one parent and no gametes. Its offspring are genetically identical to the parent, a **clone** 克隆 (apart from any mutations). In plants and animals it uses cell division by **mitosis** 有丝分裂.

Meiosis. Gametes are made by **meiosis** 减数分裂:

1. the genetic information is copied;
2. the cell divides twice, forming four gametes;
3. each gamete has a single set of chromosomes (23 in humans), and each is genetically different.

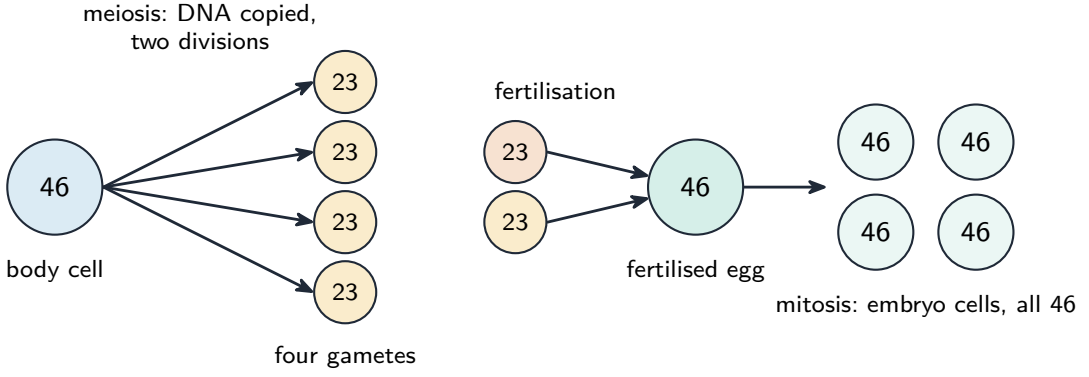
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At **fertilisation** 受精 two gametes join, restoring the full number of chromosomes (46 in humans). The new cell divides by mitosis, and as the embryo develops its cells differentiate.



other cells sort the pairs differently, so gametes vary; fertilisation: $23 + 23 = 46$

DNA is copied, the first division separates the chromosome pairs and the second separates the copies: four gametes with 23 chromosomes each; fertilisation restores 46.



Chromosome numbers through meiosis, fertilisation and mitosis

Sexual or asexual? (biology only)

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	Advantages
Sexual reproduction	produces variation, so if the environment changes some offspring may survive; humans can use the variation in selective breeding
Asexual reproduction	needs only one parent, so it saves time and energy; it is faster; many identical offspring can be produced when conditions are good

Some organisms use both. The malaria parasite reproduces asexually in humans and sexually in mosquitoes. Many fungi make spores asexually and also reproduce sexually. Strawberry plants make seeds sexually and send out runners asexually; daffodils grow from seeds and also from bulbs that divide.

> **Worked example 1.** A strawberry grower's plants are attacked by a new disease. Explain whether new plants grown from seeds or from runners are more likely to include some that survive. Seeds come from sexual reproduction, so the plants vary, and some may by chance have alleles that resist the disease. Runners are clones of the parent, so if the parent is not resistant, none of them will be.

DNA, genes and the genome

DNA is a **polymer** 聚合物 made of two strands twisted into a **double helix** 双螺旋. It is found in the nucleus, in structures called chromosomes. A **gene** 基因 is a small section of DNA that codes for a particular sequence of amino acids, which makes a particular protein. The **genome** 基因组 is all the genetic material of an organism.

Studying the human genome helps scientists to find genes linked to diseases, to understand and treat inherited disorders, and to trace how humans migrated across the world in the past.

DNA structure (biology only). DNA is made of repeating units called nucleotides. Each **nucleotide** 核苷酸 contains a sugar, a phosphate group and one of four bases: **adenine** 腺嘌呤 (A), **cytosine** 胞嘧啶 (C), **guanine** 鸟嘌呤 (G) and **thymine** 胸腺嘧啶 (T). The sugar and phosphate form the backbone of each strand. A sequence of three bases codes for one amino acid, so the order of the bases controls the order of the amino acids in a protein. On the two strands, A always pairs with T, and C with G.

Making proteins (biology only, HT). Proteins are made on each **ribosome** 核糖体, using a copy of the gene as a template. Carrier molecules bring the amino acids in the right order. The chain of amino acids then folds into a particular shape, which lets the protein do its job as an enzyme, a hormone or a structural protein such as collagen.

Mutations (biology only, HT). A **mutation** 突变 is a change in the DNA base sequence. Most have no effect on the protein. Some change it a little. A few change its

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shape so much that an enzyme's active site no longer fits its substrate, or a structural protein loses its strength. Some DNA does not code for proteins, but it can switch genes on and off, so changes there affect how genes are expressed.

Genetic inheritance

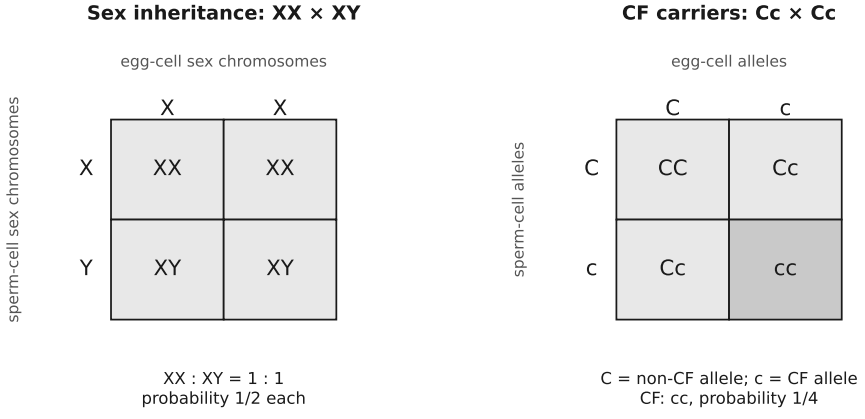
Genetic terms.

- A **chromosome** 染色体 is a long DNA molecule carrying many genes.
- An **allele** 等位基因 is a version of a gene.
- A **dominant** 显性 allele is expressed even if only one copy is present; it is shown with a capital letter, such as D.
- A **recessive** 隐性 allele is expressed only if two copies are present; it is shown with a small letter, such as d.
- **Homozygous** 纯合 means having two identical alleles (DD or dd); **heterozygous** 杂合 means having two different alleles (Dd).
- The **genotype** 基因型 is the alleles present; the **phenotype** 表现型 is the characteristic that results.

Some characteristics, such as fur colour in mice, are controlled by a single gene, but most are controlled by several genes working together.

Punnett squares. A **Punnett square** 庞氏方格 shows all the possible combinations of the parents' gametes.

> **Worked example 2.** Two parents are carriers of cystic fibrosis: both are Cc. Each makes gametes C and c. The combinations are CC, Cc, Cc and cc. So the probability that a child has cystic fibrosis (cc) is $\frac{1}{4}$, or 25%; the probability that a child is a carrier (Cc) is $\frac{1}{2}$; the ratio of unaffected to affected children is 3 : 1.



Punnett squares: XX × XY sex inheritance and Cc × Cc cystic-fibrosis carrier inheritance.

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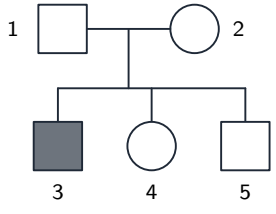
Inherited disorders.

- **Polydactyly** 多指症, having extra fingers or toes, is caused by a dominant allele, so one copy is enough.
- **Cystic fibrosis** 囊性纤维化, a disorder of cell membranes that causes thick, sticky mucus in the lungs and gut, is caused by a recessive allele, so a person must inherit two copies. A carrier (Cc) does not have the disorder.

Worked example 3. A father with polydactyly and a mother without it have a son without it. What is the father's genotype? The mother and son are dd. The son must have received a d from his father. The father has polydactyly, so he must also have a D. He is Dd.

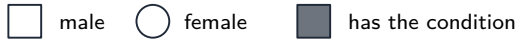
Worked example 4 (HT). A mother with polydactyly (Dd) and a father without it (dd) already have three children without it. What is the probability that their next child has polydactyly? Gametes D and d from the mother and d and d from the father give Dd, Dd, dd, dd, so the probability is $\frac{2}{4} = \frac{1}{2}$. Earlier children do not change it: each child is a new event.

Family trees. In a family tree, if two unaffected parents have an affected child, the allele must be recessive and both parents must be carriers.



Rule 1 Two *unaffected* parents with an *affected* child means the allele is **recessive**, and both parents are **heterozygous** carriers.

Rule 2 If every affected person is *male*, suspect **sex linkage**: the gene is on the X chromosome.

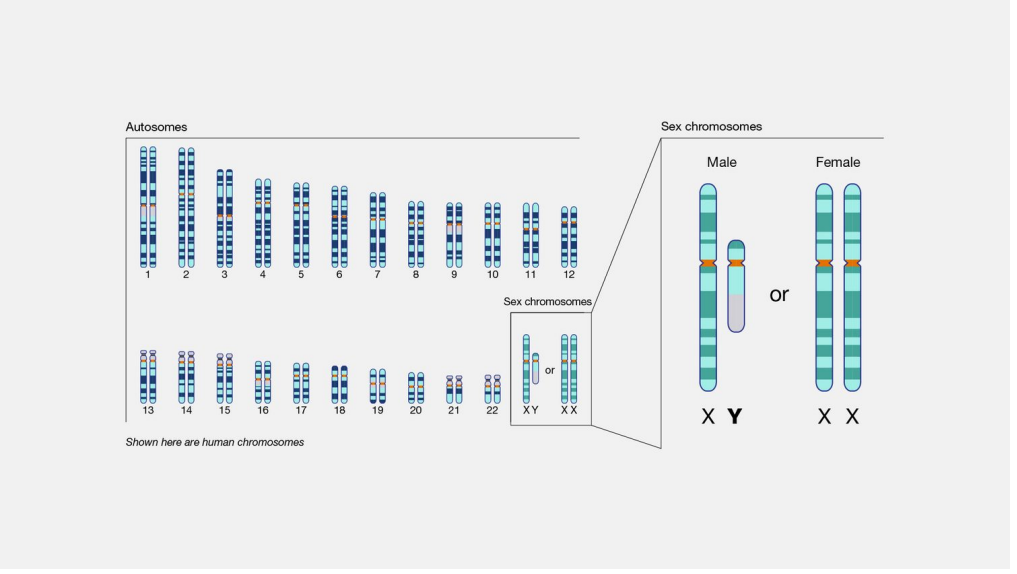


Two unaffected parents with an affected child: the allele is recessive, and both parents are carriers

Embryo screening. **Embryo screening** 胚胎筛查 tests embryos for alleles that cause inherited disorders, for example during IVF. It can help parents avoid having a child with a serious disorder. But it is expensive, it can be wrong, unused embryos are destroyed, and some people worry that it could lead to choosing embryos for other features. People weigh these economic, social and ethical issues differently.

Sex determination. Human body cells contain 23 pairs of chromosomes. 22 pairs control characteristics only; one pair carries the genes that decide sex. This **sex determination** 性别决定 works as follows: females are XX and males are XY. Every egg carries an X; half the sperm carry an X and half a Y. So each child has a probability

of $\frac{1}{2}$ of being a boy and $\frac{1}{2}$ of being a girl.



A human karyotype: 23 pairs of chromosomes, ending in XY for a male

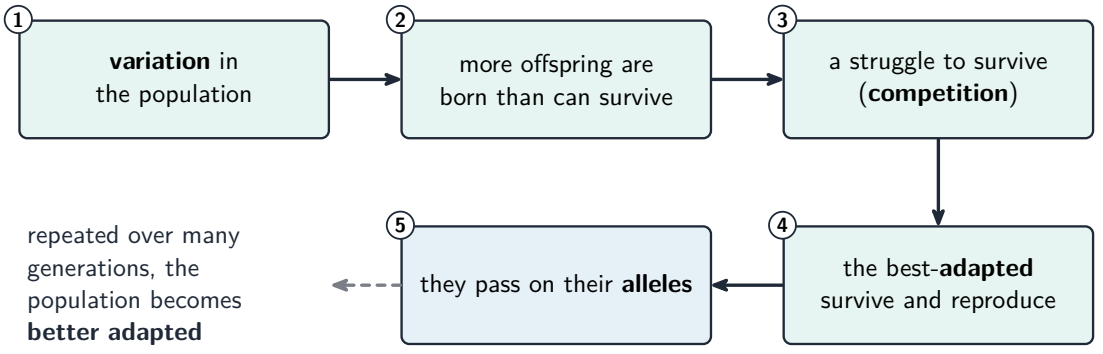
Variation and evolution

Variation 变异 is the difference between individuals of the same species. It can be caused by the genes they inherit (genetic), by the conditions in which they develop (environmental), or, most often, by both. All genetic variation comes from mutations. Most mutations have no effect on the phenotype, some change it slightly, and very few decide it completely. A rare mutation that suits a change in the environment can spread quickly through a population.

Evolution 进化 is a change in the inherited characteristics of a population over time. It happens by **natural selection** 自然选择:

1. individuals in a population vary, because of their genes;
2. more offspring are born than can survive, so they compete;
3. those best suited to the environment are more likely to survive and reproduce;
4. they pass on their alleles, so these become more common over many generations.

All species of living things evolved from simple life forms that first appeared more than three billion years ago. If two populations of a species become so different that they can no longer interbreed to produce fertile offspring, they have become two new species: this is **speciation** 物种形成.



Natural selection: the best-adapted survive, reproduce and pass on their alleles

Worked example 5. Insects in a field vary in resistance to an insecticide. Describe how the population becomes resistant. The insecticide is a **selection pressure** 选择压力. Insects without resistance are killed. Resistant insects survive, reproduce and pass on the resistance allele to their offspring. Over many generations, more and more of the population is resistant. No single insect becomes resistant by being sprayed.

Selective breeding, genetic engineering and cloning

Selective breeding. In **selective breeding** 选择育种 humans, not nature, choose which plants or animals breed:

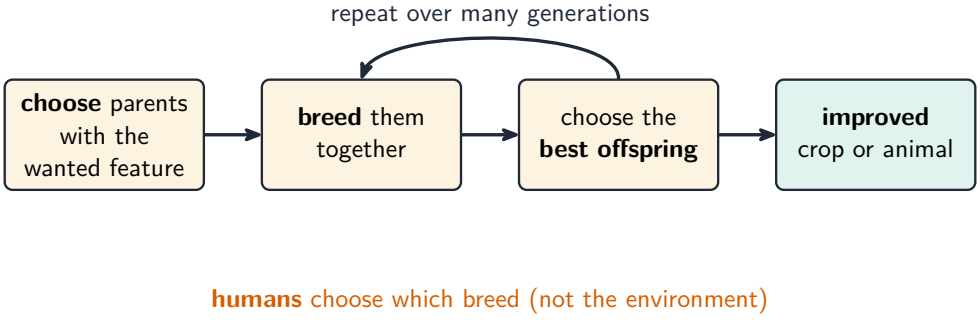
1. choose parents with the wanted characteristic;
2. breed them together;
3. choose the offspring with the characteristic most strongly, and breed them;
4. repeat over many generations.

It has produced disease-resistant crops, cows that give more milk, gentle dogs and large, unusual flowers. The risk is **inbreeding** 近交: breeding close relatives reduces variation, so a breed may be prone to inherited defects and to a disease that none of them can resist.

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Dairy cattle: generations of selective breeding for high milk yield



In selective breeding, humans choose which organisms breed, over many generations

Genetic engineering. **Genetic engineering** 基因工程 changes the genome of an organism by adding a gene from another organism, to give it a useful characteristic. Bacteria have been engineered to make human insulin, used to treat diabetes. Each **GM crop** 转基因作物 has a gene that makes it resistant to insects or to herbicides, giving bigger yields. Genetic engineering might one day cure some inherited disorders.

How it is done (HT):

1. enzymes cut the wanted gene out of the DNA;
2. the gene is put into a **vector** 载体, usually a bacterial **plasmid** 质粒 or a virus;
3. the vector inserts the gene into the cells of the organism to be modified;
4. in plants and animals, genes are put in at an early stage, so all the cells of the organism develop with the new characteristic.

Benefits include more food and new medicines. Concerns include possible effects on wild flowers and insects, and on human health, which are not yet fully known.

Worked example 6. GM soya plants are resistant to the weedkiller glyphosate. Explain how spraying the field increases the yield. The glyphosate kills the weeds but not the soya. With less competition, the soya gets more light, water and mineral ions. More light and water mean more photosynthesis, so more glucose for growth, and more nitrate means more protein. The plants grow bigger and produce more beans.

Cloning (biology only).

- **Tissue culture** 组织培养: small groups of cells from a plant are grown into new identical plants, to preserve rare species or to grow many plants for sale.
- **Cuttings** 扦插: a gardener cuts a piece of stem and grows it into a new plant.
- **Embryo transplants** 胚胎移植: cells are split apart from a young animal embryo before they specialise, and each one grows into an identical embryo, which is placed in a host mother.
- **Adult cell cloning** 成体细胞克隆: the nucleus is removed from an unfertilised egg; the nucleus from an adult body cell is put in its place; an electric shock makes the egg divide into an embryo; the embryo is placed in the uterus of a host mother. Dolly the sheep, born in 1996, was cloned in this way.

Evidence for evolution (biology only)

Darwin and Wallace. Charles Darwin, after his voyage around the world on HMS *Beagle* and years of experiments, proposed the theory of evolution by natural selection. Alfred Russel Wallace reached the same idea independently; their papers were presented together in 1858, and Darwin published *On the Origin of Species* in 1859. Wallace also studied **warning colouration** 警戒色, the bright colours that warn predators an animal is poisonous, and how new species form.

Darwin's theory was accepted only slowly, because it challenged the belief that God made all living things, because there was not enough evidence at the time, and because nobody yet knew how characteristics were inherited. Jean-Baptiste Lamarck had earlier suggested that changes made during an organism's life are passed on; we now know this is wrong in almost all cases.

From Mendel to DNA. In the late 19th century, chromosomes were seen during cell division. In the early 20th century, scientists saw that Mendel's units behaved like chromosomes, and they were named genes. In the 1950s the structure of DNA was worked out, and then how genes work.

Evidence. Today the theory is supported by genetics, by fossils and by the evolution of **antibiotic resistance** 抗生素耐药性 in bacteria.

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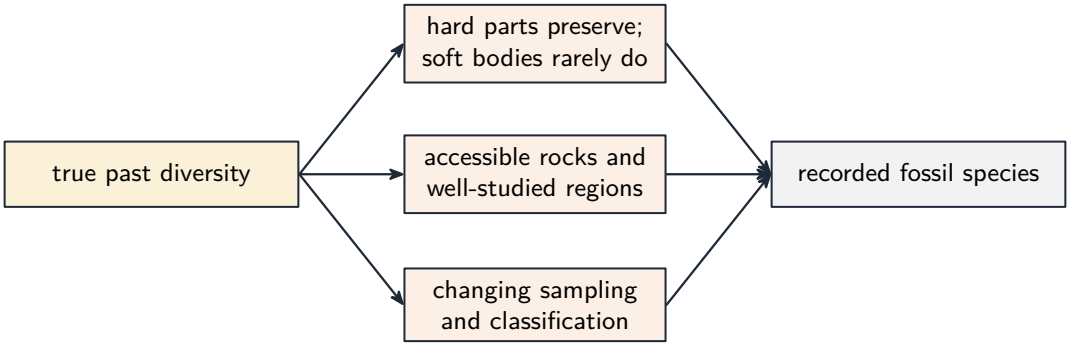


Pale and dark peppered moths on a tree trunk: the better-camouflaged form survives to breed

Fossils. A **fossil** 化石 is the remains of an organism from millions of years ago, found in rock. Fossils form:

- when parts of an organism do not decay, because one of the conditions for decay is missing;
- when parts are replaced by minerals as they decay;
- as preserved traces such as footprints, burrows and root traces; such a mark is a **trace fossil** 遗迹化石.

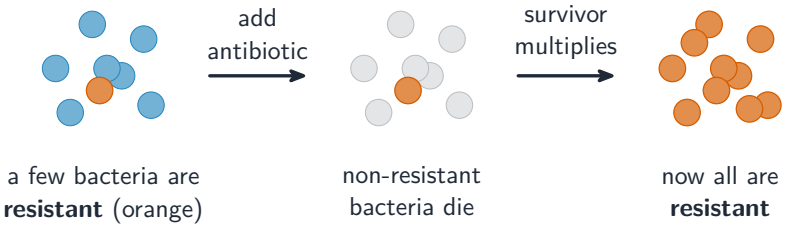
Fossils show how organisms changed over time. But the record is incomplete: many early forms of life were soft-bodied and left few traces, and many fossils have been destroyed by geological activity, so scientists cannot be certain how life began.



Why the fossil record is incomplete: each filter removes some past organisms

Extinction. A species is extinct when no individuals remain. Causes include new diseases, new predators, new competitors, changes in the environment over geological time, and single catastrophic events such as a large asteroid impact.

Resistant bacteria. Bacteria reproduce very fast, so they evolve fast. A mutation can make a bacterium resistant to an antibiotic. When the antibiotic is used, the bacteria that are not resistant die; the resistant ones survive, reproduce and pass on the resistance gene. MRSA is a strain of bacteria resistant to many antibiotics. To slow the spread of resistance, doctors should not prescribe antibiotics for viral or minor infections, patients should finish the course, and farmers should use fewer antibiotics. New antibiotics are expensive and slow to develop.



Resistant bacteria survive the antibiotic and multiply, so the population becomes resistant

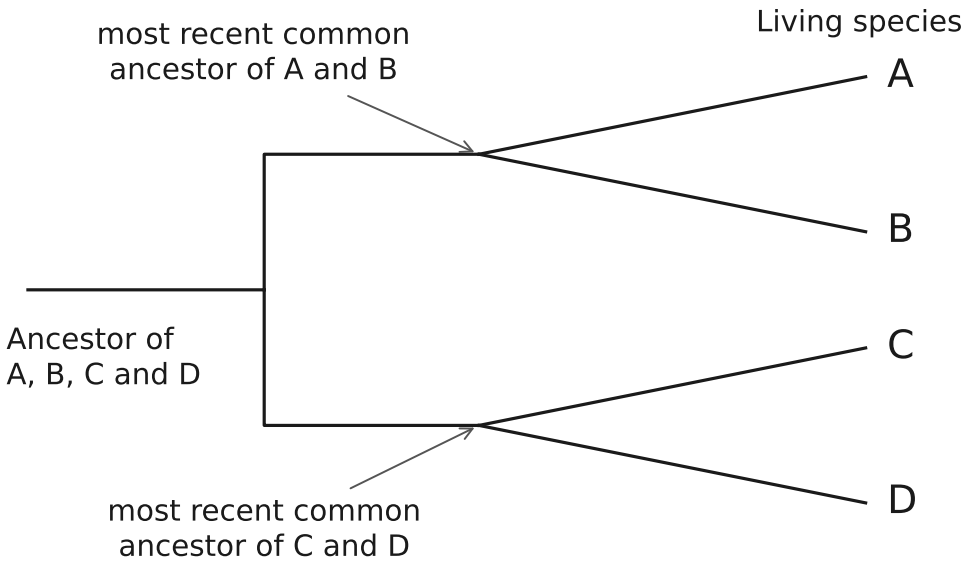
Classification

The Linnaean system. Carl Linnaeus classified living things by their structure and characteristics into groups: **kingdom** 界, **phylum** 门, **class** 纲, **order** 目, **family** 科, **genus** 属 and **species** 物种. In his **binomial system** 双名法, each organism has two names, its genus and its species: the lion is *Panthera leo* and the tiger *Panthera tigris*, so they are in the same genus.

The three domains. As microscopes and chemical analysis improved, scientists found that some organisms that looked alike were very different inside. In 1990 Carl Woese proposed the **three-domain system** 三域系统:

- **archaea** 古菌: primitive bacteria, often found in extreme places such as hot springs and salt lakes;
- bacteria: true bacteria;
- **eukaryota** 真核生物: protists, fungi, plants and animals.

Evolutionary trees. An **evolutionary tree** 进化树 shows how scientists think organisms are related, using classification data for living organisms and fossil data for extinct ones. Two species that branch from a recent fork share a recent **common ancestor** 共同祖先 and are closely related.



An evolutionary tree: A and B share a more recent common ancestor than A and C; branch lengths are not a time scale

Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.6 Inheritance, variation and evolution.
- G. Mendel, "Versuche über Pflanzen-Hybriden" (Experiments on plant hybrids), *Verhandlungen des naturforschenden Vereines in Brünn* 4 (1866), pages 3 to 47.
- C. R. Woese, O. Kandler and M. L. Wheelis, "Towards a natural system of organisms: proposal for the domains Archaea, Bacteria, and Eucarya", *Proceedings of the National Academy of Sciences* 87 (1990), pages 4576 to 4579.
- AQA, *GCSE Biology* Paper 2 Higher (June 2024), the insecticide, polydactyly and GM soya questions, adapted.

Common errors

- Saying meiosis makes two cells, or cells with 46 chromosomes; it makes four gametes with 23.
- Saying "dominant" means more common or stronger.
- Writing a gamete as Dd; each gamete carries one allele.
- Thinking earlier children change the probability for the next child.
- Saying organisms mutate "because they need to" or evolve during their own lifetime.
- Mixing up selective breeding (humans choose) and natural selection (the environment chooses).

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- Saying a species missing from one place is extinct.
- Reading branch lengths on an evolutionary tree as times when no scale is given.

Key terms

- **Meiosis**: cell division that makes four genetically different gametes with half the number of chromosomes.
- **Genome**: all the genetic material of an organism.
- **Allele**: a version of a gene.
- **Genotype**: the alleles an organism has.
- **Phenotype**: the characteristics that result from the genotype and the environment.
- **Natural selection**: the survival and reproduction of the individuals best suited to their environment.
- **Selective breeding**: humans choosing parents with useful characteristics to breed.
- **Genetic engineering**: adding a gene from one organism to the genome of another.
- **Speciation**: the formation of new species when populations can no longer interbreed.

Check yourself

1. How many gametes does meiosis make from one cell, and how many chromosomes does each human gamete have?
2. Give two advantages of asexual reproduction.
3. Define homozygous and heterozygous.
4. Two parents are Tt and tt, where T (tall) is dominant. What is the probability of a short child?
5. Explain why the probability of having a boy is 0.5.
6. Describe the steps of selective breeding, and give one risk.
7. (Biology only) Give three ways fossils can form.
8. (Biology only) Name the three domains.

Answers: 1. Four; 23. 2. Only one parent is needed; it is faster and produces many identical offspring when conditions are good. 3. Homozygous: two identical alleles; heterozygous: two different alleles. 4. Tt, Tt, tt, tt, so $\frac{1}{2}$. 5. All eggs carry X; half the sperm carry X and half Y, so XX and XY are equally likely. 6. Choose parents with the characteristic, breed them, choose the best offspring and repeat over many generations; inbreeding can cause inherited defects and less resistance to disease. 7. Parts that do not decay; parts replaced by minerals; preserved traces such as footprints. 8. Archaea, bacteria and eukaryota.

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7 · Ecology

AQA · GCSE · Biology

Ecology: communities, cycles and human impacts

Why it matters. In 1926 the last wolves in Yellowstone National Park, in the United States, were killed. Without them, elk herds grew and grazed the young willow and aspen trees along the rivers, so beavers and songbirds lost their food and homes. On 12 January 1995 the first of 31 grey wolves brought from Canada arrived in the park, and more followed in 1996. The wolves hunted elk, and elk began to avoid open river valleys where they were easy to catch. In some places willows grew back, and beaver colonies in the northern range rose from one to about nine. Ecologists still argue about how much of this was caused by the wolves, but the story shows the central idea of ecology: every organism depends on others and on its surroundings.

In this unit you will:

- describe communities, competition, interdependence and adaptations;
- explain abiotic and biotic factors, food chains and predator-prey cycles;
- sample organisms with quadrats and transects, and explain how carbon and water are recycled;
- explain how human activity affects biodiversity, and how it can be protected;
- (biology only) describe decay, trophic levels, biomass and food security.

AQA GCSE Biology (8461), topic 4.7 Ecology, examined on Paper 2. It includes required practicals 9 (estimating population size with quadrats and transects) and 10 (the effect of temperature on the rate of decay, biology only). Content marked (HT) is Higher tier only.

Communities and competition

An **ecosystem** 生态系统 is the interaction of a **community** 群落 of living organisms with the non-living parts of their environment. A **population** 种群 is all the organisms of one **species** 物种 in an area; a community is all the populations of different species living there.

Competition. Competition 竞争 happens when organisms need the same limited resource.

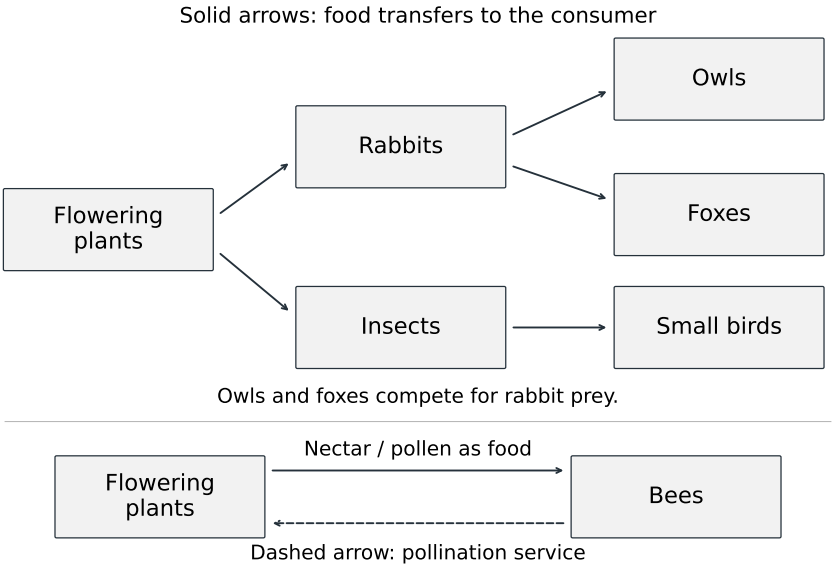
- Plants compete for light, space, water and mineral ions from the soil.
- Animals compete for food, mates and **territory** 领地.

Two kinds of **predator** 捕食者 may compete for the same **prey** 猎物.

Interdependence. In a community, species depend on each other for food, shelter, pollination and seed dispersal. This **interdependence** 相互依赖 means that removing or adding one species can affect many others. In a stable community, all the species

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and environmental factors are in balance, so population sizes stay roughly constant.



Feeding and pollination link species in a community.

Worked example 1. In a food web, bees feed on flowers and **pollinate** 传粉 them. If the bee population falls, explain one effect on the community. Fewer flowers are pollinated, so they make fewer seeds and fruits. Fewer new plants grow, so animals that eat these plants or their fruits have less food, and their numbers may fall.

Abiotic and biotic factors

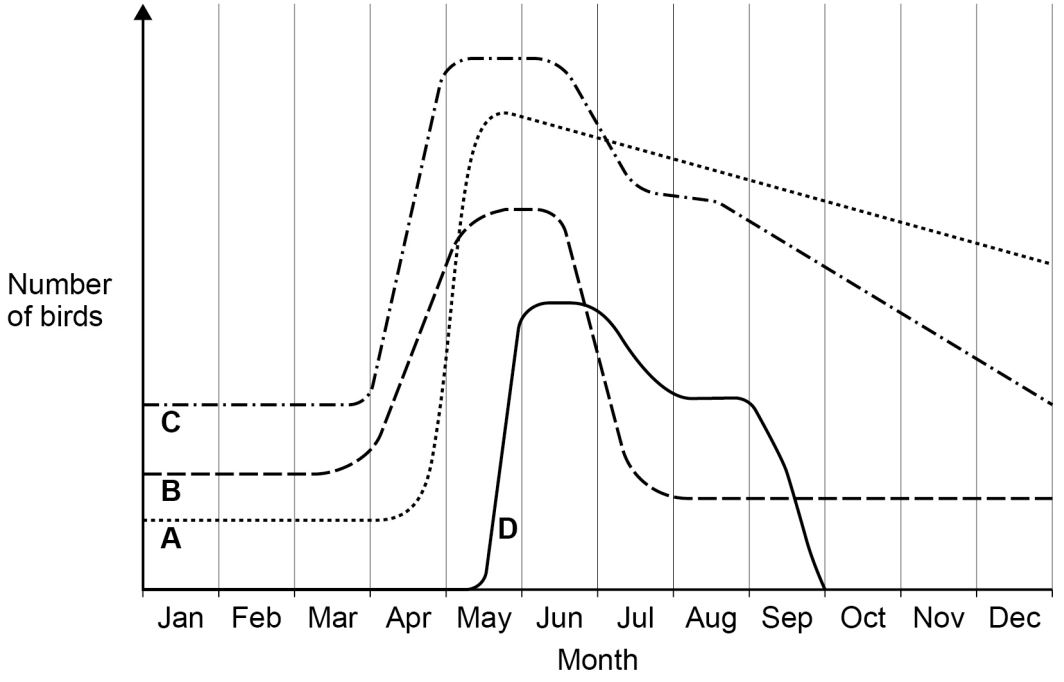
Abiotic factors 非生物因子 are non-living. They include light intensity, temperature, moisture, soil pH and mineral content, wind speed and direction, carbon dioxide for plants, and oxygen for aquatic animals.

Biotic factors 生物因子 are living. They include the availability of food, new predators arriving, new **pathogens** 病原体, and one species outcompeting another.

Worked example 2. Daisies grow more thickly further from a tree. Suggest three abiotic factors, other than soil water, that could explain this. Light intensity (the tree shades the ground), soil pH and soil mineral ion content. Temperature or wind would also be acceptable. Choose factors that fit the situation, and do not repeat the one already given.

Reading population graphs. Worked example 3. A graph shows the numbers of four bird species through one year. Species A stays constant from January to March, increases in April and May, then decreases until December. Species D is present only from about May to September, so it is probably a species that migrates. The vertical

axis has no numbers, so you can describe trends but cannot calculate percentage changes.



Four bird populations through one year (AQA GCSE Biology Paper 2H, June 2023, Figure 2).

Adaptations

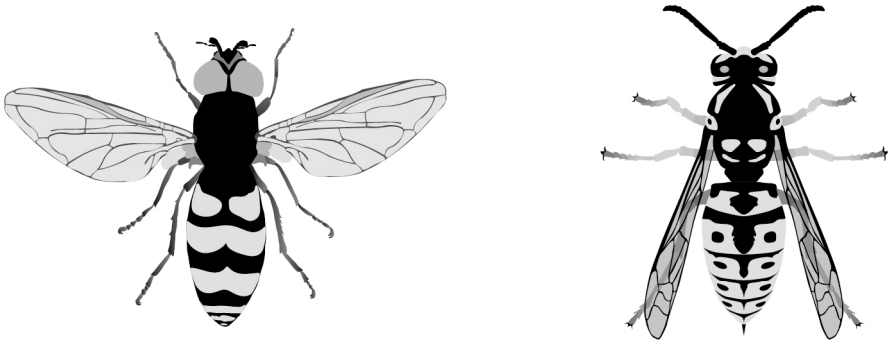
Organisms have features, called **adaptations** 适应性, that help them survive in their normal conditions.

- Structural adaptations are features of the body, such as thick fur or a layer of fat for insulation in the cold.
- Behavioural adaptations are the ways organisms behave, such as **migration** 迁徙 to warmer places in winter.
- Functional adaptations are processes inside the body, such as making venom or producing very concentrated urine in the desert.

Worked example 4. A hoverfly has yellow and black stripes like a wasp, but cannot sting. Explain how this helps it survive. The hoverfly looks like a wasp. Predators avoid wasps because they sting, so predators are also less likely to attack the hoverfly.

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Figure 1



Hoverfly **Wasp**

A hoverfly (no sting) and a wasp (AQA GCSE Biology Paper 2H, June 2024, Figure 1).

Extremophiles. An **extremophile** 极端微生物 lives in conditions that would kill most organisms, such as very high temperatures, high pressure or very salty water. Bacteria living around deep-sea hot water vents are examples.

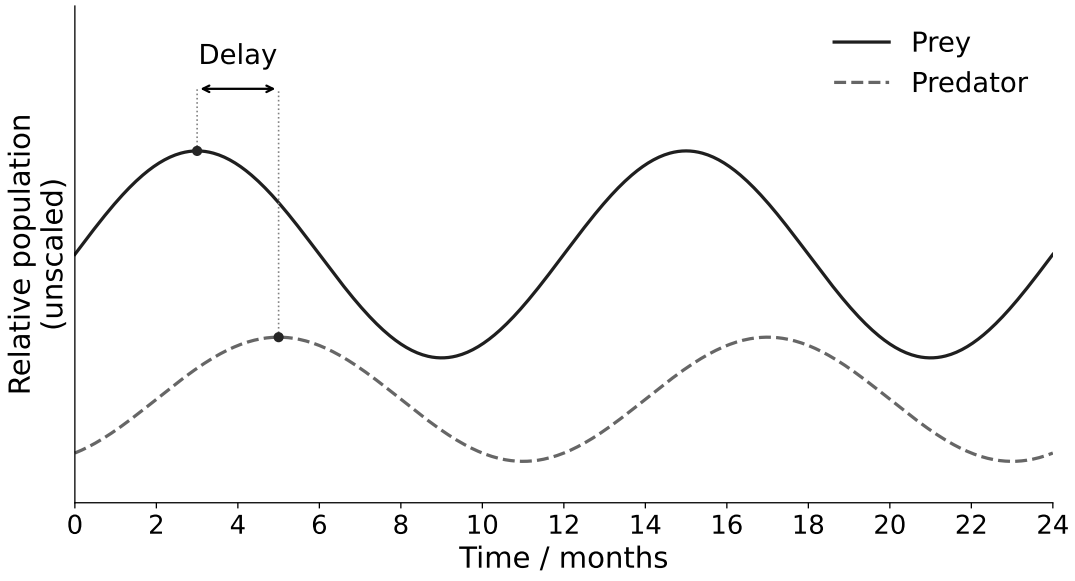
Food chains and sampling

Food chains 食物链 show feeding relationships. Each chain starts with a **producer** 生产者, a green plant or alga that makes glucose by photosynthesis and so builds **biomass** 生物量. In the chain grass → rabbit → fox, the rabbit is the **primary consumer** 初级消费者 and the fox is the **secondary consumer** 次级消费者. The arrows show the direction in which food, and so energy, is transferred.

Predator-prey cycles. When prey are plentiful, more predators survive and breed, so predator numbers rise. More predators eat more prey, so prey numbers fall. With less food, predator numbers then fall, so prey numbers recover. Predator peaks come a little after prey peaks.

> **Worked example 5.** In a graph of predator and prey numbers, the prey peak at month 3 and the predators peak at month 5. The delay is $5-3=2$ months, because predators take time to breed in response to more food.

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Predator peaks come two months after prey peaks.

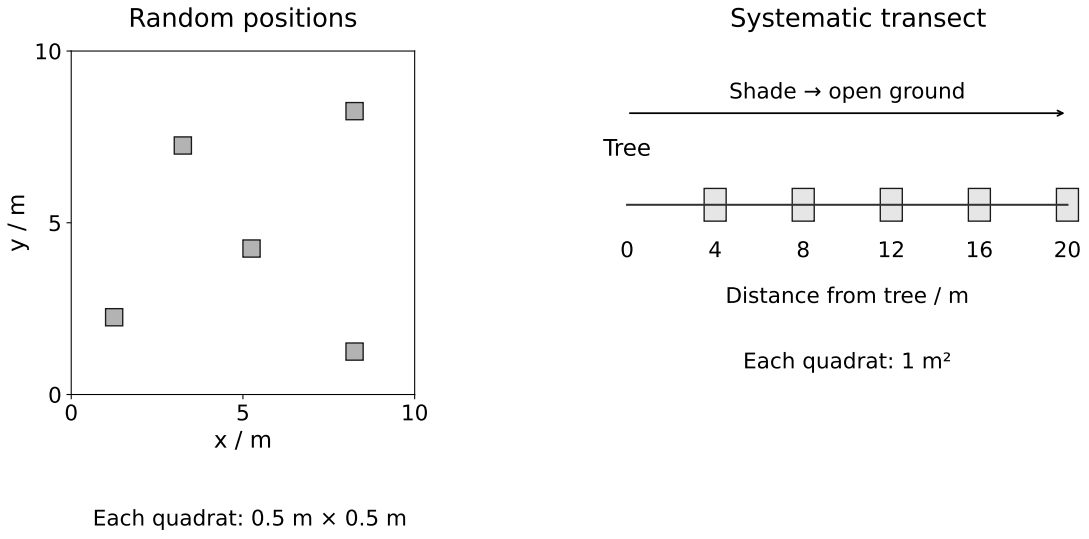
Required practical 9: sampling with quadrats. A **quadrat** 样方 is a square frame used to count organisms in a small area.

- To estimate a population in a field, place quadrats at random positions, using random numbers as coordinates, count the organisms in each, and calculate a mean.
- To see how a species changes across a habitat, for example from shade into open ground, lay a tape measure as a **transect** 样带 and place quadrats at regular distances along it. At each one, count the organisms and measure a factor such as light intensity.



A quadrat: place it at random coordinates and count, to estimate a population.

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Random 0.25 m^2 quadrats (left) and 1 m^2 quadrats at regular distances along a transect (right).

Worked example 6. Five random 0.25 m^2 quadrats in a 100 m^2 field contain 4, 6, 6, 8 and 11 plants. The mean is $\frac{4+6+6+8+11}{5} = 7$ plants per quadrat. The median and mode are both 6. The density is $7 \div 0.25 = 28$ plants per m^2, so the estimated population is $28 \times 100 = 2800$ plants. This assumes the quadrats are representative of the whole field.

Worked example 7. Soil samples were dried at 100 °C until their mass stopped changing, which shows that all the water had gone. At 20 m from a tree, 252 g of fresh soil dried to 181 g. The mass of water was $252 - 181 = 71$ g, so the percentage of water was $\frac{71}{252} \times 100 = 28\%$. To make the conclusion more reliable, repeat at each distance and calculate means.

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Table 2

	Distance from the tree in metres				
	4	**8**	**12**	**16**	**20**
Mass of fresh soil in grams	250	266	260	248	252
Mass of dried soil in grams	225	234	209	184	181
Mass of water lost from soil in grams	25	32	51	64	71
Percentage of water in soil	10	12	20	26	**X**
Number of daisies per m^2	0	7	15	28	32

Soil water and daisies at five distances (AQA GCSE Biology Paper 2H, June 2025, Table 2).

Recycling materials

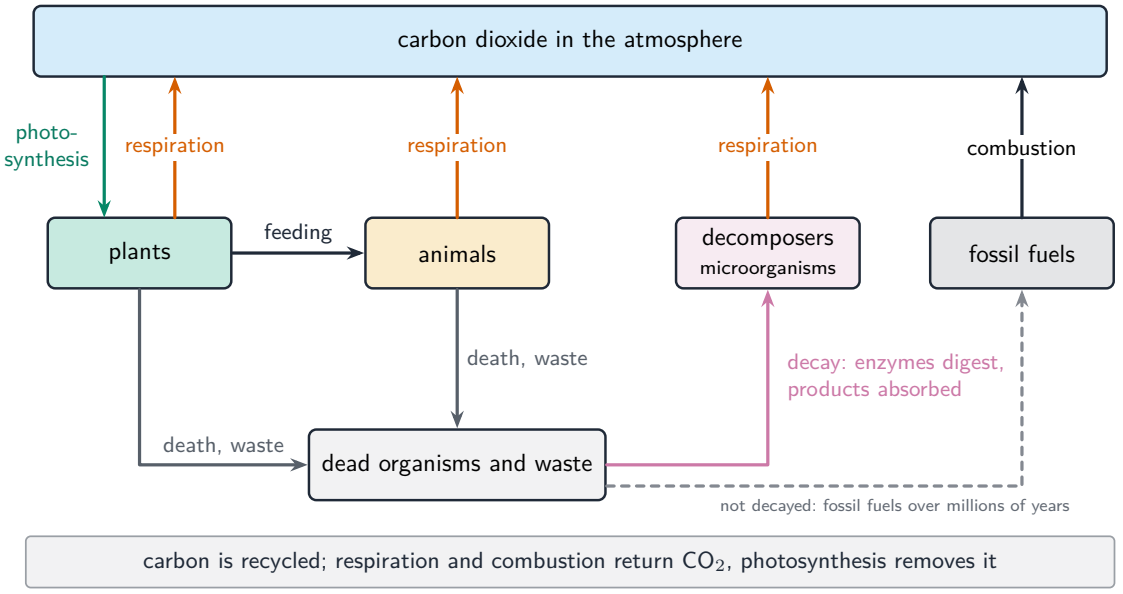
Materials such as carbon, water and mineral ions are recycled through living things and the environment, so they can be used again.

The carbon cycle.

- Photosynthesis by plants and algae takes carbon dioxide from the air and turns it into glucose and other carbon compounds.
- Feeding passes these carbon compounds along food chains.
- Respiration by plants, animals and microorganisms releases carbon dioxide back into the air.
- When organisms die, microorganisms (decomposers) break down their bodies and waste, and their respiration releases carbon dioxide.
- Combustion of wood and fossil fuels also releases carbon dioxide.

Decomposers also return mineral ions to the soil, where plants absorb them again.

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Feeding, decay and respiration are separate processes; combustion releases CO_2 but is not respiration.

The water cycle. Water **evaporation** 蒸发 from seas and lakes, and **transpiration** 蒸腾作用 from plants, put water vapour into the air. As the air cools, **condensation** 凝结 forms clouds, and **precipitation** 降水 (rain, snow and hail) returns water to the land and the sea. Evaporation leaves salts behind, so precipitation provides fresh water on land.

> **Worked example 8.** Explain how carbon and nitrogen in fallen leaves can be used again by a tree. Decomposers such as bacteria and fungi break down the leaves using enzymes. Their respiration releases carbon dioxide, which enters the tree's leaves through the **stomata** 气孔 and is used in photosynthesis. Nitrogen compounds in the leaves are turned into nitrate ions in the soil, which the roots absorb and use to make amino acids and proteins.

Decay (biology only)

Decomposition 腐解 is the breakdown of dead material by bacteria and fungi. It is faster when:

- it is warm, because the microorganisms' enzymes work faster (but very high temperatures denature them);
- it is moist, because microorganisms need water;
- there is plenty of oxygen, for aerobic respiration.

Gardeners turn their **compost** 堆肥 heaps to let in oxygen; the compost is used as a natural fertiliser. When there is no oxygen, anaerobic decay produces methane gas.

In a biogas generator this gas is collected and burned as a fuel.

Required practical 10: temperature and decay. Fresh milk goes sour as bacteria break down its fat into fatty acids, so its pH falls. Keep samples of the same milk at several temperatures and measure the pH every day, using the same volume of milk each time.

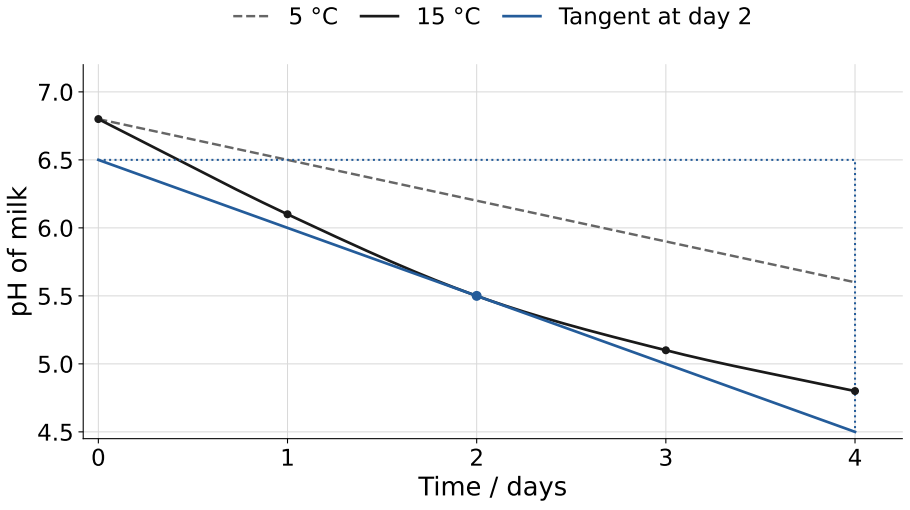
Table 1

Time in days	pH of milk		
	5 °C	15 °C	25 °C
0	6.8	6.8	6.8
1	6.5	6.1	5.3
2	6.2	5.5	4.9
3	5.9	5.1	4.8
4	5.6	4.8	4.8

Milk pH over time at three temperatures (AQA GCSE Biology Paper 2H, June 2023, Table 1).

Worked example 9. At 15 °C, a **tangent** 切线 drawn to the pH curve at day 2 passes through pH 6.5 at day 0 and pH 4.5 at day 4. The rate of pH change is $\frac{4.5-6.5}{4} = -0.5$ pH units per day. At 5 °C it is 0.3 pH units per day, so the rate at 15 °C is $\frac{0.5}{0.3} = 1.67$ times as fast. At the higher temperature the bacteria's enzymes are more active, so the fat is broken down faster and the pH falls faster.

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The milk data plotted, with a tangent drawn at day 2 on the 15 °C curve.

Environmental change (biology only, HT). Changes in temperature, rainfall and the gases in the atmosphere change where species can live. The changes may be seasonal, geographic or caused by human activity.

Biodiversity and human impacts

Biodiversity 生物多样性 is the variety of different species on Earth or in an ecosystem. High biodiversity makes an ecosystem more stable, because species depend less on any one other species for food, shelter and keeping the environment as it is. Our own future depends on keeping biodiversity high.

Waste and pollution. The human population is growing quickly, and people use more resources and produce more waste. Unless waste is handled properly, it causes **pollution** 污染, which kills plants and animals and reduces biodiversity:

- in water, from **sewage** 污水, **fertiliser** 化肥 washed off fields, and toxic chemicals;
- in the air, from smoke and acidic gases;
- on land, from **landfill** 垃圾填埋 and toxic chemicals.

Land use. Building, quarrying, farming and dumping waste destroy habitats. Large areas of tropical forest are cleared, an activity called **deforestation** 森林砍伐, to provide land for cattle and rice fields and to grow crops for biofuels. This destroys habitats, and fewer trees take in carbon dioxide; burning or rotting the wood releases more.

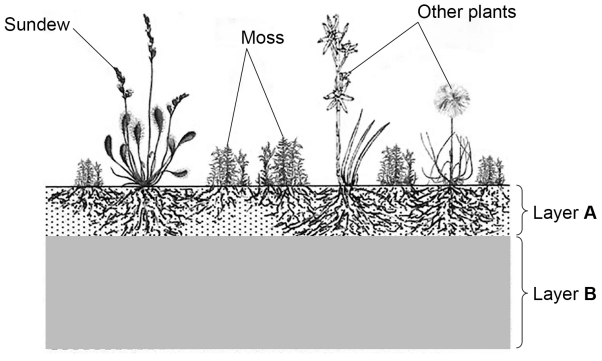
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Clearing forest destroys habitats and reduces biodiversity.

Peat bogs. Peat 泥炭 forms in bogs where dead plants decay very slowly, because the waterlogged soil has little oxygen and is acidic. It stores a lot of carbon. When peat is dug up to burn as fuel or to use as compost, the carbon is released as carbon dioxide, and stored **methane** 甲烷 escapes.

Figure 2



Layer **A** contains a lot of air.

Layer **B**:

- contains the dead remains of plants
- has a low pH
- contains very little oxygen
- contains carbon dioxide and methane.

Layers in a peat bog (AQA GCSE Biology Paper 2H, June 2024, Figure 2).

Global warming. Rising levels of carbon dioxide and methane, both **greenhouse gases** 温室气体, are causing **global warming** 全球变暖. Its effects include loss

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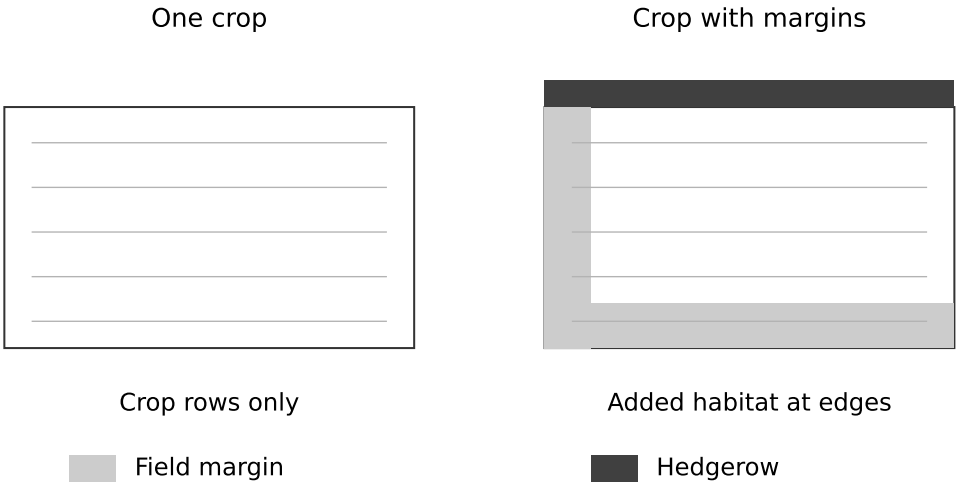
of habitat as sea levels rise, changes in where species live, and changes in migration patterns. Species that cannot move or adapt may face **extinction** 灭绝.

> **Worked example 10.** Describe the local and global effects of destroying a peat bog. Locally, the plants and animals that live only in the bog lose their habitat, food and shelter, so they die or move away, and local biodiversity falls. Globally, carbon dioxide and methane are released, which add to global warming. This changes temperatures, rainfall and sea levels around the world, so some species elsewhere lose their habitats or food, and some may become extinct.

Protecting biodiversity. Scientists and governments work to:

- run **breeding programmes** 繁育计划 for **endangered species** 濒危物种;
- protect and regenerate rare habitats such as mangroves and peat bogs;
- put **field margins** 田边地带 and **hedgerows** 树篱 back around fields of a single crop, giving food and shelter to many species;
- reduce deforestation and carbon dioxide emissions;
- recycle resources rather than dumping waste in landfill.

These aims can conflict with the need for land for food, housing and jobs, so decisions involve trade-offs.

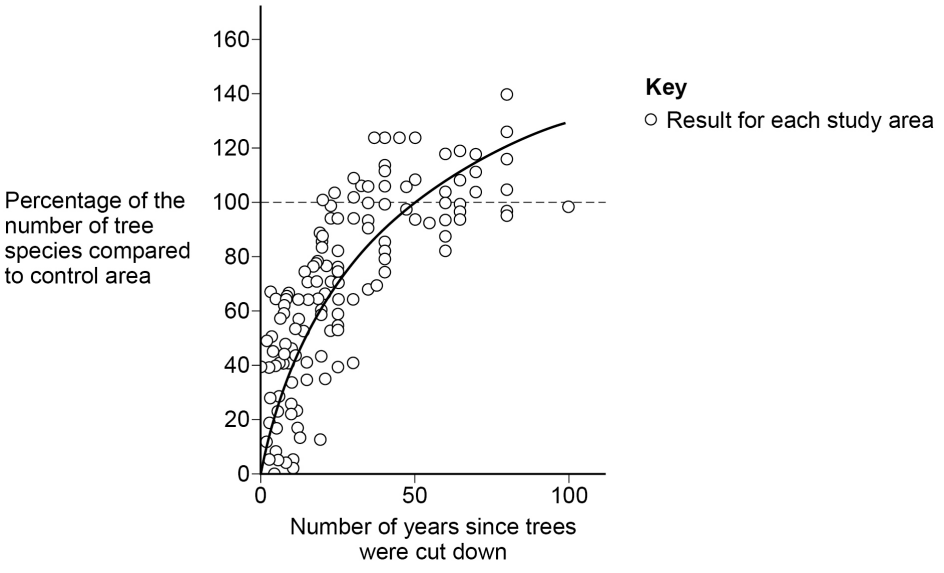


Field margins and hedgerows give food and shelter to many species.

> **Worked example 11.** A graph shows the number of tree species in cleared areas recovering over time, as a percentage of an undisturbed area nearby. Percentages are used because the areas started with different numbers of species. Recovery is fast at first, then slower. More tree species provide more kinds of food and habitat for animals.

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Figure 11



Recovery of tree species after clearing (AQA GCSE Biology Paper 2H, June 2023, Figure 11).

Trophic levels and biomass (biology only)

Trophic levels 营养级 are the feeding levels in a food chain:

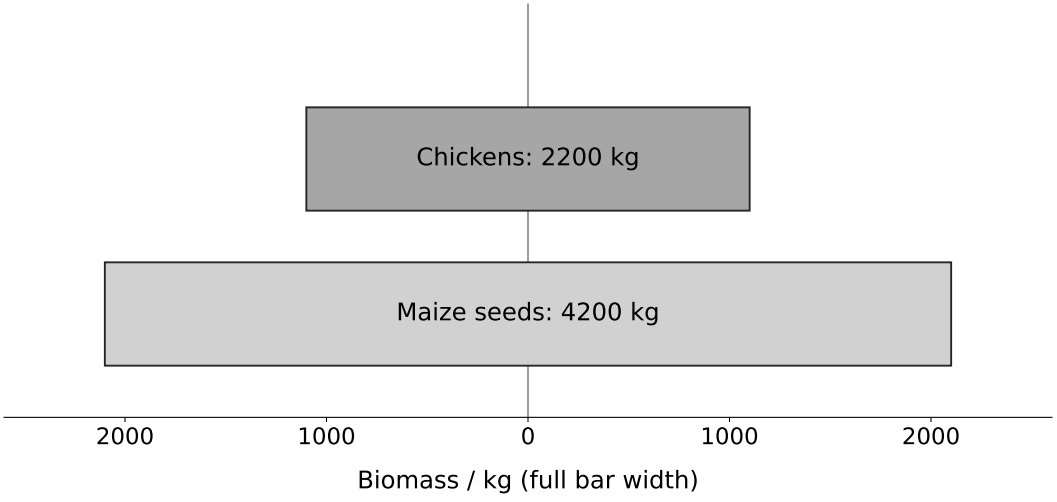
1. producers (plants and algae);
2. primary consumers, which are **herbivores** 食草动物;
3. secondary consumers, which are **carnivores** 食肉动物 that eat herbivores;
4. **tertiary consumers** 三级消费者, carnivores that eat other carnivores.

Apex predators 顶级捕食者 are carnivores with no predators. Decomposers break down dead plant and animal material from every level by releasing enzymes and absorbing the small soluble molecules.

Pyramids of biomass. A **pyramid of biomass** 生物量金字塔 shows the mass of living material at each trophic level, drawn to scale, with producers at the bottom.

> **Worked example 12.** 4200 kg of maize feeds 1000 chickens with a mean mass of 2.2 kg. The chickens' total biomass is $1000 \times 2.2 = 2200$ kg. The ratio of chicken to maize biomass is $2200 : 4200 = 11 : 21$.

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Pyramid of biomass for maize and chickens, drawn to scale with producers at the bottom.

Transfer of biomass. Producers transfer only about 1% of the light energy that falls on them into biomass, and only about 10% of the biomass at one level becomes biomass at the next. Biomass is lost because:

- not all of an organism is eaten, such as roots and bones;
- not all the food eaten is absorbed; some passes out as **faeces** 粪便;
- much of the absorbed glucose is used in respiration, releasing carbon dioxide and water, and some is lost as urea in urine.

So there is less biomass at each level, which is why food chains rarely have more than four or five links.

$$\text{efficiency} = \frac{\text{biomass transferred to the next level}}{\text{biomass available}} \times 100$$

Worked example 13. 200 kg of plants supports 18 kg of herbivores. Efficiency $= \frac{18}{200} \times 100 = 9\%$.

Food security (biology only)

Food security 粮食安全 means having enough food to feed a population. It is threatened by a rising birth rate, changing diets in richer countries that need more food from poorer ones, new pests and pathogens, environmental changes such as droughts, the cost of farming, and conflicts.

Efficient food production. Farmers can raise animals more efficiently by limiting their movement and keeping them warm, so that less energy is used in respiration for

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movement and keeping warm, and more goes into growth. They are fed high-protein food. Many people think these methods are cruel to the animals.

> **Worked example 14.** 1000 chickens each need 46 MJ of energy. One hectare (10 000 m^2) of maize produces 16 400 kg, which supplies 16 MJ per kg, of which 80% can be used. Usable energy per hectare $= 16\,400 \times 16 \times 0.8 = 209\,920$ MJ. Area needed $= \frac{46\,000}{209\,920} \times 10\,000 = 2190\ m^2$ (3 s.f.).

Sustainable fisheries. Fish stocks in the oceans are falling. Controls on the **mesh** 网眼 size of nets let young fish escape to breed, and **fishing quotas** 捕捞配额 limit the number of fish that may be caught.

Biotechnology. The fungus ***Fusarium*** 镰刀菌 is grown in large vats on glucose syrup with plenty of oxygen; its biomass is purified to make **mycoprotein** 菌蛋白, a protein-rich food for vegetarians. **GM crops** 转基因作物 could give bigger yields or more nutritious food, such as golden rice, which contains extra vitamin A. Genetically modified bacteria also make human insulin, though this is a medicine, not a food.

Sources for this lesson

- AQA, *GCSE Biology (8461) specification*, section 4.7 Ecology, and the required practical handbook.
- National Park Service, *Yellowstone Wolf Project Annual Report 1995*, and D. W. Smith and G. Ferguson, *Decade of the Wolf: Returning the Wild to Yellowstone* (2005).
- AQA, *GCSE Biology* Paper 2 Higher (June 2023 to June 2025), the bird population, hoverfly, soil water, milk decay, peat and chicken questions, adapted.

Common errors

- Defining a community as one species; it is all the populations in an area.
- Saying plants compete for food; they compete for light, space, water and mineral ions.
- Reading food chain arrows as "is eaten by" backwards; they point to the organism that eats.
- Placing quadrats where the plants look interesting instead of at random.
- Saying respiration and combustion are the same process.
- Saying biodiversity is the number of organisms; it is the variety of species.
- Using 10% when the question gives the actual masses.
- Saying keeping animals warm stops them respiring; it reduces the energy used to keep warm.

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Key terms

- **Ecosystem**: a community of organisms interacting with the non-living parts of its environment.
- **Interdependence**: species depending on each other for food, shelter, pollination and seed dispersal.
- **Abiotic factor**: a non-living factor that affects organisms.
- **Biotic factor**: a living factor that affects organisms.
- **Quadrat**: a square frame used to sample organisms in an area.
- **Biodiversity**: the variety of all the different species in an area.
- **Trophic level**: a feeding level in a food chain.
- **Food security**: having enough food to feed a population.

Check yourself

1. Name three things plants compete for and three things animals compete for.
2. Give two abiotic and two biotic factors.
3. Explain the shape of a predator-prey graph.
4. Describe how to estimate the number of daisies on a school field.
5. Describe how carbon in a dead leaf returns to the air.
6. Give three ways humans reduce biodiversity, and two ways it can be protected.
7. (Biology only) Give two reasons why biomass is lost between trophic levels.

Answers: 1. Plants: light, water, mineral ions (or space); animals: food, mates, territory. 2. Abiotic: light intensity, temperature (or moisture, soil pH, wind, carbon dioxide); biotic: food availability, new predators (or pathogens, competition). 3. More prey means more predators survive and breed; more predators eat more prey, so prey fall; then predators run short of food and fall, and the prey recover. 4. Place quadrats at random coordinates, count the daisies in each, find the mean per quadrat, divide by the quadrat area and multiply by the area of the field. 5. Decomposers break the leaf down and release carbon dioxide by respiration. 6. Pollution, deforestation, destroying peat bogs (or building, global warming); breeding programmes, hedgerows and field margins (or protecting habitats, recycling). 7. Not all of an organism is eaten; some food passes out as faeces; much glucose is used in respiration.

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