Course Companion

IGCSE Biology

Every topic handout in one volume

全部专题讲义合集

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Characteristics and classification of living organisms

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The seven characteristics of living organisms

Every living thing shares the same seven **characteristics** 特征 – seven **life processes** 生命过程 that all **organisms** 生物体 carry out. You can remember them with the letters **MRS GREN**. The examiner gives marks for the exact wording, so learn each definition.

M	Movement
R	Respiration
S	Sensitivity
G	Growth
R	Reproduction
E	Excretion
N	Nutrition

The seven life processes spell MRS GREN

- **Movement** 运动 – an action by an organism, or part of an organism, that changes its position or place.
- **Respiration** 呼吸作用 – the chemical reactions in **cells** 细胞 that break down **nutrient molecules** 营养物质 and release **energy** 能量 for **metabolism** 新陈代谢.
- **Sensitivity** 应激性 – the ability to detect and respond to changes in the internal or external **environment** 环境.
- **Growth** 生长 – a permanent increase in size and **dry mass** 干重.
- **Reproduction** 生殖 – the processes that make more of the same kind of organism.
- **Excretion** 排泄 – the removal of the **waste products** 废物 of metabolism, and of substances the body has in excess (more than it needs).

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- **Nutrition** 营养 – the taking in of materials for energy, growth and development.

Metabolism means all the chemical reactions that happen inside an organism's cells.

Classification: sorting living things into groups

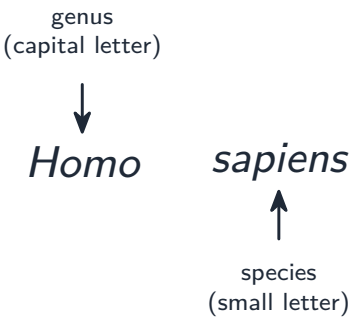


A museum insect drawer: classification groups organisms by the features they share

There are millions of kinds of living thing. To study them, scientists **classify** 分类 them – they sort them into groups by the features they share. Organisms in the same group share more features with each other than with organisms in other groups.

Species and the binomial system

The smallest common group is the **species** 物种. A species is a group of organisms that can reproduce to make **fertile offspring** 可育后代 ("fertile" means the offspring can themselves go on to have young).



A scientific name: a capital-letter genus and a small-letter species

Each species has a two-part **scientific name** 学名. This way of naming is the **binomial system** 双名法 – a system agreed all over the world, so every scientist uses the same name.

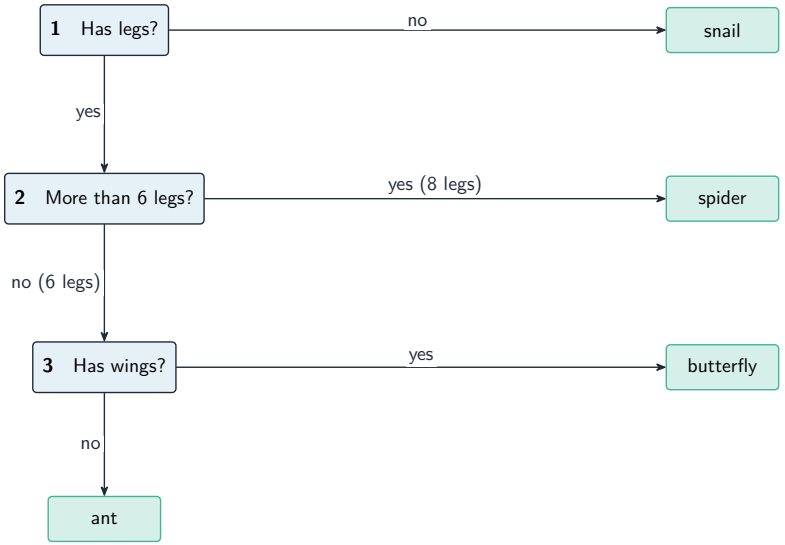
- The **first** part is the **genus** 属 (a larger group that the species belongs to). It starts with a capital letter.
- The **second** part is the species. It starts with a small letter.

The whole name is written in italics, for example *Homo sapiens* (humans). Two rats named *Rattus norvegicus* and *Rattus rattus* belong to the same genus but are different species.

> **Worked example.** A horse and a donkey can mate and produce a mule, but mules cannot reproduce. Are horses and donkeys the same species? **No.** Members of one species produce **fertile** offspring; the mule is **infertile**, so the horse (*Equus caballus*) and the donkey (*Equus asinus*) are two species. Their names share the first part, *Equus*, which shows they belong to the same **genus**.

■ Dichotomous keys

A **dichotomous key** 二歧检索表 is a tool that helps you identify an unknown organism. "Dichotomous" means "splitting into two". At each step the key gives you **two** choices about a feature. You pick the one that fits your organism, and that choice sends you on to the next pair of choices. You repeat this until you reach the organism's name.



A dichotomous key: each step gives two choices until you reach the organism

When you build a key, choose clear features you can see – for example "has wings / has no wings" – not features that change, such as size.

> **Worked example.** A key reads: step **1**, has wings, go to **2**; no wings, go to **3**. Step **2**, one pair of wings, it is a housefly; two pairs of wings, it is a butterfly. An unknown insect has two pairs of wings. Step **1** only asks "wings or no wings?", so having wings sends you to step **2**. At step **2**, "two pairs" gives **butterfly**. Follow the route the key gives you, one step at a time - never jump straight to the name that looks right.

> **Worked example (constructing a key).** Construct a dichotomous key to identify these four animals: a spider (8 legs, no wings), a beetle (6 legs, wings), an ant (6 legs, no wings), and a centipede (many legs, no wings).

Choose one feature that splits the group, then keep splitting until each animal stands alone. With four animals you need **three** steps (one fewer than the number of organisms):

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Step	Choice	Go to
1	has wings	beetle
	has no wings	2
2	has 6 legs	ant
	does not have 6 legs	3
3	has 8 legs	spider
	has more than 8 legs	centipede

Each step is a pair of opposite statements about **one** feature you can see. Check the key by running each animal through it: every one must reach its own name.

■ Classification and DNA (Supplement)

Modern classification tries to show **evolutionary relationships** 进化关系 – how closely different organisms are related. Organisms that are more closely related share a more recent **ancestor** 祖先.

To measure this, scientists compare the **base sequence** 碱基序列 of DNA (the order of the chemical "letters" that make up an organism's **genes** 基因). The rule is simple:

- Organisms that share a **more recent** ancestor (more closely related) have **more similar** DNA base sequences.
- Organisms that share only a **distant** ancestor have **less similar** base sequences.

So a DNA base sequence can be used both to classify organisms and to work out how closely two species are related.

Worked example. The table shows the same short section of a gene in four species.

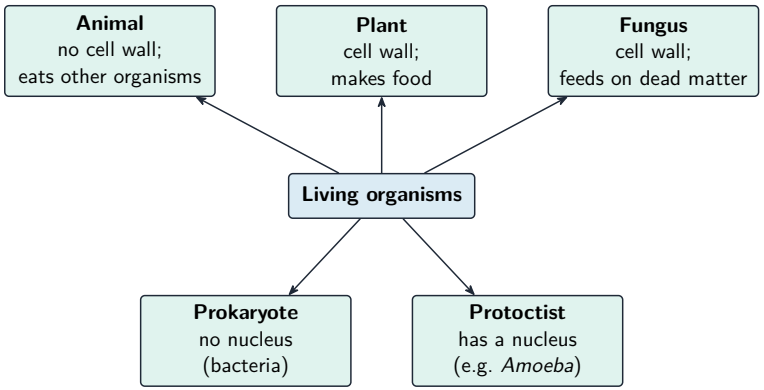
Species	Base sequence
P	A T G G C A T T C A
Q	A T G G C T T T C A
R	A T C G C T A T G A
S	A T G G C A T T C G

Which species is most closely related to P? Compare each sequence with P base by base and count the differences: Q differs at **1** position, R at **4**, S at **1**. Q and S are equally close to P and R is the most distant, so P shares its most recent ancestor with Q and S, and a much more distant one with R. A real study compares far longer sequences, so that a single difference does not decide the answer.

Kingdoms

The biggest groups that organisms are sorted into are called **kingdoms** 界. At Core level you place organisms into the first two kingdoms below; for Supplement you need all **five kingdoms**. You decide where an organism belongs by looking at its main features.

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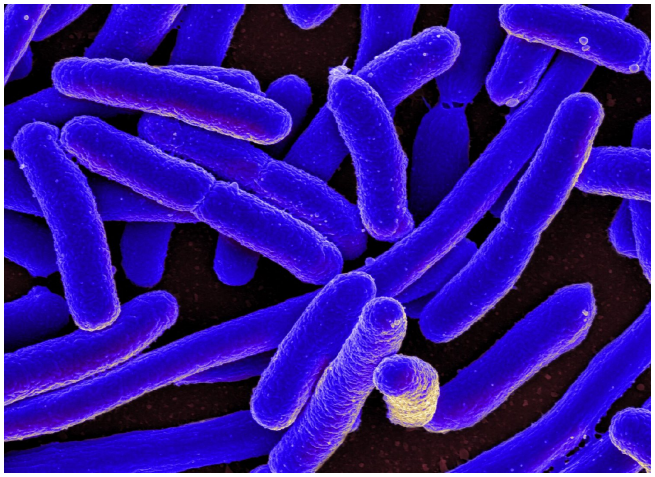
Living organisms are sorted into five kingdoms by their main features

Kingdom	Main features
Animal 动物	made of many cells; cells have no **cell wall** 细胞壁; cannot make their own food, so they feed on other organisms; most can move their whole body
Plant 植物	made of many cells; cells have a cell wall; make their own food by **photosynthesis** 光合作用, so many cells contain **chloroplasts** 叶绿体
Fungus 真菌	for example **moulds** 霉菌, **mushrooms** 蘑菇 and **yeast** 酵母; have cell walls; cannot photosynthesise; feed on dead or living matter
Prokaryote 原核生物	for example **bacteria** 细菌; **single-celled** 单细胞; cells have no **nucleus** 细胞核
Protoctist 原生生物	for example *Amoeba* and **algae** 藻类; usually single-celled; cells do have a nucleus

The fungus, prokaryote and protoctist kingdoms are Supplement only.



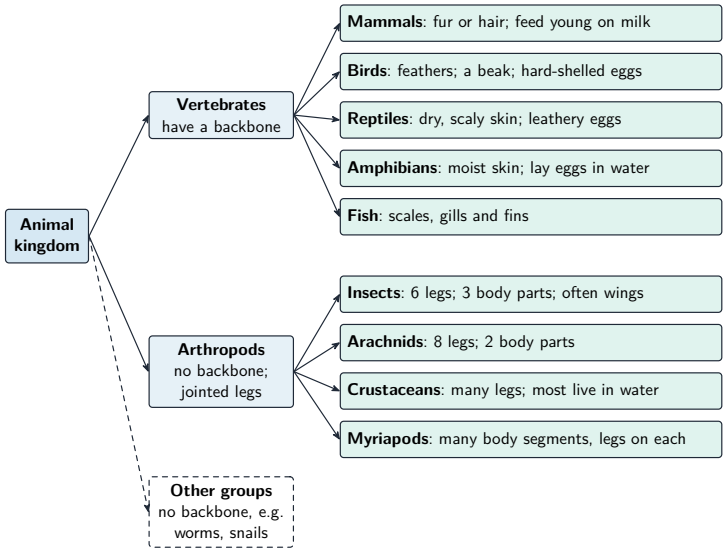
A fungus: the fly agaric, a mushroom



A prokaryote (bacterium): E. coli seen under an electron microscope

Grouping the animal kingdom

The animal kingdom is split first into two: animals with a backbone and animals without one.



Vertebrates have a backbone; arthropods are the largest of the groups without one, and other groups such as worms and snails have none either

Vertebrates 脊椎动物 are animals with a **backbone** 脊柱. There are five main groups.

Group	Main features
Mammals 哺乳动物	have **fur** 毛发 or hair; feed their young on milk
Birds 鸟类	have **feathers** 羽毛 and a **beak** 喙; lay eggs with hard shells
Reptiles 爬行动物	have dry skin covered with **scales** 鳞片; lay eggs with leathery shells on land
Amphibians 两栖动物	have moist skin; lay eggs in water; the young live in water
Fish 鱼类	have wet scales and **fins** 鳍; breathe using **gills** 鳃; lay eggs in water

Arthropods 节肢动物 are the largest group of animals with no backbone. They have a hard outer skeleton (an **exoskeleton** 外骨骼) and legs that bend at **joints** 关节. There are four main groups.

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Group	Main features
Insects 昆虫	body in 3 parts; 3 pairs of legs; usually 2 pairs of wings; 1 pair of **antennae** 触角
Arachnids 蛛形类	body in 2 parts; 4 pairs of legs; no wings; no antennae
Crustaceans 甲壳类	many pairs of legs; 2 pairs of antennae; most live in water
Myriapods 多足类	long body made of many **segments** 体节; one or two pairs of legs on each segment

Worked example. Classify each animal: (a) it has a backbone, dry scaly skin, and lays eggs with leathery shells on land; (b) it has no backbone, jointed legs, a body in two parts and four pairs of legs; (c) it has a backbone, moist skin, and its young live in water.

(a) **Reptile**: backbone, dry scales, leathery eggs on land. (b) **Arachnid**: jointed legs make it an arthropod, and two body parts with four pairs of legs is an arachnid. (c) **Amphibian**: moist skin, with young that live in water. Always state the group **and** the features from the description that place it there.

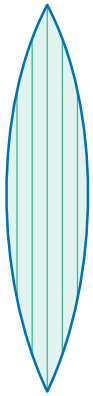
Grouping the plant kingdom (Supplement)

Plants are placed into groups too. You need two of them.

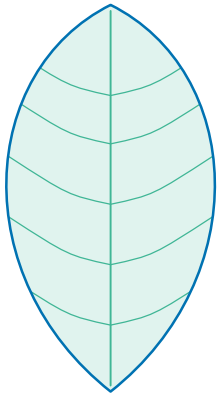
- **Ferns** 蕨类植物 – have roots, stems and leaves, but make **no** flowers or seeds. They reproduce using tiny **spores** 孢子.
- **Flowering plants** 开花植物 – make flowers, and form **seeds** 种子 inside the flower. They split into two groups by their seed-leaves (the first leaves inside a seed, called **cotyledons** 子叶):

Group	Features
Monocotyledons 单子叶植物	seed has **one** cotyledon; long narrow leaves; **veins** 叶脉 run side by side (parallel)
Dicotyledons 双子叶植物	seed has **two** cotyledons; broad leaves; veins form a branching net

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Monocotyledon
parallel veins, 1 cotyledon



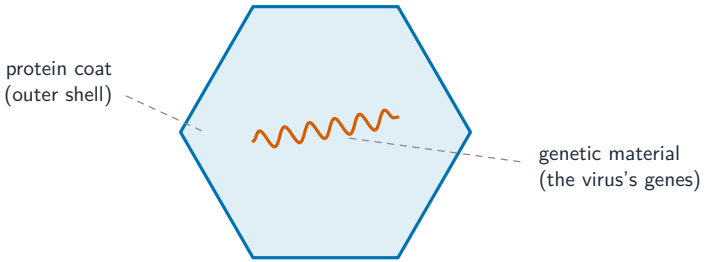
Dicotyledon
net (branching) veins, 2 cotyledons

Monocot leaves have parallel veins; dicot leaves have a net of branching veins

Viruses (Supplement)

Viruses 病毒 are not placed in any kingdom. They are not made of cells, so many scientists do not count them as living. A virus is very simple, with only two parts:

- an outer **protein coat** 蛋白质外壳, and
- **genetic material** 遗传物质 (its genes) inside.



A virus is just a protein coat around its genetic material

A virus cannot carry out the life processes on its own. It can only reproduce inside the living cells of a **host** 宿主 – the organism it infects.

Common mistakes.

- Writing "breathing" for respiration. Respiration is the **chemical reactions in cells** that release energy; breathing is only the movement of air in and out of the lungs.

- Defining growth as "getting bigger". Growth is a **permanent** increase in size and **dry mass**: a cell that swells with water has not grown.
- Saying excretion is getting rid of undigested food. Undigested food was never made by the body's cells, so removing it is not excretion.
- Writing *homo Sapiens*, or the species name first. The genus comes first with a capital letter, the species second with a small letter: *Homo sapiens*.
- Building a key on features such as "big / small" or "light / dark". Use features that are **clear and do not change**, such as the number of legs or "has wings / has no wings".
- Calling a spider an insect. A spider has **4 pairs of legs** and a body in 2 parts, so it is an arachnid; an insect has 3 pairs of legs.
- Calling a fungus a plant. Fungi have cell walls but **cannot photosynthesise**; they feed on dead or living matter.

Exam tips

- Learn the **seven characteristics** by heart, with their exact definitions. Write them as clear, full sentences.
- **Digestion** 消化 is *not* one of the seven characteristics – it is just one part of nutrition. "Breathing" is not one of the seven either.
- In a scientific name, the genus starts with a capital letter and the species with a small letter, and both are in italics.
- To use a dichotomous key, start at the first pair of choices and follow the route step by step. Do not jump ahead.
- More similar DNA base sequence → the organisms are more closely related (they share a more recent ancestor).

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Organisation of the organism

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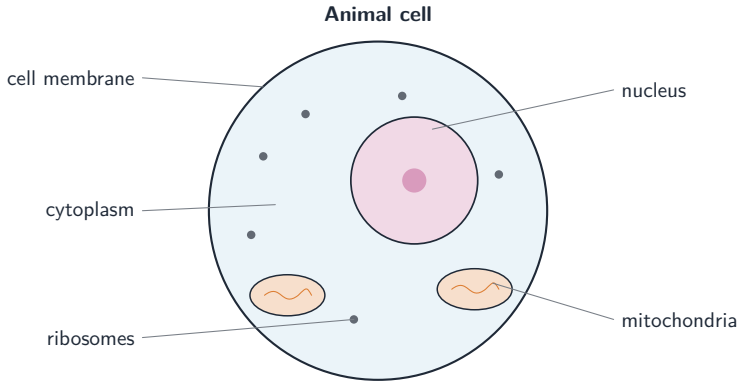
Cells: the building blocks of life

Every living thing is made of **cells** 细胞. A cell is the smallest part that can carry out the life processes. In this topic you compare a **plant** 植物 cell, an **animal** 动物 cell and the cell of a **bacterium** 细菌. All new cells are made by the **division** 分裂 of cells that already exist.

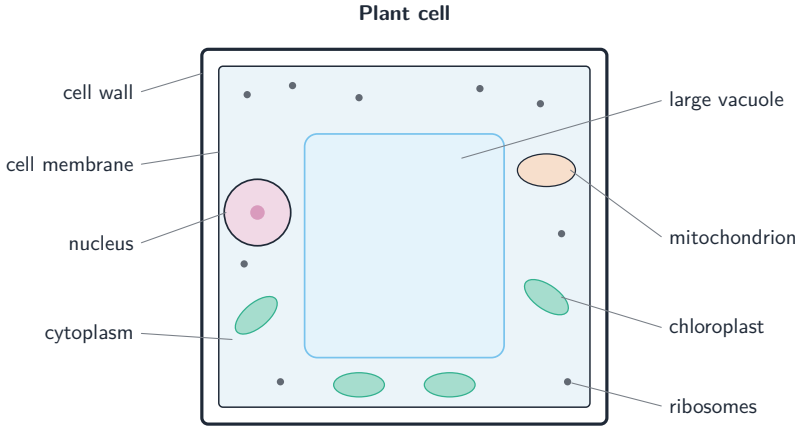
Which structures are in each cell?

Structure	Animal cell	Plant cell	Bacterial cell
cell membrane 细胞膜	yes	yes	yes
cytoplasm 细胞质	yes	yes	yes
ribosomes 核糖体	yes	yes	yes
nucleus 细胞核	yes	yes	no – has a loop of DNA instead
mitochondria 线粒体	yes	yes	no
cell wall 细胞壁	no	yes	yes (different material)
chloroplasts 叶绿体	no	yes (only in green parts)	no
large **vacuole** 液泡	no	yes	no
plasmids	no	no	sometimes

So plant and animal cells share five structures: cell membrane, cytoplasm, ribosomes, nucleus and mitochondria. A plant cell has three extra structures: a cell wall, a large vacuole and (in green parts) chloroplasts.

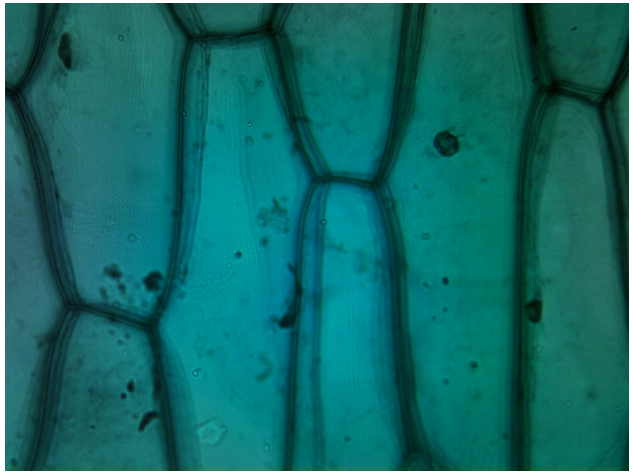


An animal cell: membrane, cytoplasm, nucleus, mitochondria and ribosomes



A plant cell also has a cell wall, a large vacuole and chloroplasts

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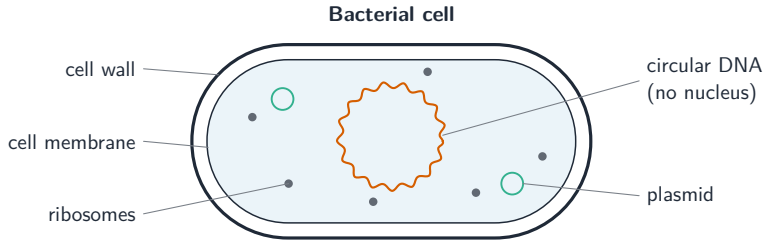
Onion epidermis cells under a light microscope – each cell has a clear cell wall

What each structure does

- **Cell membrane** – controls which substances enter and leave the cell.
- **Cytoplasm** – a jelly-like liquid where many chemical reactions happen.
- **Nucleus** – controls the cell's activities and holds the **genetic material** 遗传物质.
- **Ribosomes** – where **proteins** 蛋白质 are made.
- **Mitochondria** – where **respiration** 呼吸作用 happens to release **energy** 能量.
- **Cell wall** – made of **cellulose** 纤维素; it gives a plant cell strength and a fixed shape.
- **Chloroplasts** – contain **chlorophyll** 叶绿素, a green substance that traps light for **photosynthesis** 光合作用.
- **Large vacuole** – filled with **cell sap** 细胞液; it helps keep the plant cell firm.

Bacterial cells

A **bacterium** is a **prokaryote** 原核生物 – its cell has **no** nucleus. Instead its DNA is a single loop (a ring), loose in the cytoplasm. Bacteria also have small extra rings of DNA called **plasmids** 质粒. A bacterial cell has a cell wall and cell membrane, cytoplasm and ribosomes, but no mitochondria and no chloroplasts.



A bacterial cell has no nucleus – its DNA is a single loop, plus small plasmids

The parts of a bacterial cell do these jobs:

- **circular DNA** 环状 DNA – the single loop holds most of the genes, so it controls the cell's activities (the job a nucleus does in a plant or animal cell).
- **plasmids** – hold a few extra genes, for example a gene for resistance to an antibiotic. Plasmids can pass from one bacterium to another, and scientists use them to put new genes into bacteria.
- **cell wall** – keeps the shape of the cell and stops it bursting when water enters. It is **not** made of cellulose.
- **cell membrane, cytoplasm and ribosomes** – the same jobs as in other cells: control what enters and leaves, hold the reactions, and make proteins.

Bacteria have no mitochondria, but they still respire: the reactions of respiration happen in their cytoplasm and on their cell membrane.

Identifying a cell from a diagram

In the exam you are often shown an unfamiliar cell and asked what kind it is. Look for these clues, in this order:

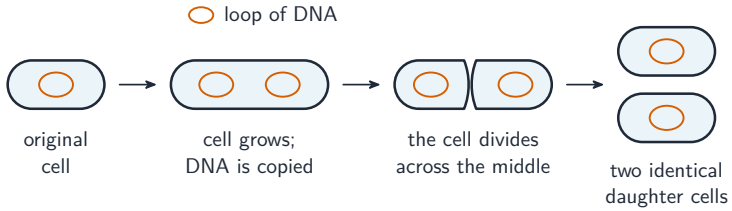
1. **Is there a nucleus?** No nucleus but a loop of DNA (and perhaps plasmids) → a **bacterium**.
2. **Is there a cell wall?** A nucleus but no cell wall → an **animal** cell.
3. **Are there chloroplasts or a large permanent vacuole?** A nucleus, a cell wall and chloroplasts → a **plant** cell (a plant cell from a root has no chloroplasts, but still has a cell wall and a large vacuole).

> **Worked example.** A single-celled organism, *Euglena*, has chloroplasts, a large permanent vacuole, a nucleus, cytoplasm and a cell membrane. Which of these would also be found in an animal cell? Animal cells have no chloroplasts and no large permanent vacuole, so the answer is **cell membrane, cytoplasm and nucleus**. A yeast cell (a fungus) is another trap: it has a nucleus, a cell wall and a vacuole but **no** chloroplasts, because it cannot photosynthesise.

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New cells come from old cells

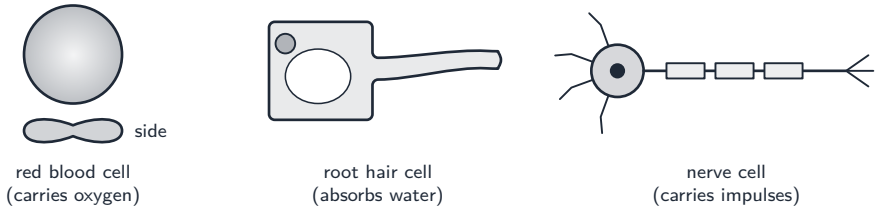
New cells are made **only** by the division of cells that already exist. When a cell divides, it first copies its genetic material, so each new cell gets a full copy. A bacterium grows, copies its loop of DNA and then splits into two **daughter cells** 子细胞, each with one loop of DNA. The two daughter cells are **genetically identical** 遗传上相同的 to the original cell.



A bacterium copies its DNA and divides into two genetically identical cells

Specialised cells

Most cells are **specialised cells** 特化细胞 – their shape and parts suit one special job.



Specialised cells have shapes that suit their jobs

Cell	Job	How its shape helps
ciliated cells 纤毛细胞	move **mucus** 黏液 along the **trachea** 气管 and **bronchi** 支气管	tiny hairs (cilia) on top sweep the mucus along
root hair cells 根毛细胞	**absorption** 吸收 of water and minerals from the soil	a long, thin "hair" gives a large surface
palisade mesophyll cells 栅栏叶肉细胞	photosynthesis	packed with chloroplasts, near the top of the leaf
neurones 神经元	carry **electrical impulses** 电脉冲	very long, to reach far across the body
red blood cells 红细胞	transport **oxygen** 氧气	no nucleus and a disc shape with a thin centre, to carry more oxygen
sperm 精子 and **egg cells** 卵细胞	reproduction	the sperm can swim; the egg cell stores food

Sperm and egg cells are the sex cells, called **gametes** 配子.

In an exam answer, link the **feature** to the **job** with "so" or "which means". For example:

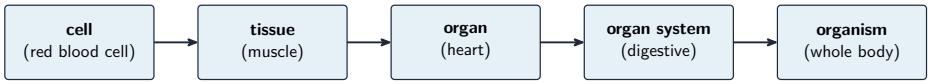
- **Ciliated cells** line the trachea and bronchi. **Goblet cells** next to them make mucus, which traps dust and bacteria; the cilia **beat** (wave) to sweep the mucus up to the throat, so the dirt is kept away from the lungs.
- A **root hair cell** has a long extension that gives a large **surface area**, so it absorbs water (by osmosis) and mineral ions faster. It has no chloroplasts, because it is underground in the dark.
- **Palisade mesophyll cells** are packed with chloroplasts and sit near the **upper** surface of the leaf, so they absorb as much light as possible.
- A **neurone** has a very long fibre, so one cell can carry an impulse a long way (for example from the spinal cord to a foot).
- A **red blood cell** contains **haemoglobin** 血红蛋白, which carries oxygen; having no nucleus leaves more room for haemoglobin, and the disc shape gives a large surface for oxygen to diffuse in and out.
- A **sperm** has a tail (flagellum) to swim to the egg and many mitochondria to release energy for swimming. An **egg cell** is large and has food stored in its cytoplasm for the early growth of the embryo.

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Levels of organisation

An **organism** 生物体 made of many cells is built up in levels, from small to large:

- **cell** – the smallest unit of life (for example a red blood cell).
- **tissue** 组织 – a group of similar cells that work together (for example **muscle** 肌肉).
- **organ** 器官 – several different tissues that work together to do a job (for example the heart, or a leaf).
- **organ system** 器官系统 – several organs that work together (for example the **digestive system** 消化系统, which breaks down food).
- **organism** – all the organ systems together make one whole living thing.



From a single cell up to the whole organism

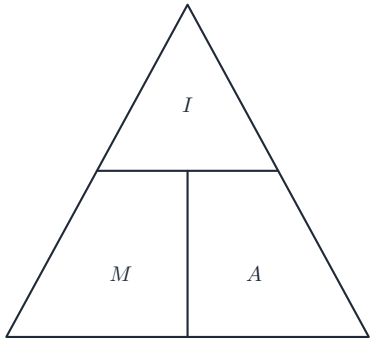
The size of cells: magnification

Cells are tiny, so you look at them under a **microscope** 显微镜, which makes them appear much larger. How many times larger the image is, is called the **magnification** 放大倍数.



A light microscope, used to look at cells

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



I = image size
M = magnification
A = actual size

$$M = \frac{I}{A}$$

cover a letter to get its formula

Cover the quantity you want in the triangle to read off its formula

- **image size** = the size in the drawing or photo.
- **actual size** = the real size of the **specimen** 标本.

Magnification has **no unit** – it is just a number, for example ×250. You can rearrange the formula:

$$\text{actual size} = \frac{\text{image size}}{\text{magnification}}, \qquad \text{image size} = \text{actual size} \times \text{magnification}$$

Worked example. A structure is shown at a magnification of 250. Its image size is 5.00 mm. So the actual size = 5.00 ÷ 250 = 0.02 mm. Always put both sizes in the **same unit** before you divide.

Changing units (Supplement)

Cells are often measured in **micrometres** 微米 (μm), which are smaller than millimetres (mm):

$$1 \text{ mm} = 1000 \ \mu\text{m}, \qquad 1 \ \mu\text{m} = 0.001 \text{ mm}$$

So 0.02 mm = 20 μm. To change mm into μm, multiply by 1000. To change μm into mm, divide by 1000.

From	To	Do this	Example
mm	μm	× 1000	0.045 mm = 45 μm
μm	mm	÷ 1000	250 μm = 0.25 mm
cm	mm	× 10	3.2 cm = 32 mm

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Worked example. A cell is drawn 60 mm wide, and its real width is 30 μm. Find the magnification. First make the units match: image size = 60 mm = 60 × 1000 = 60,000 μm. Then magnification = image ÷ actual = 60,000 ÷ 30 = ×2000. If you forget to convert and divide 60 ÷ 30, you get ×2 – a thousand times too small. This is the most common mistake in the whole topic.

Measuring an image yourself

Many questions give you a photo or drawing and a ruler, and expect you to measure the image size.

1. Measure the structure **in millimetres** with a ruler, across the line the question names (for example the length marked X–Y). Measure to the nearest mm, edge to edge.
2. Write down the measurement – there is often a mark for it.
3. Put it into the formula, converting to μm if the answer must be in μm.
4. Give the answer to a sensible number of figures, with its unit (no unit for a magnification).

Using a scale bar. Some images have no magnification printed, but show a **scale bar** 比例尺: a line with its real length written next to it (for example a line labelled 10 μm). Measure the scale bar too. Its magnification = measured length of the bar ÷ the real length it shows.

Worked example (scale bar). A drawing of a yeast cell has a scale bar labelled 1 μm. The bar measures 12 mm on the page, and the cell measures 54 mm long. Magnification = 12 mm ÷ 1 μm = 12,000 μm ÷ 1 μm = ×12,000. Actual length of the cell = 54 mm ÷ 12,000 = 0.0045 mm = **4.5 μm**. A quicker way: the cell is 54 ÷ 12 = 4.5 times as long as the bar, so it is 4.5 × 1 μm = 4.5 μm.

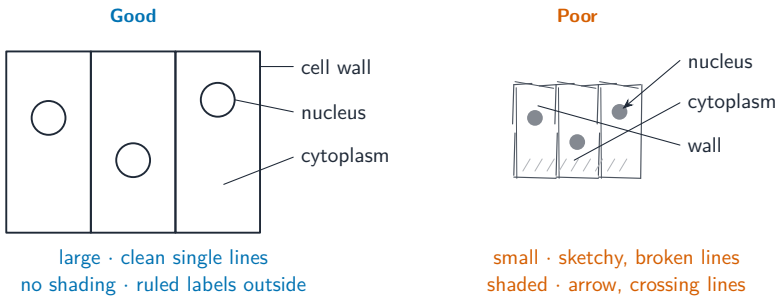
Worked example (finding the image size). A palisade cell is 0.08 mm long. How long will it look in a drawing at ×400? Image size = actual size × magnification = 0.08 × 400 = **32 mm**.

Making a biological drawing

Practical questions often say "Make a large drawing of …" a specimen or a photograph, and then ask for its magnification. The marks are for a clear, accurate record, not for art. Follow these rules:

- Use a sharp **pencil** 铅笔, not a pen, so you can rub out mistakes.
- Make it **large**: fill most of the space given.
- Draw clear, **continuous outlines** 轮廓线 with no gaps and no sketchy, repeated lines.
- Do **not** shade or colour.

- Keep the **proportions** 比例 right: if a part is twice as long as another on the specimen, it should be twice as long on your drawing.
- Draw only what you can see, including the number of parts (for example the number of seeds).
- Rule the **label lines** with a ruler: they touch the part, do not cross each other, and have no arrowheads. Write the labels outside the drawing.



A good biological drawing is large, with clean outlines and ruled labels; shading, sketchy lines and arrows all lose marks

Worked example (magnification of your drawing). A student draws a bean seed. The seed is 15 mm long; on the drawing it is 75 mm long. Magnification of the drawing = image size ÷ actual size = 75 ÷ 15 = **×5**. Both lengths are in mm, so no conversion is needed. If the question says "measure along line AB", draw the line on your drawing at the same place as on the specimen, and measure both along it.

Common mistakes.

- Saying mitochondria "make energy". Energy cannot be made; respiration in the mitochondria **releases** energy from glucose.
- Saying all plant cells have chloroplasts. Root cells are underground and have **no** chloroplasts, though they still have a cell wall and a vacuole.
- Mixing up the cell wall and the cell membrane. The **cell membrane** controls what enters and leaves; the **cell wall** (plants and bacteria) gives strength and shape.
- Putting units on a magnification. Magnification is just a number, such as ×250.
- Shading a drawing or putting arrowheads on label lines. Use clean outlines and ruled lines that just touch the part.
- Measuring the image in mm but the actual size in μm. Change both to the **same unit** before you divide.
- Calling the heart a tissue, or muscle an organ. A **tissue** is one kind of similar cell; an **organ** is several tissues working together.

Exam tips

- A plant cell has a cell wall, a large vacuole and chloroplasts; an animal cell has none of these. Both have a nucleus, cytoplasm, cell membrane, mitochondria and ribosomes.
- A cell with **no nucleus** but with plasmids and a loop of DNA is a bacterium.
- For magnification, cover the quantity you want: magnification = image ÷ actual; actual = image ÷ magnification.
- Always convert to the same unit before you calculate. Remember 1 mm = 1000 μm.
- For a specialised cell, link its job to the one feature that suits it (for example a red blood cell has no nucleus, so it can hold more oxygen).
- To name an unknown cell, ask in turn: a nucleus? a cell wall? chloroplasts or a large vacuole?
- New cells come only from the division of existing cells; a dividing bacterium makes two genetically identical daughter cells.
- With a scale bar, measure the bar and the structure in the same unit: actual size = (structure ÷ bar) × the length the bar shows.

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Movement into and out of cells

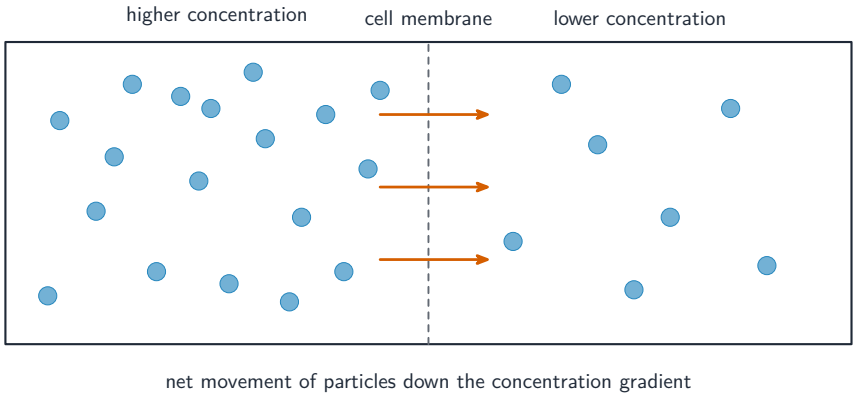
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Diffusion

Diffusion 扩散 is the **net movement** 净移动 of **particles** 粒子 from a region of their higher **concentration** 浓度 to a region of their lower concentration. We say the particles move **down a concentration gradient** 浓度梯度.

The particles spread out because of their own **random movement** 随机运动. The **energy** 能量 for diffusion comes from the **kinetic energy** 动能 of the random movement of **molecules** 分子 and **ions** 离子 – so diffusion needs **no** extra energy.

Some substances pass into and out of cells by diffusion through the **cell membrane** 细胞膜.



Diffusion: particles move from higher to lower concentration, down the gradient

Why diffusion matters. Many **gases** 气体 and dissolved substances (**solutes** 溶质) move by diffusion in living things. For example, **oxygen** 氧气 diffuses into cells for respiration, and **carbon dioxide** 二氧化碳 diffuses out.

The rate of diffusion changes with four factors:

Factor	Diffusion is faster when...
surface area 表面积	the surface is larger
temperature 温度	it is hotter (particles move faster)
concentration gradient	the difference in concentration is bigger
distance	the distance to travel is shorter (a thinner barrier)

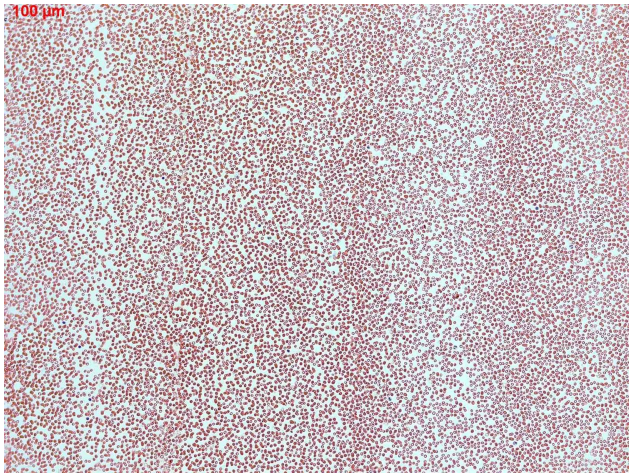
Investigating diffusion. Cut cubes of agar jelly that contain an indicator (for example, pink with phenolphthalein, which goes colourless in acid). Drop them into dilute acid and time how long each takes to lose its colour completely: the acid particles must diffuse in to the centre.

- **surface area**: use cubes of different sizes (1 cm, 2 cm, 3 cm sides). The small cube has the largest **surface area to volume ratio** 表面积与体积比, and the acid has the shortest distance to travel to its centre, so it changes colour first.
- **temperature**: use the same size of cube in acid at different temperatures (in water baths).
- **concentration gradient**: use acid of different concentrations.

Keep the other factors the same in each test. Another quick method is to drop a crystal of a coloured substance (such as potassium manganate(VII)) into water at different temperatures and time how long the colour takes to spread.

> **Worked example (surface area to volume ratio).** Find the ratio for a 1 cm cube and a 3 cm cube. For the 1 cm cube: surface area $= 6 \times 1 \times 1 = 6$ cm^2, volume $= 1$ cm^3, ratio $=$ **6 : 1**. For the 3 cm cube: surface area $= 6 \times 3 \times 3 = 54$ cm^2, volume $= 27$ cm^3, ratio $= 54 : 27 =$ **2 : 1**. The larger cube has **less** surface for each unit of volume, so the centre is reached more slowly. This is why large organisms need special exchange surfaces (such as the alveoli and villi) and transport systems: diffusion alone would be far too slow.

Osmosis



Red blood cells: water moves in and out of cells by osmosis.

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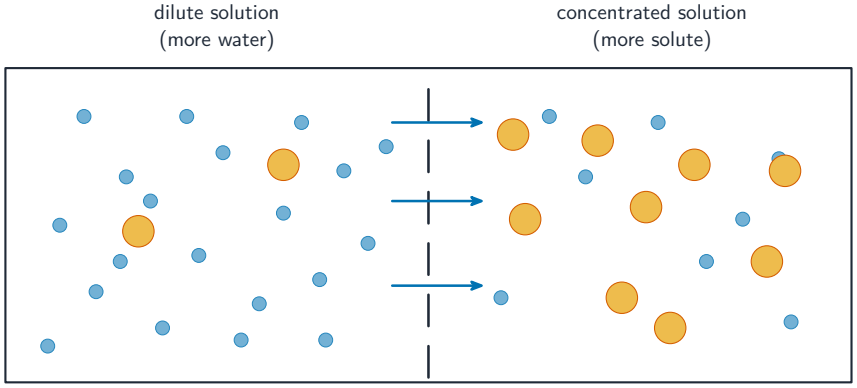
Water as a solvent

Water is a very good **solvent** 溶剂 – many substances **dissolve** 溶解 in it to make a **solution** 溶液. This matters for **digestion** 消化 (food must dissolve before it can be used), **excretion** 排泄 (wastes are carried away dissolved in water) and **transport** 运输 (substances travel around the body dissolved in blood and sap).

What osmosis is

Osmosis 渗透 is a special kind of diffusion: the net movement of water across a **partially permeable membrane** 半透膜. This kind of membrane has tiny holes that let small water molecules through but hold back larger solute particles. Water moves into and out of cells by osmosis through the cell membrane.

A **concentrated** solution has a lot of dissolved solute and little water. A **dilute** solution has little solute and a lot of water.



water moves by osmosis to the concentrated side; solute is too big to cross

Osmosis: water crosses the partially permeable membrane; the solute cannot

(Supplement) Osmosis is the net movement of water molecules from a region of **higher water potential** 水势 (a dilute solution – more water) to a region of lower water potential (a concentrated solution – less water), through a partially permeable membrane.

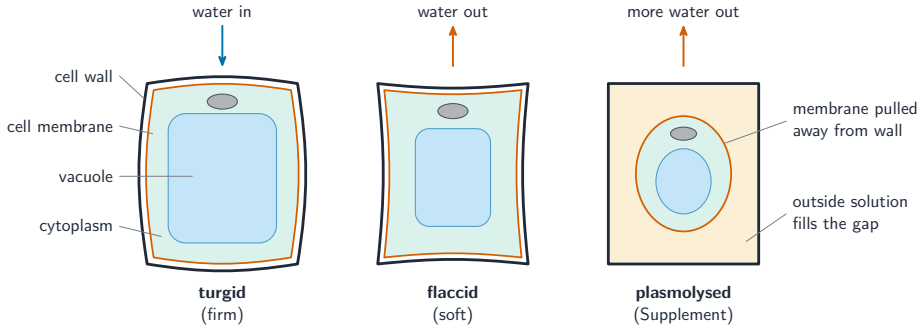
Osmosis and plant cells

When you put plant tissue into different solutions, water moves by osmosis:

- In **pure water or a dilute solution**, water moves **into** the cells. The cells swell and become firm, or **turgid** 膨胀. The water presses outward on the cell wall; this outward push is the **turgor pressure** 膨压. Turgid cells make a plant stand up straight – this is how plants are supported.

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- In a **concentrated solution**, water moves **out** of the cells. The cells lose their firmness and become soft, or **flaccid** 松软.
- **(Supplement)** If even more water leaves, the cell membrane pulls away from the cell wall. This is **plasmolysis** 质壁分离.



Water entering or leaving a plant cell makes it turgid, flaccid or plasmolysed



Plasmolysed red onion cells: the purple contents have pulled away from the cell walls

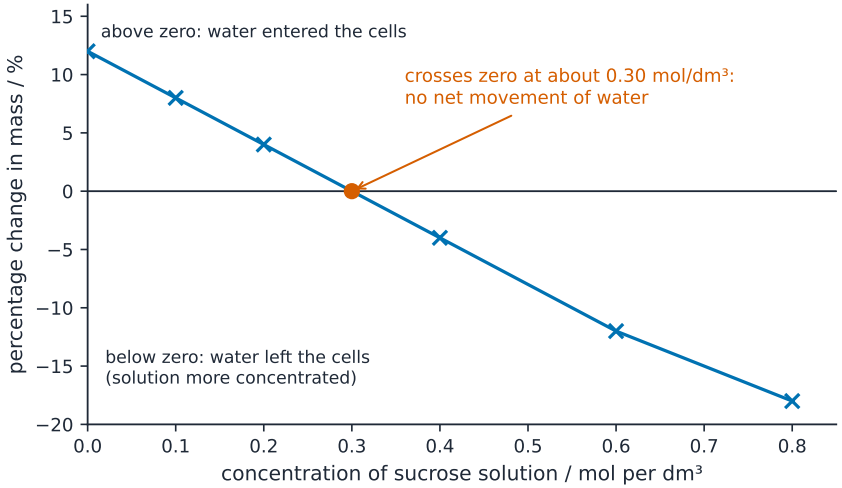
You can investigate osmosis using **dialysis tubing** 透析管 (an artificial partially permeable membrane), or using cylinders cut from a potato. Measure their length or mass before and after soaking. Cylinders in pure water or a dilute solution gain length and mass; cylinders in a concentrated solution lose length and mass; in a solution of equal concentration there is no change.

> **Worked example.** A potato cylinder has a mass of 5.0 g before soaking and 5.6 g after soaking in a dilute solution. Find the percentage change in mass.

- change in mass = 5.6 - 5.0 = 0.6 g (a gain).
- percentage change = change ÷ starting mass × 100 = 0.6 ÷ 5.0 × 100 = +12%.

A positive answer means the cylinder gained water, so the solution was more dilute than the cell contents. Always work out the *percentage* change, not just the change in grams – it lets you compare cylinders that started at different masses fairly.

Using a graph of the results. Put cylinders into a range of sugar solutions (for example 0.0, 0.1, 0.2, 0.4, 0.6 and 0.8 mol per dm^3), find the percentage change in mass for each, and plot it against concentration. Where the line **crosses zero**, the cylinder neither gained nor lost mass: the solution has the same concentration (the same water potential) as the potato cells, so there is no net movement of water.



Where the line crosses zero, the solution matches the potato cells, so there is no net osmosis

To make the experiment reliable, cut all cylinders the same size with a cork borer, blot them dry before each weighing (so surface water is not weighed), leave them for the same time at the same temperature, and repeat each concentration.

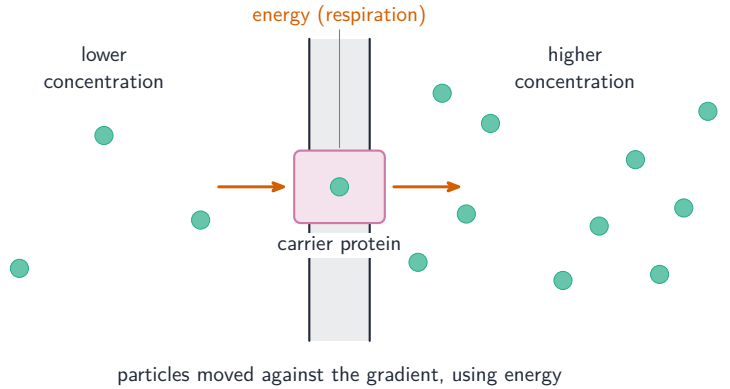
Dialysis tubing. Fill a length of dialysis tubing with a concentrated sugar solution, tie both ends, and put it in a beaker of water. Water moves **in** by osmosis, so the tubing swells and its mass increases; if it is fixed to a capillary tube, the liquid rises up the tube. The sugar molecules are too large to pass out through the membrane. With water inside and sugar solution outside, the tubing loses water and becomes floppy.

Animal cells. An animal cell has no cell wall. In pure water a red blood cell takes in water by osmosis until it **bursts**; in a concentrated solution it loses water and **shrinks**, with a crinkled surface. This is why body fluids such as blood plasma must be kept at the right concentration, and why a drip into a vein uses a salt solution of the same concentration as the blood, not pure water.

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Active transport

Active transport 主动运输 is the movement of particles through a cell membrane from a region of **lower** concentration to a region of **higher** concentration – that is, **against** the concentration gradient. Because this is "uphill", it needs energy from **respiration** 呼吸作用.

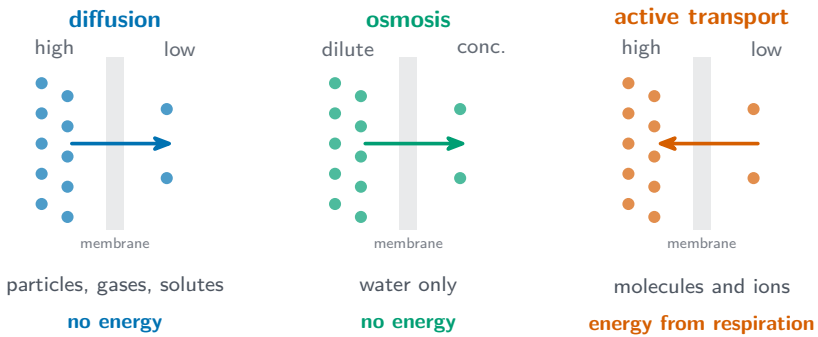


Active transport uses energy and a carrier protein to move particles against the gradient

(Supplement) Active transport lets a cell take in useful molecules or ions even when they are already more concentrated inside the cell. For example, **root hairs** 根毛 take up mineral ions from the soil by active transport. **Protein carriers** 载体蛋白 in the membrane pick up the molecules or ions and carry them across, using energy.

Comparing the three processes

Process	Direction	Energy from respiration?	What moves
diffusion	high → low concentration	no	particles, gases, solutes
osmosis	high → low water potential	no	water only
active transport	low → high concentration (against the gradient)	yes	molecules and ions



Only active transport goes against the gradient, and only it needs energy from respiration.

Common mistakes.

- Saying water moves from a high to a low concentration of **solution**. Water moves from a **dilute** solution (more water) to a **concentrated** one (less water). Say which concentration you mean, or use water potential.
- Saying the solute moves in osmosis. In osmosis only **water** crosses the membrane; the solute particles are too big to pass.
- Saying a plant cell bursts in pure water. The strong **cell wall** stops it bursting, so the cell becomes turgid. An animal cell, such as a red blood cell, has no cell wall and can burst.
- Saying diffusion stops when the concentrations are equal. The particles still move both ways; there is just **no net movement**.

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- Saying diffusion and osmosis need energy from respiration. They use the particles' own **kinetic energy**; only active transport needs energy from respiration.
- Comparing potato cylinders by the change in grams. Use the **percentage** change, because the cylinders started at different masses.

Exam tips

- Always write **net** movement: particles move both ways, but the overall flow is down the gradient (for diffusion and osmosis).
- Osmosis moves **water only**, and **only** through a partially permeable membrane. Diffusion can move many kinds of particle.
- Only **active transport** uses energy from respiration, and only it goes **against** the gradient.
- For the potato or plant experiment: water in → turgid, longer and heavier; water out → flaccid, shorter and lighter; equal concentration → no change.
- On a graph of percentage change against concentration, the point where the line **crosses zero** gives the concentration of the cell contents.
- A smaller cube has a larger **surface area to volume ratio**, so diffusion reaches its centre faster.
- A larger surface area, higher temperature, steeper concentration gradient and shorter distance all make diffusion faster.

Biological molecules

IGCSE Biology

The chemical elements in food



Bread is rich in carbohydrates, one of the main food groups.



Carbohydrates and fats contain C, H and O; proteins also contain nitrogen

Living things are built from a few kinds of **molecule** 分子. The most important are carbohydrates, fats and proteins. Each is made from a small number of chemical **elements** 元素.

- **Carbohydrates** 碳水化合物 and **fats** 脂肪 contain three elements: **carbon** 碳 (C), **hydrogen** 氢 (H) and oxygen (O).
- **Proteins** 蛋白质 contain carbon, hydrogen and oxygen too, plus **nitrogen** 氮 (N). (Some proteins also contain sulfur, S.)

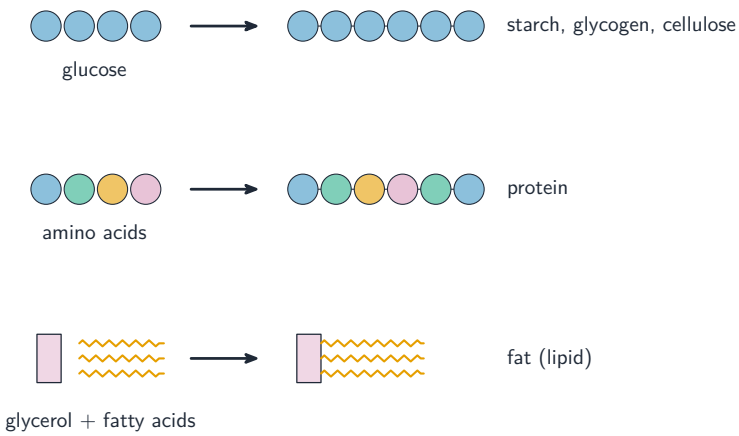
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Building large molecules from small ones

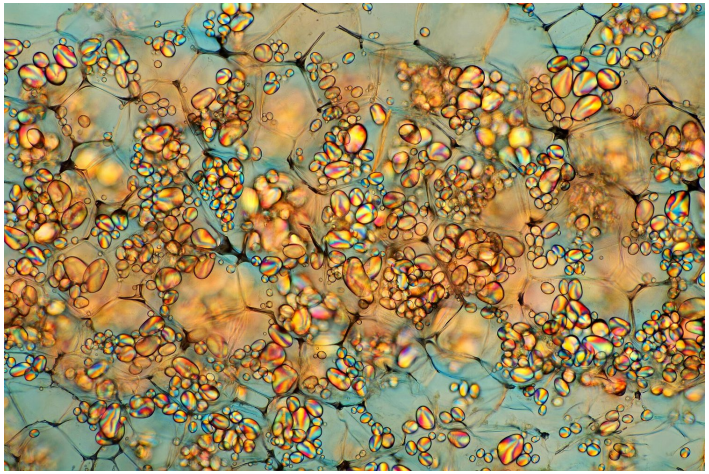
Large molecules are made by joining many small molecules together, like beads on a string.

Large molecule	Built from
starch 淀粉, **glycogen** 糖原 and **cellulose** 纤维素	many **glucose** 葡萄糖 units
proteins	**amino acids** 氨基酸
fats and oils	**fatty acids** 脂肪酸 and **glycerol** 甘油

Starch and glycogen are energy stores; cellulose makes plant cell walls. Proteins are built from about 20 different kinds of amino acid joined in a chain. One fat molecule is made from three fatty acids joined to one glycerol.



Large molecules are built by joining many small units, like beads on a string



Starch grains from a potato, seen under a microscope – each grain is built from many glucose units

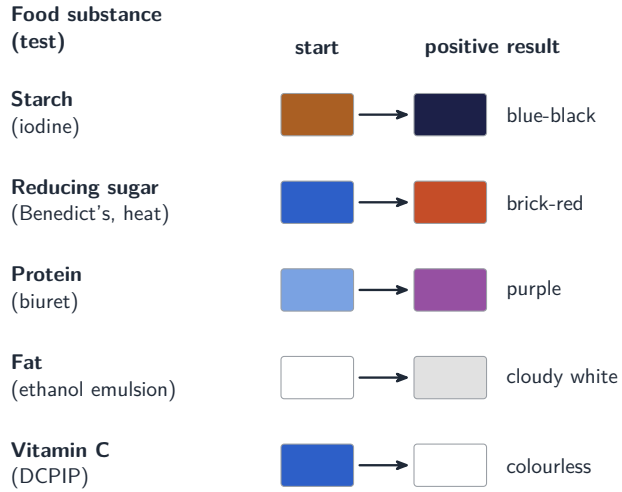
Food tests

You can test a piece of food to find out which substances it contains. Add the test chemical and watch for a colour change.

Food substance	Test	Positive result
starch	add **iodine solution** 碘液	orange-brown → blue-black
reducing sugars 还原糖 (such as glucose)	add **Benedict's solution** 本尼迪特试剂 and heat	blue → brick-red / orange
protein	add **biuret** 双缩脲 solution	blue → purple
fats and oils	**ethanol** 乙醇 **emulsion** 乳浊液 test	a cloudy white layer forms
vitamin 维生素 C	add to blue DCPIP	blue → colourless

Two things to remember: only the Benedict's test needs **heat**; and DCPIP loses its colour (goes colourless), while the other tests gain a new colour.

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Each food test gives its own colour change for a positive result

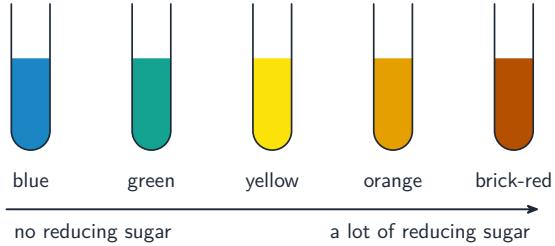


Benedict's test in real life: blue means no reducing sugar; an orange to brick-red precipitate means it is there

Carrying out the food tests

Exam questions ask you to **describe** a test, so learn the method, not just the colours. First prepare the food: cut or grind a small amount with a pestle and mortar, add a little water and mix, so the substances dissolve or spread out. Then:

- **Starch.** Put a few drops of the food (or a piece of solid food) on a spotting tile and add a few drops of iodine solution. Blue-black = starch present; it stays orange-brown if not.
- **Reducing sugars.** Put about 2 cm^3 of the food solution in a test tube, add the **same volume** of Benedict's solution, and heat the tube in a **water bath** 水浴 at about 80 °C for 5 minutes. Use a water bath rather than a flame, so the tube heats safely and evenly.
- **Protein.** Add about 2 cm^3 of biuret solution to 2 cm^3 of the food solution and shake gently. Do not heat. Purple (lilac) = protein present; it stays blue if not.
- **Fats and oils.** Add about 2 cm^3 of **ethanol** to the food and shake well, so any fat dissolves. Pour this liquid into a test tube of **water**. A cloudy white **emulsion** = fat present, because the fat cannot stay dissolved in water and forms tiny droplets. Keep ethanol away from flames: it is flammable.
- **Vitamin C.** Put 1 cm^3 of blue DCPIP in a test tube and add the food juice drop by drop, shaking after each drop. If the DCPIP turns colourless, vitamin C is present.



After heating, the colour of Benedict's solution shows how much reducing sugar is present

The Benedict's colour also shows **how much** reducing sugar there is: green means a little, yellow and orange more, and brick-red a lot. To compare foods fairly, use the same volume of each food solution and of Benedict's, and heat for the same time at the same temperature.

Comparing vitamin C. The **fewer** drops of juice needed to make the DCPIP colourless, the **more** vitamin C the juice contains.

> **Worked example.** A student adds orange juice drop by drop to 1 cm^3 of DCPIP; it goes colourless after 5 drops. Apple juice takes 20 drops. Which juice has more vitamin C, and how many times more? Orange juice, because it needs fewer drops. $20 \div 5 = 4$, so orange juice has about **4 times** as much vitamin C as apple juice. To make this a fair test, keep the volume and concentration of DCPIP the same, use the same dropper (so the drops are the same size), and shake in the same way after each drop.

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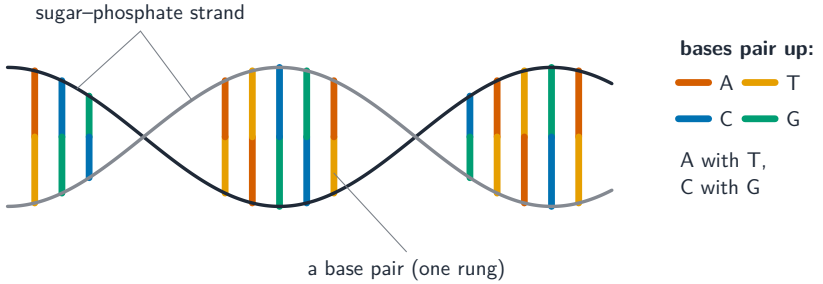
Safety. Wear eye protection: Benedict's and biuret solutions are irritants, and biuret contains an alkali. Ethanol is flammable, so no flames near the fat test.

> **Worked example.** A student tests an unknown food. Iodine solution stays orange-brown. Benedict's solution, after heating, turns brick-red. Biuret solution turns purple. What does the food contain? Iodine staying orange-brown is a **negative** result, so there is no starch. Brick-red is a **positive** Benedict's result, so reducing sugar is present. Purple is a **positive** biuret result, so protein is present. The food contains reducing sugar and protein, but no starch. "No colour change" is a real result - it tells you the substance is **absent**.

The structure of DNA (Supplement)

DNA is the **genetic material** 遗传物质 – it carries the instructions for building and running an organism. Its structure has four key points:

- two **strands** 链 are coiled together to form a **double helix** 双螺旋 (like a twisted ladder).
- each strand carries chemicals called **bases** 碱基.
- **bonds** 化学键 between pairs of bases hold the two strands together.
- the bases always pair in the same way: **A with T**, and **C with G**.



DNA is a double helix; the bases always pair A–T and C–G

> **Worked example.** One strand of DNA has the bases **A T G C C A**. Write the bases on the other strand. Pair each base in turn: A–T, T–A, G–C, C–G, C–G, A–T, so the other strand reads **T A C G G T**.

Because A always pairs with T, a DNA molecule always has the **same number** of A and T bases, and the same number of C and G bases. So if 30% of the bases in a DNA molecule are A, then 30% are T; the other 40% are shared equally between C and G, so 20% are C and 20% are G.

Common mistakes.

- Saying iodine turns "black" or "blue". Write the full change: **orange-brown → blue-black**.
- Forgetting to heat in the Benedict's test, or heating in the other tests. Only Benedict's needs heating, in a water bath.
- Saying Benedict's tests for "sugar" or for starch. It tests for **reducing sugars** such as glucose; starch gives no brick-red colour.
- Writing "turns clear" for DCPIP. Clear means see-through and may still be coloured; DCPIP turns **colourless**.
- Saying proteins are made of glucose, or that fats are made of amino acids. Proteins are built from **amino acids**; a fat is **three fatty acids and one glycerol**.
- Pairing A with G, or A with C. The bases always pair **A–T** and **C–G**.

Exam tips

- Carbohydrates and fats are made of C, H and O. Proteins also contain N (nitrogen).
- Learn each food test and its colour change. For reducing sugars you must **heat** the Benedict's solution.
- DCPIP goes from blue to **colourless**; the other four tests each give a **new** colour.
- In DNA, the bases pair only A–T and C–G. So if you know the bases on one strand, you can work out the other.
- To describe a food test, give the reagent, the method (heat in a water bath only for Benedict's; ethanol then water for fats), and the colour **before → after**.
- For vitamin C, fewer drops to decolourise DCPIP means more vitamin C.

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Enzymes

IGCSE Biology

What enzymes are



Biological washing powders contain enzymes that break down stains.

A **catalyst** 催化剂 is a substance that speeds up the **rate** 速率 of a **chemical reaction** 化学反应 but is **not** used up or changed by the reaction. The same catalyst can be used again and again.

Enzymes 酶 are biological catalysts – catalysts made by living cells. They are **proteins** 蛋白质. Enzymes take part in all the reactions of **metabolism** 新陈代谢, so they control almost every chemical reaction in a living thing.

Enzymes are vital. Without them, the reactions that keep you alive would be far too slow. Enzymes raise the reaction rate enough to keep the organism alive.

How an enzyme works

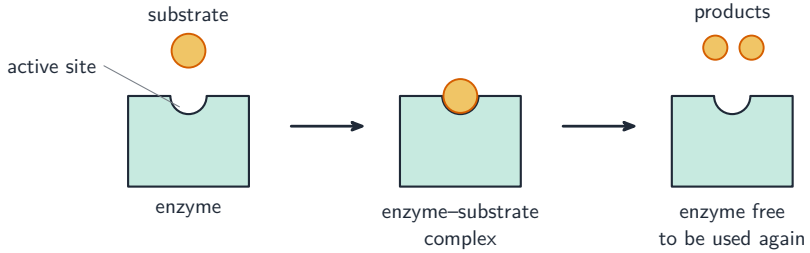
Each enzyme has a special pocket called its **active site** 活性位点. The **molecule** 分子 it works on is called the **substrate** 底物.

- The shape of the active site is **complementary** 互补 to the shape of the substrate – they fit together like a key in a lock.
- The substrate slots into the active site. **(Supplement)** This makes an **enzyme-substrate complex** 酶底物复合物.
- The reaction takes place, and the substrate is changed into one or more **products** 产物.

- The products leave the active site, which is then free to be used again.



Kiwi fruit contains a protease enzyme that breaks down protein.



The substrate fits the active site like a key in a lock, then leaves as products

Why enzymes are specific (Supplement)

Each enzyme is **specific** 专一 – it works on only one kind of substrate. This is because only that substrate has the right shape to fit the active site. A substrate of a different shape will not fit, just as the wrong key will not open a lock.



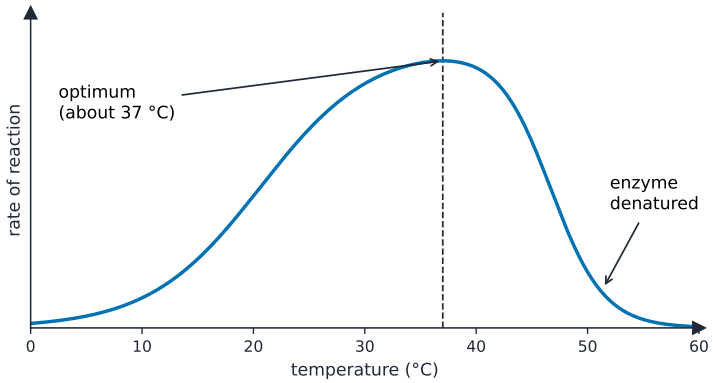
Only the matching substrate fits the active site

The effect of temperature and pH

The activity of an enzyme depends on **temperature** 温度 and pH. You can investigate this by measuring how fast the reaction goes at different temperatures or pH values.

Temperature

- As the temperature rises from cold, enzyme activity speeds up. The enzyme and substrate molecules have more **kinetic energy** 动能, so they move faster and meet more often. **(Supplement)** There are more useful **collisions** 碰撞 each second.
- Activity is highest at the **optimum temperature** 最适温度 (about 37 °C in the human body).
- Above the optimum, activity falls fast. The heat changes the shape of the active site, so the substrate no longer fits. The enzyme is **denatured** 变性. Denaturation is permanent – the enzyme cannot recover.



optimum ~37 °C for many human enzymes · higher *T* denatures the active site

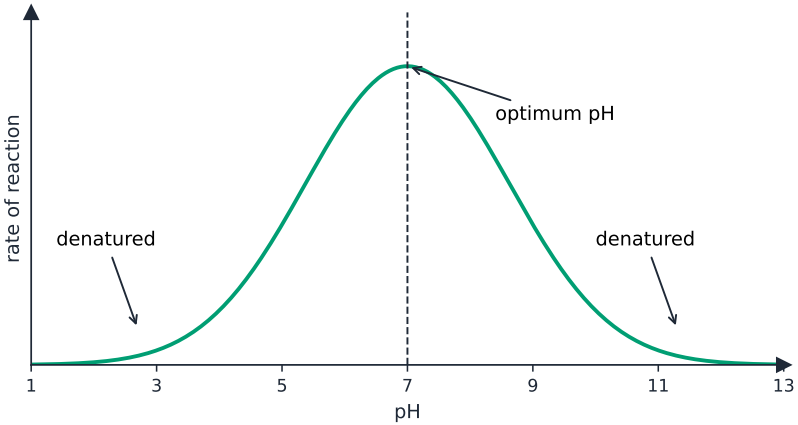
Activity peaks at the optimum temperature, then falls sharply as the enzyme denatures

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Worked example. A reaction finishes in 50 s at 20 °C, and in 20 s at 37 °C. Which temperature is faster, and by how much? A **shorter** time means a **faster** rate, so work out a rate with rate = 1000 ÷ time. At 20 °C the rate is 1000 ÷ 50 = 20 units; at 37 °C it is 1000 ÷ 20 = 50 units. So 37 °C is 50 ÷ 20 = **2.5 times faster**. Do not say the rate "went up by 30 s" - a time is not a rate. Turn the time into a rate first, and remember the bigger rate always goes with the smaller time.

pH

- Each enzyme works best at one particular pH.
- If the pH is too high or too low, the shape of the active site changes, the substrate stops fitting, and the enzyme is denatured.



optimum pH maximises rate; extremes denature the active site

Each enzyme has one optimum pH; far from it the enzyme is denatured

Different enzymes have different optimum pH values. They match the place where each enzyme works:

Enzyme	Where it works	Optimum pH
protease in the stomach	stomach (contains acid)	about 2
amylase in saliva	mouth	about 7

So "the best pH is 7" is not true for every enzyme.

(Supplement) A full explanation of the temperature graph. Examiners look for these ideas, in this order:

1. As temperature increases towards the optimum, the enzyme and substrate molecules gain **kinetic energy** and move faster.
2. So there are **more frequent effective collisions** between substrate and active site, and more **enzyme-substrate complexes** form each second.
3. At the **optimum**, the rate is highest.
4. Above the optimum, the active site **changes shape** (the enzyme is denatured), so the substrate no longer **fits**; fewer complexes form and the rate falls.

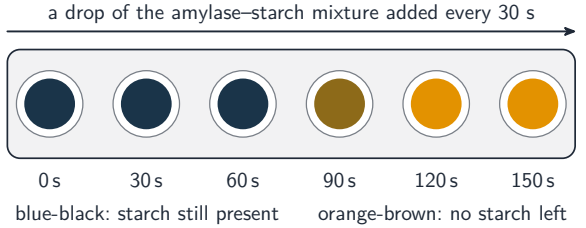
For pH, only the last idea applies: away from the optimum pH the active site changes shape, so the substrate no longer fits, and the enzyme is denatured.

Investigating enzyme activity

You need to be able to plan and explain enzyme experiments. Two are used most often.

1. Amylase and starch (iodine test). Amylase breaks starch down into maltose (a sugar). Iodine solution turns **blue-black** when starch is present and stays **orange-brown** when there is none.

1. Put drops of iodine solution into each well of a **spotting tile** 点滴板.
2. Put a tube of starch solution and a tube of amylase solution in a **water bath** 水浴 at the chosen temperature for a few minutes, so both reach that temperature before they are mixed.
3. Mix them and start a stopwatch. Every 30 seconds, add one drop of the mixture to a new well of iodine.
4. Record the time when the iodine first stays orange-brown: the starch has all been digested.
5. Repeat at other temperatures (for example 20, 30, 40, 50 and 60 °C).



Iodine on a spotting tile stays blue-black while starch remains and turns orange-brown when the amylase has digested it all

2. Catalase and hydrogen peroxide. **Catalase** 过氧化氢酶, found in potato, liver and most living cells, breaks hydrogen peroxide down into water and oxygen gas. Measure the **volume of oxygen** collected in a gas syringe or an upturned measuring cylinder in a fixed time, or count the bubbles. More oxygen per minute means a faster rate.

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Variables. In every plan, name all three kinds of **variable** 变量:

Variable	Meaning	Temperature experiment with amylase
independent 自变量	the one you change	temperature
dependent 因变量	the one you measure	time for the starch to disappear
controlled 控制变量	the ones you keep the same	volume and concentration of starch and of amylase; pH (use a buffer solution); the time between samples

To keep a mixture at one temperature, use a **thermostatically controlled water bath** (or a beaker of water heated or cooled, checked often with a thermometer). To vary pH, use **buffer solutions** 缓冲液 of different pH values. For a **control** 对照, repeat the experiment with **boiled** (denatured) enzyme: if the starch is not digested, the change was caused by the enzyme. Do **repeats** at each temperature and calculate a mean, so the results are more reliable, and you can spot anomalous results.

> **Worked example (planning).** *A student wants to find the effect of pH on the activity of catalase in potato. Describe a method.* "Cut equal-sized discs of potato (same mass). Put 10 cm^3 of hydrogen peroxide of the same concentration in a test tube with 2 cm^3 of a pH 5 buffer, in a water bath at 30 °C. Add five potato discs and collect the oxygen in a gas syringe for 2 minutes. Record the volume. Repeat three times and find the mean. Repeat with buffers of pH 6, 7, 8 and 9. Keep the temperature, the volume and concentration of hydrogen peroxide, and the number and size of discs the same." The pH (independent) is changed, the volume of oxygen (dependent) is measured, and everything else is controlled.

Describing results. When you describe a graph or a table, give the trend **and** quote data with units: "As the temperature increased from 20 °C to 40 °C, the time taken fell from 300 s to 90 s; above 40 °C it rose again, to 400 s at 60 °C. The optimum is about 40 °C." To find the optimum more precisely, repeat the experiment at smaller intervals (such as 2 °C steps) around the highest rate.

Common mistakes

- **"The enzyme is killed."** Enzymes are proteins, not living things. Say it is **denatured**: the active site has changed shape.
- **"At low temperature the enzyme is denatured."** It is not. At low temperature the molecules move slowly and meet less often, so the reaction is slow. When it is warmed up again, the enzyme works normally. Only **high** temperatures (and the wrong pH) denature an enzyme.

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- **"The active site is the same shape as the substrate."** It is **complementary**: the two shapes fit together, like a key and a lock.
- **"The enzyme is used up."** An enzyme is a catalyst, so the same molecule is used again and again.
- **"Above the optimum, the rate falls because the molecules move too fast."** The molecules do move faster, but the rate falls because more and more enzyme molecules are **denatured**.

Exam tips

- An enzyme is both a **protein** and a biological catalyst: it speeds up a reaction and is **not** used up.
- Describe the shape: the active site is **complementary** to the substrate (the lock-and-key idea). Each enzyme is **specific** to one substrate.
- Low temperature → slow (too little kinetic energy). Optimum → fastest. Too hot → **denatured** (the active site loses its shape, permanently).
- The wrong pH also **denatures** the enzyme by changing the shape of the active site.
- "Denatured" does **not** mean "killed" – enzymes are not alive. Say that the shape of the active site has changed so the substrate no longer fits.
- In a practical question, name the **independent**, **dependent** and at least two **controlled** variables; say how temperature is kept constant (a water bath) and why you repeat.
- Iodine: blue-black = starch present; orange-brown = starch gone. A shorter time to lose the blue-black colour means a **faster** rate.

Plant nutrition

IGCSE Biology

Photosynthesis



Green leaves capture sunlight for photosynthesis.

Photosynthesis 光合作用 is the process by which plants make **carbohydrates** 碳水化合物 from simple **raw materials** 原料, using **energy** 能量 from light. It is how plants feed themselves.

The word equation

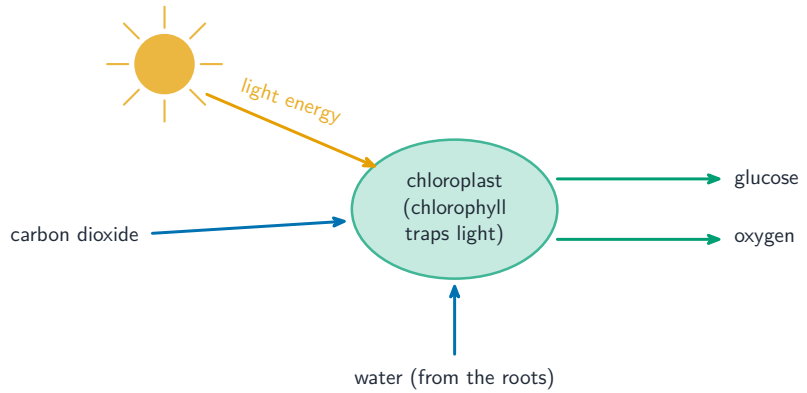
$$\text{carbon dioxide} + \text{water} \rightarrow \text{glucose} + \text{oxygen}$$

In words: plants take in **carbon dioxide** 二氧化碳 and water, and make **glucose** 葡萄糖 and **oxygen** 氧气. This reaction can only happen in the light, and only where there is **chlorophyll** 叶绿素.

(Supplement) The balanced chemical equation is:

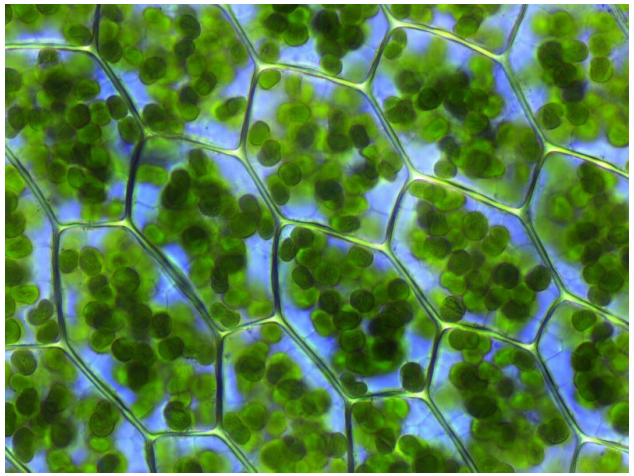
$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

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carbon dioxide + water → glucose + oxygen

Photosynthesis takes in carbon dioxide and water and makes glucose and oxygen, using light



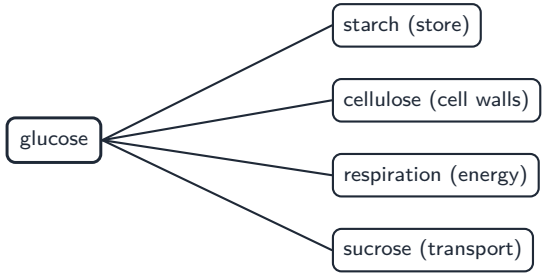
The same chloroplasts under a microscope, packed inside moss leaf cells – the green is chlorophyll

What chlorophyll does

Chlorophyll is a green **pigment** 色素 found in the **chloroplasts** 叶绿体. It traps light and transfers the energy from light into energy stored in chemicals. That chemical energy is then used to build carbohydrates.

What the plant does with the glucose

Use	What happens
store	changed to **starch** 淀粉, an energy store that does not dissolve
build	made into **cellulose** 纤维素 to build **cell walls** 细胞壁
release energy	broken down in **respiration** 呼吸作用 to release energy
transport	changed to **sucrose** 蔗糖 and moved around the plant in the **phloem** 韧皮部
attract animals	made into **nectar** 花蜜 to attract **insects** 昆虫 for **pollination** 传粉



What a plant does with the glucose it makes

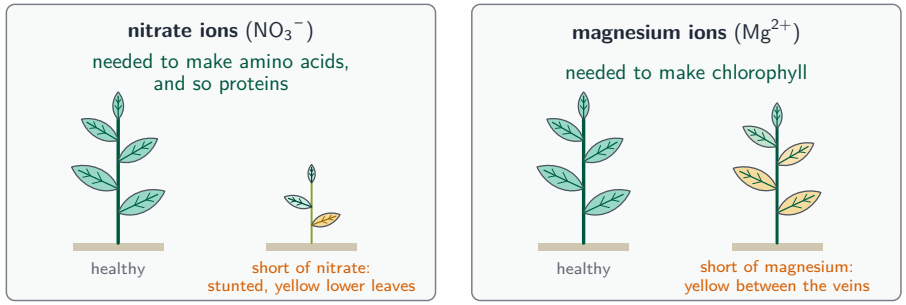
Minerals from the soil

Plants also take up mineral **ions** 离子 from the soil through their roots:

- **nitrate ions** 硝酸根离子 – needed to make **amino acids** 氨基酸 (and so proteins).
- **magnesium ions** 镁离子 – needed to make chlorophyll.

A plant short of nitrate grows poorly with weak stems; a plant short of magnesium has yellow leaves (it cannot make enough chlorophyll).

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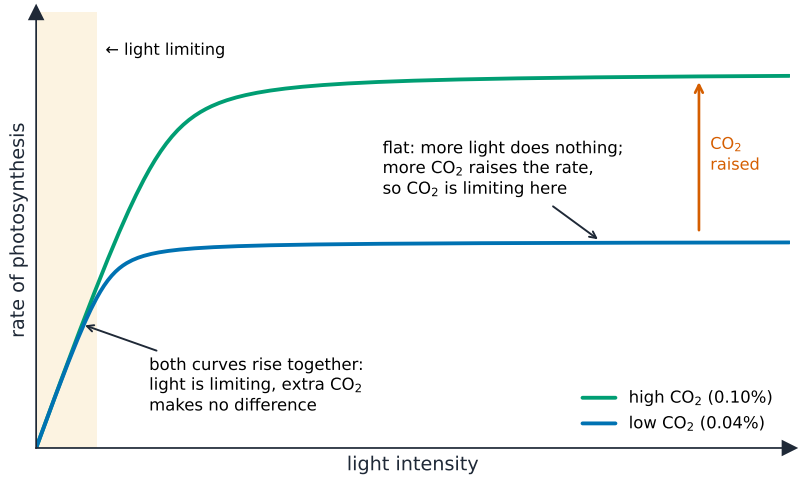
A plant short of nitrate grows poorly; a plant short of magnesium has yellow leaves

The rate of photosynthesis

The **rate** 速率 of photosynthesis depends on three things:

- **light intensity** 光照强度 – more light gives a faster rate, up to a point.
- carbon dioxide **concentration** 浓度 – more carbon dioxide gives a faster rate.
- **temperature** 温度 – a warmer temperature is faster, until it gets so hot that the enzymes are denatured.

(Supplement) At any moment, the one factor that is in shortest supply holds back the rate. This is called the **limiting factor** 限制因素. For example, on a dull day light intensity is usually the limiting factor; on a bright day carbon dioxide may be.



At low light both curves are the same: light is limiting. On the low-carbon-dioxide curve's flat part, more carbon dioxide raises the rate, so carbon dioxide is limiting there

Worked example. On a graph of rate against light intensity, the line rises steeply at first and then levels off flat. Which factor is limiting on each part? On the **rising** part, adding light raises the rate, so **light intensity** is the limiting factor there. On the **flat** part, adding more light changes nothing, so light is no longer limiting - something else is, usually carbon dioxide concentration or temperature. The test is always the same: if adding more of a factor speeds the reaction up, that factor was the one holding it back.

(Supplement) Reading two curves. Exam graphs often show the same experiment at two carbon dioxide concentrations, as in the figure.

- Where the two curves are on **top of each other**, extra carbon dioxide does nothing, so carbon dioxide is not limiting there. Light is.
- Where a curve is **flat**, more light does nothing, so light is not limiting there.
- Moving from the lower curve to the higher one only changed carbon dioxide. The rate went up, so carbon dioxide **was** the limiting factor on the lower curve's flat part.

Common mistakes.

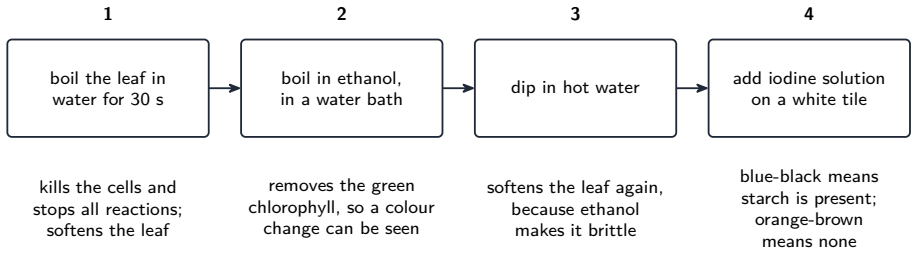
- Saying "light is limiting" on the flat part of the curve. Light is limiting only where adding more light still **raises** the rate.
- Saying the rate falls when the curve levels off. A flat line means the rate stays **constant** at its highest value.
- Saying high temperature "kills" photosynthesis. Above the optimum the rate falls because the **enzymes** are denatured.
- Forgetting that the plant also respires. In dim light, a plant can take in **no** carbon dioxide overall, because respiration releases as much as photosynthesis uses.

■ Investigating photosynthesis

To show that a plant needs light, chlorophyll and carbon dioxide, you test a leaf for starch after taking one of them away. A **control** 对照 keeps every other condition the same, so the test is fair. (First leave the plant in the dark to use up its starch.) A leaf with green and white parts shows starch only in the green parts, which have chlorophyll.

Testing a leaf for starch. Starch is the sign that the leaf has been photosynthesising. Follow the four steps in order and know the reason for each:

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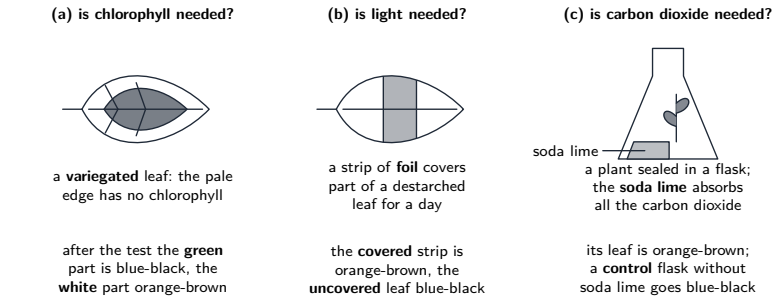


Ethanol catches fire easily, so it is heated in a **water bath** and never over a flame. That is a mark on its own whenever the method is asked for.

The starch test on a leaf: each step has a reason, and the ethanol is heated in a water bath, never over a flame

Destarching 去淀粉 comes first: keep the plant in the dark for 48 hours so it uses up its stored starch. Then any starch found must have been made **during** the experiment. Each of the three experiments removes **one** factor from part of a plant, and compares it with a part that has everything:

- **chlorophyll**: a **variegated** 斑叶的 leaf (green and white). Only the green parts turn blue-black.
- **light**: cover part of a leaf with black paper or foil for a day. The covered part stays orange-brown.
- **carbon dioxide**: seal one plant in a flask with **soda lime** 碱石灰 or sodium hydroxide, which absorb carbon dioxide, and a control plant in a flask without it. Only the control's leaves turn blue-black.



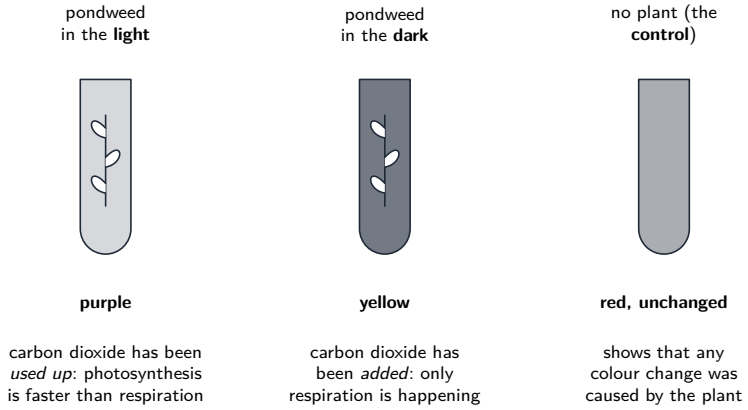
Destarch the plant first, 48 hours in the dark, or the starch you find may have been made before the experiment began.

Testing for chlorophyll, light and carbon dioxide: each experiment removes one factor, and a control keeps it

Gas exchange in a water plant. You can also watch **gas exchange** 气体交换 in a water plant using hydrogencarbonate **indicator** 指示剂, which changes colour as the carbon dioxide level changes:

Carbon dioxide in the water	Colour of the indicator
less than in normal air	**purple**
the same as in normal air	**red** (orange-red)
more than in normal air	**yellow**

Set up three tubes of indicator: pondweed in the light, pondweed in the dark (covered in foil), and a tube with no plant as the control. In bright light the indicator turns **purple**: photosynthesis uses carbon dioxide faster than respiration releases it. In the dark it turns **yellow**: only respiration happens, so carbon dioxide builds up. The control stays red, which shows the plant caused the changes. In dim light the colour may not change at all, because photosynthesis and respiration are balanced.

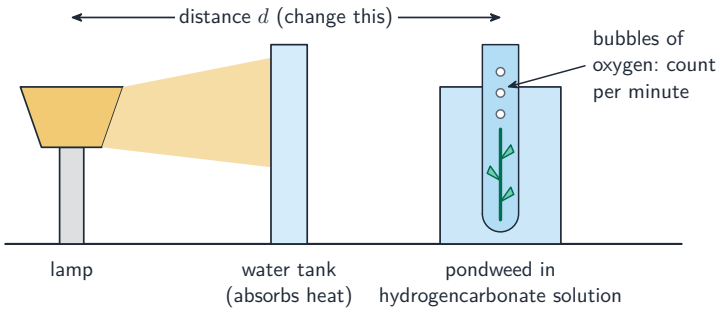


The indicator measures **carbon dioxide in the water**, so it reports the *net* exchange. In the light the plant respires as well; it simply takes in more carbon dioxide than it gives out.

Hydrogencarbonate indicator shows the net gas exchange: purple in the light, yellow in the dark, red in the control

Measuring the rate. To investigate the effect of light intensity, put a piece of pondweed in a tube of water with a little sodium hydrogencarbonate (to supply carbon dioxide) and place a lamp at a measured distance. Count the bubbles of oxygen given off in one minute, or collect the gas and measure its volume. Repeat with the lamp at different distances.

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Measuring the rate of photosynthesis: count the oxygen bubbles from pondweed with the lamp at different distances

- **independent variable**: light intensity (the distance of the lamp; a closer lamp gives more light).
- **dependent variable**: the number of bubbles per minute (or volume of gas).
- **controlled variables**: temperature (a tank of water between lamp and plant absorbs the lamp's heat), carbon dioxide concentration, the same piece of pondweed, and the time it is left to adjust at each distance before counting.

To investigate temperature, put the tube in water baths at different temperatures with the lamp at a fixed distance; for carbon dioxide, use different concentrations of sodium hydrogencarbonate. Bubbles can be different sizes, so collecting the gas in a syringe or measuring tube is more **accurate** than counting.

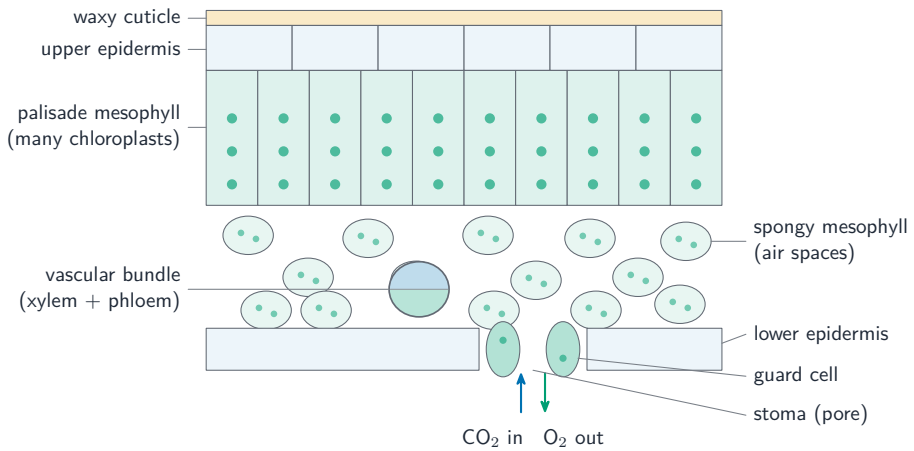
> **Worked example (rate of photosynthesis).** A student counted bubbles from pondweed: 40 per minute with the lamp at 10 cm, 20 at 20 cm, 9 at 30 cm and 5 at 40 cm. Describe and explain the results. "As the distance increased from 10 cm to 40 cm, the number of bubbles fell from 40 to 5 per minute. Further from the lamp the light intensity is lower, so less light energy is absorbed by chlorophyll and the rate of photosynthesis falls, producing less oxygen." Light intensity falls quickly with distance, so the rate drops sharply at first.

Leaf structure

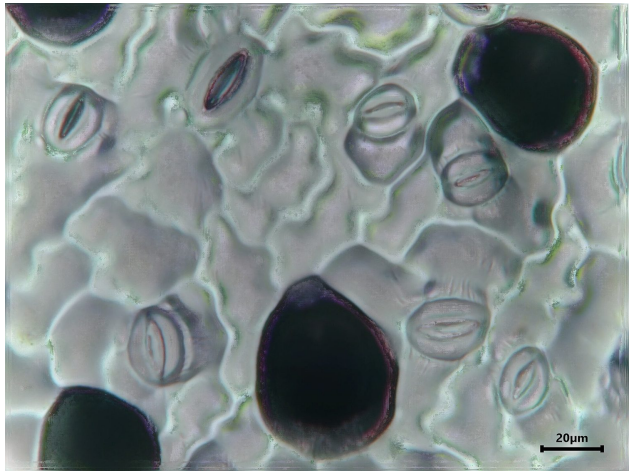
A leaf is well **adapted** 适应 for photosynthesis. Most leaves are broad, with a large **surface area** 表面积 to catch plenty of light, and thin, so that gases and light quickly reach all the cells.

The middle of the leaf, the **mesophyll** 叶肉, is where most photosynthesis happens. These are the main parts of a leaf:

Structure	Job / how it helps photosynthesis
cuticle 角质层	a clear waxy layer on top; it reduces water loss but still lets light through
upper **epidermis** 表皮	a clear layer of cells with no chloroplasts; it lets light pass to the cells below
palisade mesophyll 栅栏叶肉	tall, column-shaped cells packed with chloroplasts, near the top; they do most of the photosynthesis
spongy mesophyll 海绵叶肉	rounded cells with **air spaces** 气腔 between them, so gases can move easily
stomata 气孔	tiny holes, mostly on the lower surface, that let carbon dioxide in and oxygen out
guard cells 保卫细胞	a pair of cells around each stoma; they open and close it
lower epidermis	a thin layer that holds the stomata
vascular bundles 维管束	contain **xylem** 木质部 (brings water to the leaf) and phloem (carries sugars away)



A leaf in cross-section: each tissue is adapted for photosynthesis and gas exchange



Real stomata in the lower surface of a leaf – each pore has two guard cells (scale bar 20 µm)

Exam tips

- Learn the word equation exactly: carbon dioxide + water → glucose + oxygen (in light, with chlorophyll).
- Chlorophyll is in the chloroplasts; it does not get used up – it transfers light energy.
- Link each factor to the rate: more light, more carbon dioxide, warmer (but not too hot) → faster, until a **limiting factor** stops further increase.
- For leaf structure, always link the part to its job: broad and thin to catch light; palisade cells full of chloroplasts; stomata and air spaces for gas exchange.
- Nitrate ions → amino acids; magnesium ions → chlorophyll.
- Starch test: water, ethanol (in a water bath – it is flammable), hot water, iodine. Destarch the plant first.
- Hydrogencarbonate indicator: purple = less carbon dioxide, red = normal, yellow = more. A tube with no plant is the control.
- In the pondweed experiment, light intensity is changed by moving the lamp; a water tank keeps the temperature constant.

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Human nutrition

IGCSE Biology

A balanced diet



A balanced diet includes plenty of fruit and vegetables.

A **balanced diet** 均衡饮食 gives you all the substances you need, in the right amounts. There are seven parts.

a balanced diet: seven parts

carbohydrates main energy source	**fats and oils** energy store, warmth	**proteins** growth and repair	**vitamins** C: skin & gums; D: calcium

mineral ions calcium: bones, teeth; iron: red blood cells	**fibre** keeps the gut moving	**water** most reactions happen in it

the right **amounts** matter too - too much or too little each brings its own problems

The seven parts of a balanced diet and the job each one does

Part of diet	Good sources	Why you need it
carbohydrates 碳水化合物	rice, bread, potatoes	the main source of **energy** 能量
fats 脂肪 and oils	butter, oil, nuts	an energy store; help keep you warm
proteins 蛋白质	meat, fish, eggs, beans	growth and repair of cells
vitamin 维生素 C	fresh fruit, vegetables	keeps skin and gums healthy
vitamin D	sunlight, oily fish, eggs	helps the body take in **calcium** 钙
mineral ions 矿物质离子 – calcium	milk, cheese	strong bones and teeth
mineral ions – **iron** 铁	red meat, leafy greens	needed to make **haemoglobin** 血红蛋白, the red pigment in red blood cells that carries oxygen
fibre 膳食纤维 (roughage)	vegetables, whole grains	keeps food moving through the gut
water	drinks and food	needed for all reactions; most of the body is water

Two diseases come from missing a vitamin:

- too little vitamin C → **scurvy** 坏血病 (bleeding gums, slow healing).
- too little vitamin D → **rickets** 佝偻病 (soft, bent bones), because the body cannot take in enough calcium.

> **Worked example.** A child eats almost no fresh fruit or vegetables. Their gums bleed and small cuts heal slowly. Which part of the diet is missing, and why does that explain the symptoms? Fresh fruit and vegetables are the main source of **vitamin C**, and too little vitamin C causes **scurvy** - whose signs are exactly bleeding gums and slow healing. So the missing part is vitamin C. Name the **substance** and the **disease** separately: an answer that says only "a vitamin deficiency" does not earn the mark.

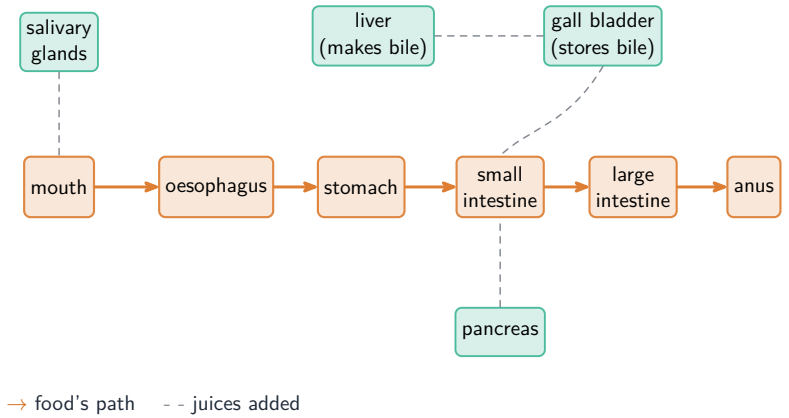
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The digestive system

The **digestive system** 消化系统 breaks food down. Food passes along one long tube, the **alimentary canal** 消化道:

mouth → **oesophagus** 食道 → **stomach** 胃 → **small intestine** 小肠 (the **duodenum** 十二指肠 then the **ileum** 回肠) → **large intestine** 大肠 (the **colon** 结肠, **rectum** 直肠 and **anus** 肛门).

Some organs help with digestion but food does not pass through them: the **salivary glands** 唾液腺 in the mouth, the **pancreas** 胰腺, the **liver** 肝脏 and the **gall bladder** 胆囊.



The alimentary canal that food passes through, plus the organs that add digestive juices

Five things happen to food, in order:

Process	What it means
ingestion 摄入	taking food and drink into the body through the mouth
digestion 消化	breaking food down into small molecules
absorption 吸收	**nutrients** 营养物质 move from the intestine into the blood
assimilation 同化	cells take in and use the nutrients
egestion 排遗	undigested food leaves the body as **faeces** 粪便

What each organ does:

Organ	Its job
mouth	ingestion; teeth break food up; saliva from the salivary glands contains amylase, which starts digesting starch
oesophagus	muscles in its wall push the food down to the stomach

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Organ	Its job
stomach	churns food; makes protease and hydrochloric acid, so protein digestion starts here
duodenum	receives pancreatic juice and bile; digestion of starch, protein and fat continues
ileum	the last digestion, then absorption of digested food and most of the water
pancreas	makes amylase, protease and lipase, and releases them into the duodenum
liver	makes bile; assimilation, for example turning glucose into glycogen and amino acids into proteins
gall bladder	stores bile and releases it into the duodenum
colon	absorbs some water
rectum and anus	store faeces, then egestion through the anus

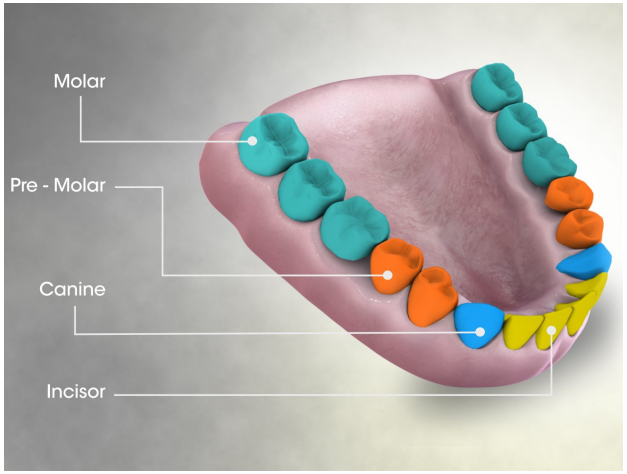
Physical digestion

Physical digestion breaks food into smaller pieces **without** changing the food molecules. This gives a larger **surface area** 表面积 for the **enzymes** 酶 to act on later.

Teeth

You have four kinds of **teeth** 牙齿:

Tooth	Job
incisors 门齿	sharp front teeth for biting and cutting
canines 犬齿	pointed teeth for tearing
premolars 前臼齿	flat teeth for chewing and grinding
molars 臼齿	flat back teeth for chewing and grinding

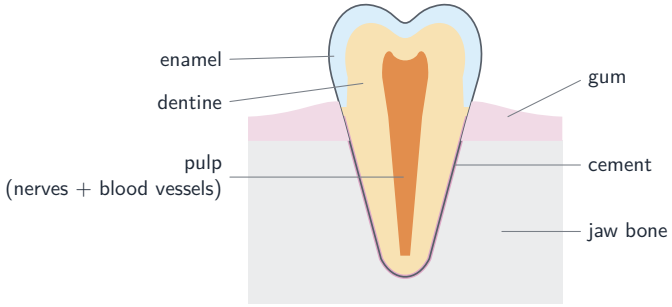


The four kinds of teeth: incisors and canines at the front, premolars and molars at the back

A tooth is built from these parts:

Part	Description
enamel 牙釉质	hard white outer layer; the hardest material in the body
dentine 牙本质	softer, bone-like layer under the enamel
pulp 牙髓	soft centre with **nerves** 神经 and **blood vessels** 血管
cement 牙骨质	fixes the root into the jaw

Teeth are set into the bone of the jaw and held firm by the **gums** 牙龈.



A tooth in section: hard enamel over dentine, a soft pulp, and a root set in the jaw

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The stomach

The wall of the stomach is made of **muscle** 肌肉 that squeezes and mixes the food, breaking it into smaller pieces.

Bile (Supplement)

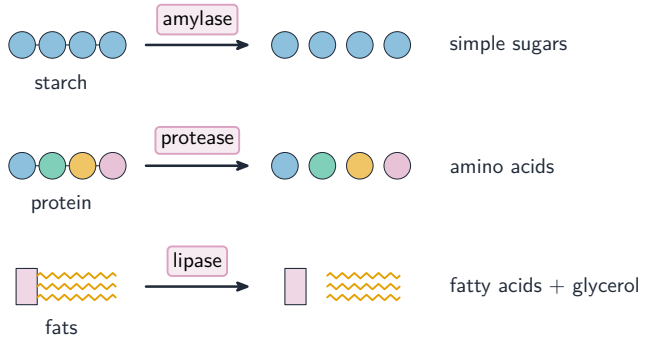
Bile 胆汁 is made in the liver and stored in the gall bladder. It **emulsifies** 乳化 fats and oils – it breaks large drops of fat into many tiny droplets. This gives a much larger surface area for the enzyme **lipase** 脂肪酶 to digest the fat. Bile itself contains no enzymes.

Chemical digestion

Chemical digestion breaks large **insoluble** 不溶性 molecules into small **soluble** 可溶性 molecules. Only small soluble molecules can be absorbed into the blood. Enzymes carry out this work.

Enzyme	Breaks down	Into	Made in	Acts in
amylase 淀粉酶	**starch** 淀粉	**reducing sugars** 还原糖	salivary glands, pancreas	mouth, small intestine
protease 蛋白酶	protein	**amino acids** 氨基酸	stomach, pancreas	stomach, small intestine
lipase	fats and oils	**fatty acids** 脂肪酸 and **glycerol** 甘油	pancreas	small intestine

An enzyme is often made in one place and acts in another: the pancreas makes all three, but they work in the **small intestine**, where pancreatic juice is released.



Digestive enzymes break large insoluble molecules into small soluble ones

Acid in the stomach

The stomach makes **hydrochloric acid** 盐酸, which is part of the **gastric juice** 胃液. This acid:

- kills harmful **microorganisms** 微生物 in the food, and
- gives an **acidic** 酸性 pH, the best pH for the stomach's protease to work.

Digesting starch and protein (Supplement)

Starch is digested in two steps:

- amylase breaks starch into **maltose** 麦芽糖.
- **maltase** 麦芽糖酶, on the membranes of the **epithelium** 上皮 lining the small intestine, breaks maltose into **glucose** 葡萄糖.

Protein is digested by two proteases:

- **pepsin** 胃蛋白酶 breaks protein down in the acidic stomach.
- **trypsin** 胰蛋白酶 breaks protein down in the **alkaline** 碱性 small intestine.

Bile is alkaline. It **neutralises** 中和 the acidic food and gastric juice as they enter the duodenum, giving a suitable pH for the enzymes there.

> **Worked example.** A patient has their gall bladder removed. Suggest how this affects the digestion of a fatty meal. The liver still **makes** bile, but there is no store to release a large amount when fatty food arrives. So less bile reaches the duodenum at that time, fewer fat drops are **emulsified**, and the fat has a smaller **surface area** for lipase. Fat is digested more slowly, and the acid from the stomach is neutralised less well, so the enzymes in the small intestine work less well too. The doctor may advise small, low-fat meals.

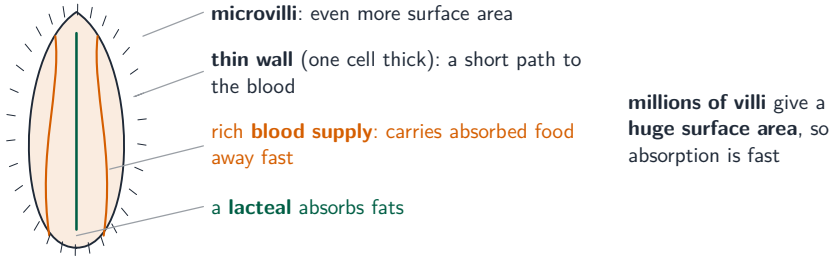
Absorption

Digested nutrients are absorbed into the blood in the small intestine. Most water is absorbed here too; the colon absorbs the rest, leaving solid faeces.

Villi (Supplement)

The inside of the small intestine is covered with millions of tiny finger-shaped **villi** 绒毛. Each villus is itself covered in much smaller **microvilli** 微绒毛. Together these give a huge surface area, so absorption is fast.

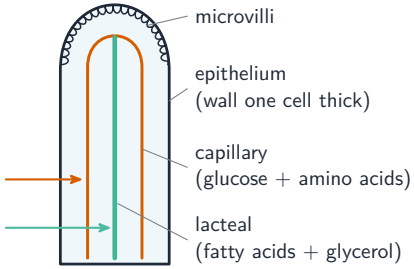
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A villus is adapted for fast absorption: microvilli, a thin wall, a rich blood supply and a lacteal

A single villus has:

- a wall just one cell thick, so molecules have only a short distance to travel.
- a network of **capillaries** 毛细血管 that carry away absorbed glucose and amino acids.
- a **lacteal** 乳糜管 in the centre that carries away absorbed fatty acids and glycerol.



a villus (huge surface area for absorption)

A villus has a thin wall, a capillary network and a lacteal, for fast absorption

Common mistakes.

- Saying bile digests fat. Bile has **no** enzymes. It breaks fat into small droplets (emulsifies it), which is physical digestion; lipase then digests the fat.
- Saying the stomach acid digests protein. The acid kills microorganisms and gives the low pH that the stomach protease needs; the **protease** digests the protein.
- (Supplement) Saying amylase turns starch straight into glucose. Amylase makes **maltose**; maltase on the small intestine lining then turns maltose into glucose.
- Saying an enzyme is "used up" in digestion. Each enzyme molecule is not changed, so it can digest many food molecules.

- Saying villi help absorption because they are "long". Say what they give: a **large surface area**, a wall one cell thick (a short distance) and a good blood supply.

Exam tips

- A balanced diet has the right amount of each part. Learn one source and one use for each.
- Vitamin C ↔ scurvy; vitamin D ↔ rickets.
- The five processes in order: ingestion → digestion → absorption → assimilation → egestion. Egestion (faeces) is **not** excretion.
- Physical digestion makes pieces smaller (more surface area); chemical digestion uses enzymes to make molecules smaller and soluble.
- amylase → sugars, protease → amino acids, lipase → fatty acids + glycerol. Stomach acid kills microorganisms and sets a low pH.
- Villi and microvilli give a large surface area, and a thin wall gives a short distance – both make absorption faster.

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Transport in plants

IGCSE Biology

Xylem and phloem



A tree moves water up from its roots through xylem vessels.

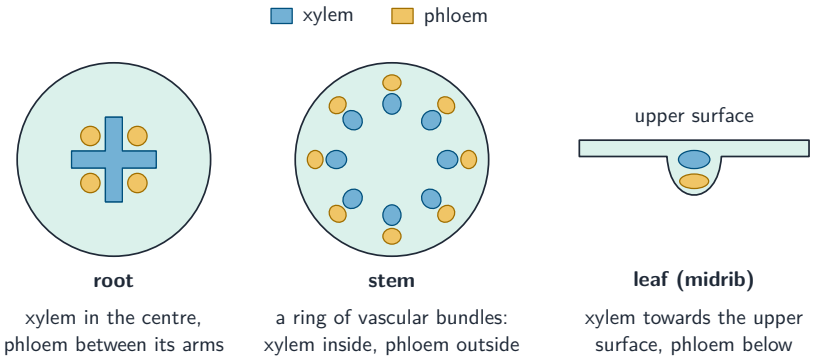
Plants have two transport tissues that run through the roots, stems and leaves:

- **xylem** 木质部 – carries water and **mineral ions** 矿物质离子 up from the roots, and gives the plant **support** 支撑.
- **phloem** 韧皮部 – carries **sucrose** 蔗糖 and **amino acids** 氨基酸 to wherever they are needed.

In a root, stem or leaf, the xylem and phloem lie side by side in **vascular bundles** 维管束.

Exams show a section through a root, stem or leaf and ask you to identify the xylem and the phloem. Learn where each one lies:

- **root**: the xylem is in the **centre**, often in an X or star shape; the phloem lies in the gaps between its arms. A central core resists the pulling force as the root anchors the plant.
- **stem**: the vascular bundles form a **ring** near the outside; in each bundle the xylem is on the **inside** (towards the centre) and the phloem on the **outside**. This ring helps the stem resist bending.
- **leaf**: in the midrib and veins, the xylem is towards the **upper** surface and the phloem towards the lower surface.



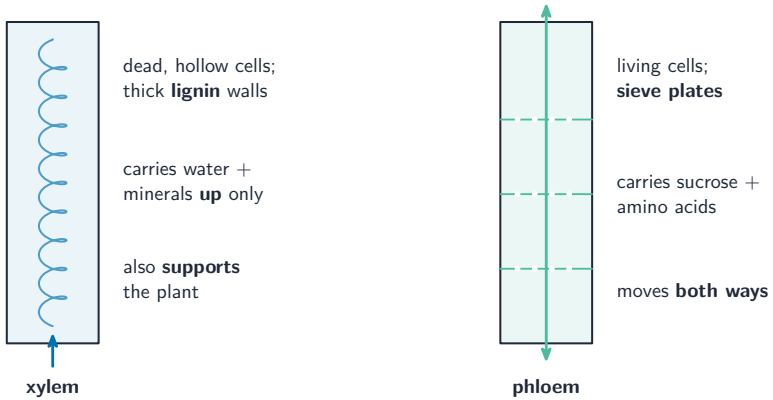
Where xylem and phloem lie in sections of a root, a stem and a leaf

In a photograph, the xylem vessels are the cells with the **widest** openings and the thickest walls; stains such as the red in the stem section below colour the lignin in their walls.

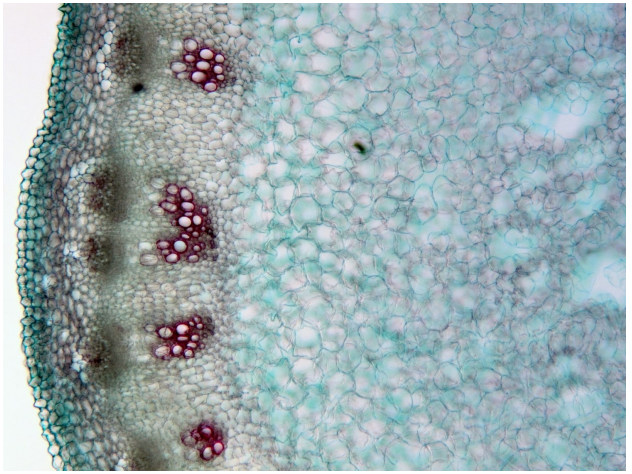
■ Xylem structure (Supplement)

Xylem is made of long tubes called **vessels** 导管, well suited to carrying water:

- their walls are thick and strengthened with **lignin** 木质素, which also helps support the plant.
- the cells are dead and empty (they have no cell contents), so water flows through freely.
- the cells are joined end to end with no walls across the tube, making one long, continuous pipe.



Xylem carries water up in dead lignified tubes; phloem carries sucrose in living cells



A stem in cross-section: the red-stained xylem sits in vascular bundles near the edge

Water uptake

Water and mineral ions enter the plant through **root hair cells** 根毛细胞. The huge number of **root hairs** 根毛 gives a very large **surface area** 表面积, which speeds up the uptake of water and mineral ions.

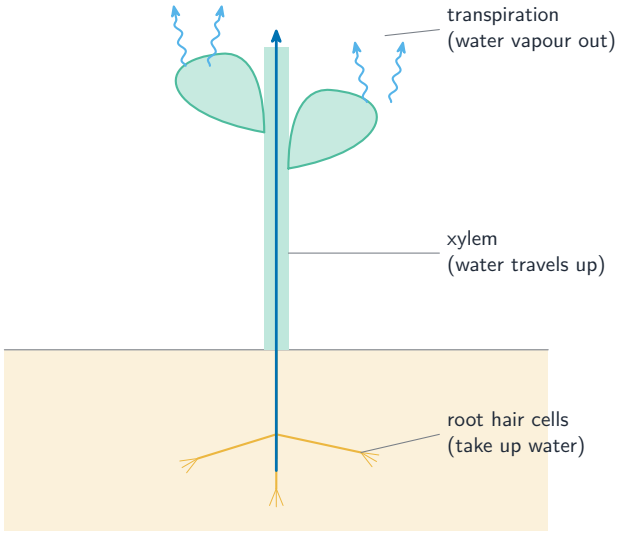
The water then follows this pathway:

root hair cells → root **cortex** 皮层 cells → xylem → **mesophyll** 叶肉 cells in the leaf.

You can show this pathway by standing a plant or a white flower in water that contains a coloured **stain** 染色剂. The stain is carried up the xylem and colours the veins.

Investigating the pathway. Stand a celery stalk with leaves in water containing a dye (such as food colouring or eosin) for a few hours, in a warm, bright place so that transpiration is fast. Cut thin slices across the stalk and look at them with a hand lens: only small dots near the edge, the **xylem** in the vascular bundles, are coloured. The leaf veins also become coloured. This shows that water travels up the stem in the xylem and out into the leaves.

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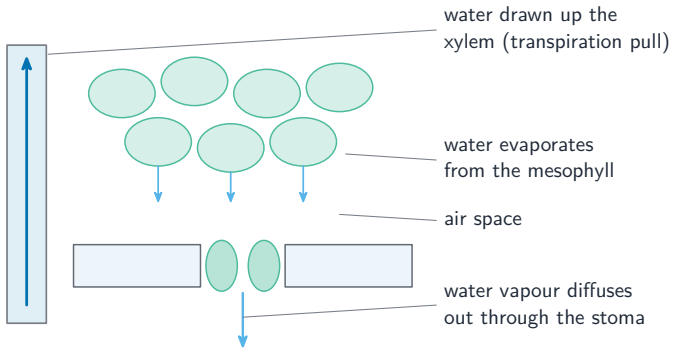
Water is taken up by root hairs, carried up the xylem, and lost from the leaves

Transpiration

Transpiration 蒸腾作用 is the loss of **water vapour** 水蒸气 from the leaves.

- Water **evaporates** 蒸发 from the wet surfaces of the mesophyll cells into the **air spaces** 气腔 inside the leaf.
- The water vapour then **diffuses** 扩散 out of the leaf through the **stomata** 气孔.

(Supplement) The structure of the leaf makes this loss large. The mesophyll cells are surrounded by **interconnecting air spaces**, which give a very large **internal surface area** for water to evaporate from. The more stomata there are, and the wider they are open, the faster water vapour diffuses out. Most stomata are on the lower surface, which is cooler and shaded, and the stomata close at night or when the plant is short of water, which cuts water loss.



Water evaporates from the mesophyll and diffuses out of the stomata as water vapour

What changes the rate of transpiration

Factor	Transpiration is faster when...	Why
temperature 温度	it is hotter	water evaporates faster
wind speed 风速	it is windier	wind carries the water vapour away
humidity 湿度 (Supplement)	the air is drier	a bigger difference makes water diffuse out faster

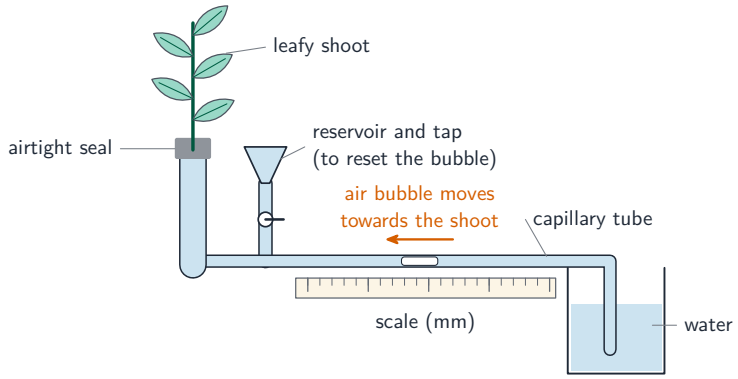
(Supplement) Explaining the factors. Give the full reason:

- **temperature**: water molecules have more **kinetic energy**, so more water evaporates from the mesophyll cells and the vapour diffuses out faster.
- **wind speed**: the wind carries away the water vapour just outside the stomata, so the **concentration gradient** 浓度梯度 of water vapour between the air spaces and the outside air stays steep.
- **humidity**: humid air already holds a lot of water vapour, so the concentration gradient between the inside and the outside of the leaf is **smaller** and diffusion is slower.

Investigating temperature and wind speed. Use a potometer (below). Measure how far the bubble moves in a fixed time, for example 5 minutes, then change **one** factor: place the shoot at different distances from a **fan** (or use the fan at different speeds) for wind speed, or put it in rooms or by a heater at different temperatures, checked with a thermometer. Keep the other factors constant: the same shoot, light intensity and humidity. Repeat each reading and find a mean. Reset the bubble each time using the reservoir.

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A **potometer** 蒸腾计 measures how fast a leafy shoot takes up water. The shoot is sealed into a tube full of water; as the leaves lose water by transpiration, the shoot draws water along a thin capillary tube, and an air bubble in the tube moves towards the shoot. The distance the bubble moves in a measured time gives the rate.



A potometer: the air bubble moves towards the shoot as it takes up water

> **Worked example.** In a potometer the air bubble moves 60 mm in 5 minutes. Find the rate of water uptake, and say what happens when a fan is switched on. Rate = distance ÷ time = 60 ÷ 5 = **12 mm per minute**. Always give a rate its full unit, "mm per minute", not just "12". A fan raises the wind speed, which carries water vapour away from the leaf, so transpiration speeds up and the bubble moves further in the same 5 minutes.

How water rises up the xylem (Supplement)

As water vapour leaves the leaf, it pulls more water up behind it. This pull is called the **transpiration pull** 蒸腾拉力. The water molecules stick to one another by **forces of attraction** 吸引力, so they are drawn up the xylem together as one long **column** 水柱 of water.

Wilting (Supplement)

If a plant loses water faster than it can take it up, its cells become soft and the plant **wilts** 萎蔫 – the leaves and stem droop. This often happens on a hot, dry, windy day.

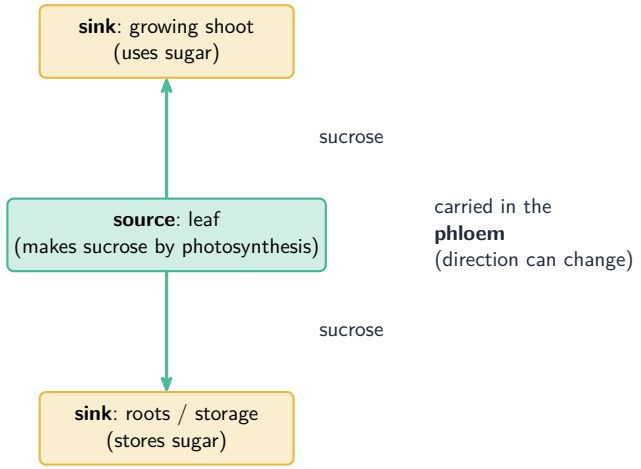
The reason is **turgor** 膨压. Normally the vacuoles are full of water, which pushes the cytoplasm and cell membrane outwards against the cell wall; the cells are **turgid** 膨胀 (firm), and they press against each other and hold the plant upright. When more water is lost by transpiration than enters the roots, water leaves the cells by **osmosis**. The vacuoles shrink, the cells become **flaccid** 松软 (soft) and no longer support the leaves and stem, so the plant wilts. Wilting also helps the plant: the drooping leaves expose less surface to the sun, and the stomata close, so less water is lost. Watering the plant, or a cool night, lets the cells take up water again and become turgid.

Translocation (Supplement)

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

- sources are the parts that **release** sucrose or amino acids – for example the leaves, which make sugar by photosynthesis.
- sinks are the parts that **use or store** them – for example growing roots, or a storage organ.

The same part of a plant can be a **sink at one time and a source at another**. A potato tuber is a **sink** in summer, when sucrose arrives from the leaves and is stored as starch. In spring, before the new shoots have leaves, the starch is broken down to sucrose and sent to the growing shoots: now the tuber is a **source**. In the same way, a young leaf is a sink while it grows, and becomes a source once it is photosynthesising more than it needs. This is why phloem can carry sucrose **upwards or downwards**, unlike xylem.



The phloem moves sucrose from a source to a sink; the direction can change

Common mistakes.

- Saying transpiration is the loss of water through the stomata. Be exact: water **evaporates** from the mesophyll cell surfaces into the air spaces, and then water **vapour** diffuses out through the stomata.
- Saying root hairs take up water by **active transport** 主动运输. Water enters by **osmosis** 渗透; only mineral ions can need active transport.

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- Saying humid air speeds up transpiration. More humid air means a **smaller** difference in water vapour between the leaf and the air, so transpiration is **slower**.
- Saying a potometer measures transpiration directly. It measures water **uptake**; a little of the water taken up is used in the plant (for example in photosynthesis), so uptake is only close to the transpiration rate.
- Saying xylem carries sugar, or that phloem carries water up from the roots. Xylem: water and mineral ions, upward. Phloem: sucrose and amino acids, from source to sink, up or down.
- Giving a rate as a bare number. A bubble that moves 60 mm in 5 minutes gives **12 mm per minute**, not "12".

Exam tips

- Xylem: water and mineral ions, upward only, plus support – its cells are dead, with thick lignin walls. Phloem: sucrose and amino acids, in living cells.
- Learn the water pathway: root hair cell → cortex → xylem → mesophyll.
- Transpiration = evaporation from the mesophyll, then diffusion out of the stomata. It is faster when hotter, windier or drier.
- Water rises by the **transpiration pull**; the water molecules hold together as a column.
- Translocation goes from a **source** (where sugar is made or stored) to a **sink** (where it is used). The direction can change with the season.
- To identify the tissues in a section: root – xylem in the centre; stem – bundles in a ring, xylem inside and phloem outside; leaf – xylem above, phloem below.
- (Supplement) Explain wilting with **osmosis** and **turgor**: water leaves the cells, they become **flaccid**, and they stop supporting the plant.

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Transport in animals

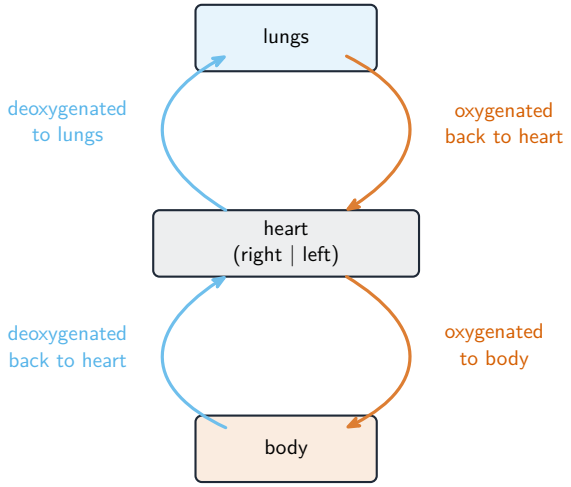
IGCSE Biology

The circulatory system

The **circulatory system** 循环系统 carries blood around the body. It has three parts: a **pump** 泵 (the **heart** 心脏), a network of **blood vessels** 血管, and **valves** 瓣膜 that keep the blood flowing one way only.

Single and double circulation (Supplement)

- A fish has a **single circulation** 单循环: the blood passes through the heart **once** on each trip around the body.
- A **mammal** 哺乳动物 has a **double circulation** 双循环: the blood passes through the heart **twice** on each full trip – once on the way to the lungs, and once on the way to the rest of the body.
- The advantage of a double circulation: the blood can be pumped again at **high pressure** 压力 before going to the body, so it travels faster and delivers **oxygen** 氧气 quickly.



In a double circulation, blood passes through the heart twice on each trip round the body

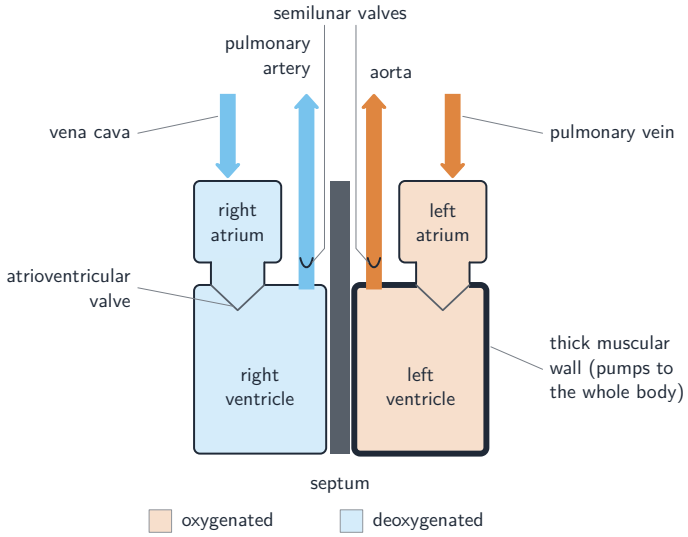
The heart

The heart is made of **muscle** 肌肉. A wall called the **septum** 隔膜 divides it into a left side and a right side. On each side there is an upper chamber, the **atrium** 心房, and a lower chamber, the **ventricle** 心室. Valves between the chambers stop the blood flowing backwards. The heart muscle is fed with blood by the **coronary arteries** 冠状动脉.

(Supplement) The wall of the left ventricle is thicker than the right, because it must pump blood all the way around the body; the right side only pumps blood to the nearby lungs. The atria have thin walls, as they only push blood into the ventricles just below them.

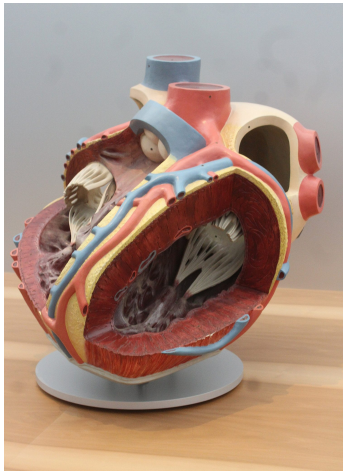
The septum keeps **oxygenated blood** 含氧血 on the left side apart from **deoxygenated blood** 缺氧血 on the right side, so the two never mix.

(Supplement) The valves between each atrium and ventricle are the **atrioventricular valves** 房室瓣. The valves at the exit of each ventricle are the **semilunar valves** 半月瓣.



The heart's four chambers; the left ventricle has the thickest wall, to pump to the whole body

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The same heart as a museum model: four chambers, and a left ventricle wall you can see is thicker

How the heart beats (Supplement)

1. The atria **contract** 收缩 and push blood down into the ventricles.
2. The ventricles contract and force blood out into the arteries; the valves snap shut so blood cannot flow back.
3. The muscle relaxes and the heart fills with blood again.

Blood is pumped away from the heart in arteries and returns to the heart in veins.

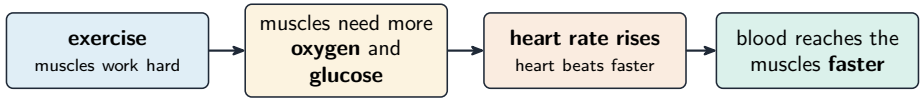
> **Worked example: the route of the blood.** Describe the path of a red blood cell from the vena cava until it leaves the heart again in the aorta. Follow it one step at a time, naming each chamber, valve and vessel in order:

1. **vena cava** → **right atrium**
2. through an atrioventricular valve → **right ventricle**
3. through a semilunar valve → **pulmonary artery** → **lungs**, where the blood collects oxygen
4. **pulmonary vein** → **left atrium**
5. through an atrioventricular valve → **left ventricle**
6. through a semilunar valve → **aorta** → the rest of the body

Check your answer: the right side carries deoxygenated blood and the left side carries oxygenated blood, and the blood goes to the lungs **between** the two sides. A common mistake is to send blood straight from the right side of the heart to the left side; the septum stops this.

Heart rate and exercise

You can check the heart's activity with an **ECG**, by feeling the **pulse** 脉搏 in an artery, or by listening to the valves closing. During exercise the **heart rate** 心率 goes up, so blood reaches the muscles faster, bringing the extra oxygen and glucose they need.



check the heart's activity by feeling the **pulse**, listening to the valves, or with an **ECG**

During exercise the heart rate rises so blood reaches the muscles faster

> **Worked example.** A student counts 18 pulse beats in 15 seconds at rest, and 33 beats in 15 seconds straight after exercise. Give both heart rates in beats per minute. A minute holds $60 \div 15 = 4$ lots of 15 seconds, so multiply by 4. At rest: $18 \times 4 =$ **72 beats per minute**. After exercise: $33 \times 4 =$ **132 beats per minute**. The rise delivers more oxygen and glucose to the muscles. Writing the 15-second count straight down as the heart rate is the commonest mistake - always scale it up to a full minute.

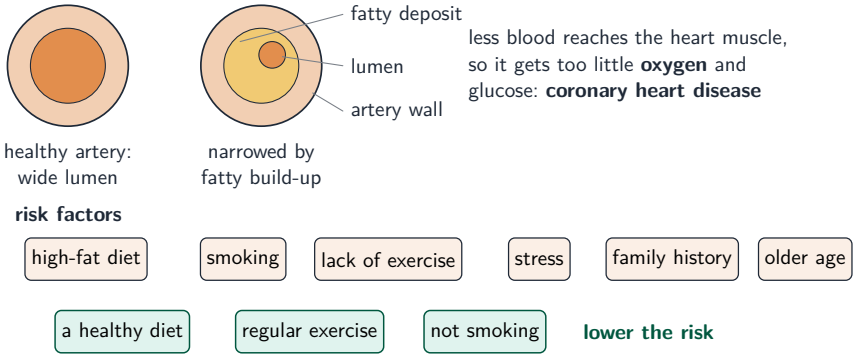
Planning the investigation. To find out how the length of exercise affects heart rate, change one thing and keep the rest the same:

- the **independent variable** 自变量 (what you change): the time spent exercising, for example 1, 2, 3 and 4 minutes of step-ups.
- the **dependent variable** 因变量 (what you measure): the pulse rate in beats per minute, counted straight after the exercise.
- keep these the same: the type and speed of exercise (step-ups in time with a metronome), the same person, and a rest until the pulse is back to its resting rate before each new test.
- repeat each test three times and find the mean.

A typical result: the pulse rises from about 70 at rest to about 130 beats per minute and then takes several minutes to fall back. A fitter person usually has a lower resting rate and returns to it sooner.

Coronary heart disease

Coronary heart disease 冠心病 happens when the coronary arteries become narrow or blocked, so the heart muscle cannot get enough oxygen. **Risk factors** 风险因素 include a diet high in fat, lack of exercise, stress, smoking, family history (genetics), older age, and being male. A healthy diet and regular exercise lower the risk.



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

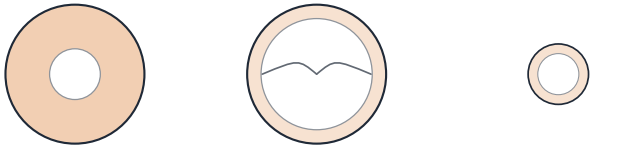
Blood vessels

There are three kinds of blood vessel. The space inside a vessel is its **lumen** 管腔.

Vessel	Wall	Lumen	Valves?	Job
arteries 动脉	thick, muscular, elastic	narrow	no	carry blood **away** from the heart, at high pressure
veins 静脉	thin	wide	yes	carry blood **back** to the heart, at low pressure
capillaries 毛细血管	one cell thick	very narrow	no	let **oxygen**, glucose and wastes pass between blood and cells

(Supplement) Arteries have thick elastic walls to cope with the high pressure from the heart. Veins have valves because their blood is at low pressure and could otherwise flow backwards. Capillaries are very thin (one cell thick) and very narrow, giving a large **surface area** 表面积 and a short distance for fast exchange.

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artery
thick muscular, elastic wall; narrow lumen; high pressure

vein
thin wall; wide lumen; has **valves**; low pressure

capillary
wall one cell thick; lets substances be exchanged

Arteries, veins and capillaries are each built for their job

Main blood vessels

Connects	Artery (carries blood out)	Vein (carries blood in)
heart ↔ body	**aorta** 主动脉	**vena cava** 腔静脉
heart ↔ lungs	**pulmonary artery** 肺动脉	**pulmonary vein** 肺静脉
↔ kidney	**renal artery** 肾动脉	**renal vein** 肾静脉

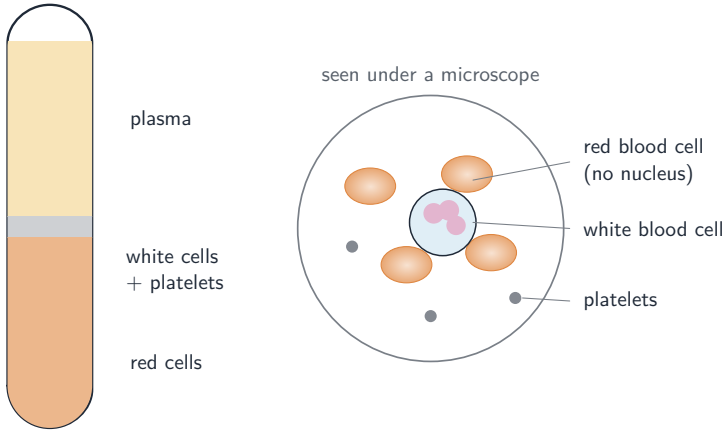
(Supplement) The liver is served by the **hepatic artery** 肝动脉, the **hepatic vein** 肝静脉, and the **hepatic portal vein** 肝门静脉, which brings blood from the gut to the liver.

Blood

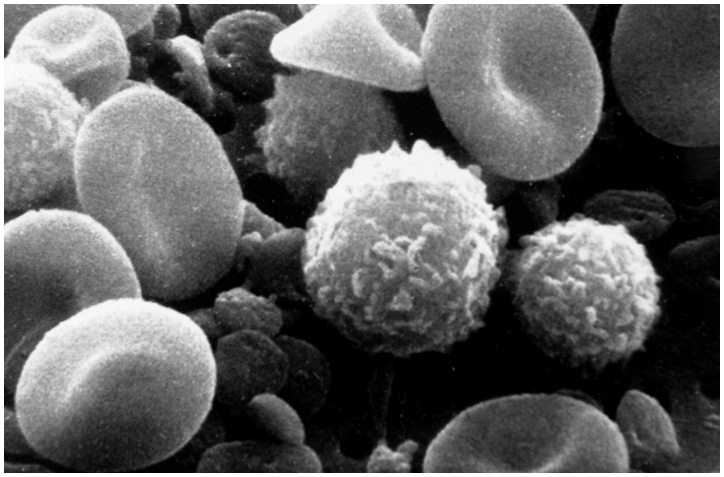
Blood has four parts:

Part	Function
red blood cells 红细胞	carry oxygen, using the red **pigment** 色素 **haemoglobin** 血红蛋白
white blood cells 白细胞	defend the body against disease
platelets 血小板	help the blood to **clot** 凝血
plasma 血浆	a liquid that carries blood cells, **ions** 离子, **nutrients** 营养物质, **urea** 尿素, **hormones** 激素 and **carbon dioxide** 二氧化碳

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Blood is red cells, white cells and platelets carried in liquid plasma



Real blood cells under an electron microscope: red cells (discs), white cells and platelets

Defending the body, and clotting

White blood cells fight **pathogens** 病原体 (the microbes that cause disease) in two ways:

- **phagocytes** 吞噬细胞 carry out **phagocytosis** 吞噬作用 – they surround and digest the pathogens.
- Some **lymphocytes** 淋巴细胞 make **antibodies** 抗体, which bind to specific antigens and help neutralise pathogens or mark them for destruction.

When you cut yourself, the blood **clots** to seal the wound. This stops blood loss and stops pathogens getting in. **(Supplement)** During clotting, a soluble protein called **fibrinogen** 纤维蛋白原 is changed into threads of **fibrin** 纤维蛋白. The threads form a net that traps blood cells and makes a solid clot.

Common mistakes.

- Saying arteries carry oxygenated blood and veins carry deoxygenated blood. Arteries carry blood **away from** the heart and veins carry it **back**. The pulmonary artery carries deoxygenated blood to the lungs, and the pulmonary vein brings oxygenated blood back.
- Saying the left ventricle has a thicker wall because it holds more blood. Both ventricles pump the same volume; the left one pumps the blood all round the body, so it needs a higher pressure.
- Saying veins have valves because of high pressure. Blood in veins is at **low** pressure, and the valves stop it flowing backwards.
- Saying capillary walls are thin so blood flows fast. Blood flows **slowly** in capillaries; the thin wall gives a short distance for oxygen and glucose to diffuse into the cells.
- (Supplement) Saying blood in a double circulation collects oxygen twice. It collects oxygen once, in the lungs; the second pass through the heart raises its pressure again.

Exam tips

- Circulatory system = pump (heart) + vessels + valves for one-way flow.
- Double circulation (mammals): blood passes through the heart twice. The left ventricle wall is thickest because it pumps to the whole body.
- Arteries carry blood **away** (thick, high pressure); veins carry it **back** (valves, low pressure); capillaries are for exchange (one cell thick).
- Blood = red cells (oxygen, haemoglobin) + white cells (defence) + platelets (clotting) + plasma (transport).
- Phagocytes engulf pathogens; lymphocytes make antibodies.

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Diseases and immunity

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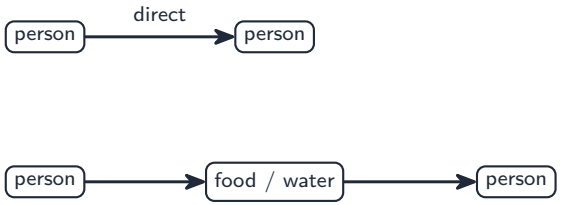
Pathogens and disease

A **pathogen** 病原体 is an organism that causes **disease** 疾病. A **transmissible disease** 传染病 is one in which the pathogen can pass from one **host** 宿主 to another.

How pathogens spread



A mosquito can spread pathogens from person to person when it bites.



Pathogens spread by direct contact or indirectly

A pathogen is **transmitted** 传播 in two main ways:

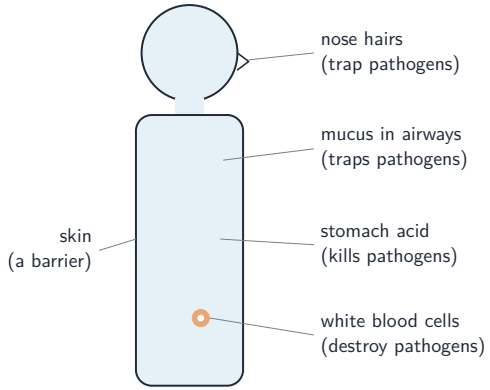
- by **direct contact** 直接接触 – for example through blood and other **body fluids** 体液.
- indirectly – for example from **contaminated** 污染 surfaces, food, animals, or the air.

Route	Examples
direct contact: blood and body fluids	HIV (sex, shared needles, mother to baby); hepatitis B
direct contact: touching	athlete's foot fungus; some skin infections
indirect: air (droplets from coughs and sneezes)	influenza (flu), the common cold, tuberculosis
indirect: food and water	cholera (contaminated water); *Salmonella* food poisoning
indirect: animals (**vectors** 媒介)	malaria, carried by mosquitoes; flies carrying bacteria from faeces to food
indirect: surfaces	cold viruses on door handles and phones

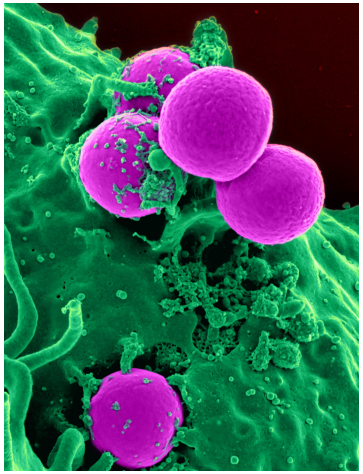
The body's defences

Your body has several **defences** 防御 that keep pathogens out or destroy them:

- **skin** – a barrier that covers and protects the body.
- **hairs in the nose** – trap dust and pathogens in the air you breathe in.
- **mucus** 黏液 – sticky liquid in the airways that traps pathogens.
- **stomach acid** 胃酸 – kills most pathogens in your food.
- **white blood cells** 白细胞 – find and destroy any pathogens that get inside.



The body keeps most pathogens out; white blood cells deal with any that get in



A white blood cell (green) engulfing round bacteria (purple), a key body defence

The skin is the first barrier: pathogens cannot pass through unbroken skin. When the skin is cut, the blood **clots**, sealing the wound quickly so pathogens cannot enter. Skin, nose hairs, mucus and stomach acid are **mechanical** or **chemical** barriers that work on every pathogen the same way. White blood cells are the defence inside the body: **phagocytes** engulf and digest pathogens, and (Supplement) **lymphocytes** make antibodies that target one kind of pathogen.

Controlling the spread of disease

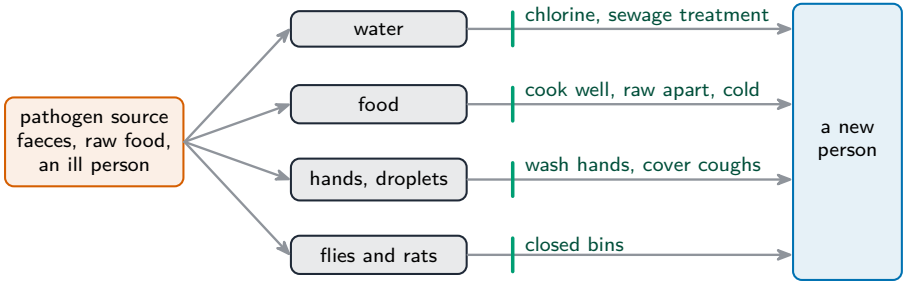
Good public health stops disease spreading:

- a clean water supply, so drinking water carries no pathogens.
- **hygienic** 卫生 food preparation and good personal hygiene, such as washing your hands.
- proper waste disposal and **sewage treatment** 污水处理, so waste does not contaminate water or food.

Exam questions ask you to **explain** why each one matters, so link it to how the pathogen spreads:

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Measure	Why it controls disease
a clean water supply (treated with chlorine, or boiled)	kills pathogens in drinking water, such as the cholera bacterium
hygienic food preparation	washing hands, keeping raw meat apart from cooked food, cooking food thoroughly and storing it cold stop bacteria growing and passing into food
good personal hygiene	washing hands after the toilet and before eating removes pathogens; covering coughs stops droplets spreading
waste disposal	rubbish collected in closed bins does not attract flies and rats, which carry pathogens
sewage treatment	removes or kills the pathogens in human faeces before the water returns to rivers, so drinking water is not contaminated



Each measure cuts one route from the source to a new person.

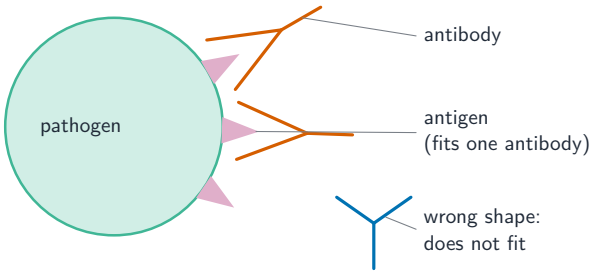
Immunity (Supplement)

Antigens and antibodies

Every pathogen carries **antigens** 抗原 on its surface, and each kind of antigen has its own special shape.

Antibodies 抗体 are **proteins** 蛋白质 made by **lymphocytes** 淋巴细胞 (a kind of white blood cell). An antibody has a shape that is **complementary** 互补 to one antigen, so it fits only that antigen. Binding can neutralise pathogens or their toxins, or mark pathogens so that **phagocytes** 吞噬细胞 can engulf and destroy them.

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An antibody's shape is complementary to one antigen, so it fits only that pathogen

Active immunity and vaccination

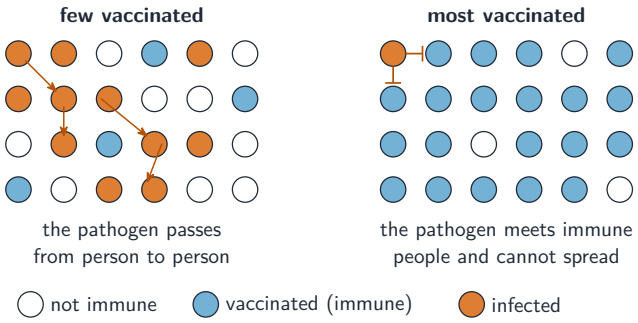
Active immunity 主动免疫 is protection made by your **own** body producing antibodies. You gain it after an infection, or after **vaccination** 疫苗接种.

Vaccination works like this:

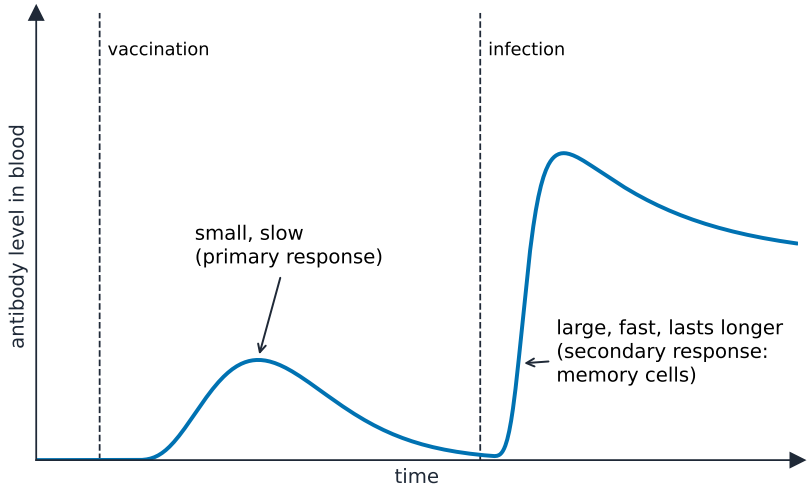
1. weakened pathogens, or just their antigens, are put into the body; they cannot make you ill.
2. the antigens make your lymphocytes produce antibodies.
3. the body also makes **memory cells** 记忆细胞 that stay for years.

If the real pathogen enters later, the memory cells make antibodies very fast, so you do not become ill. This gives long-term protection. If most people in a group are vaccinated, the disease cannot spread easily.

How vaccination controls the spread of a disease. A vaccinated person does not become ill, so they do not pass the pathogen on. When a large proportion of a population is vaccinated, an infected person meets mostly immune people, so the pathogen cannot find new hosts and the chain of transmission is broken. This also protects the few people who cannot be vaccinated (such as newborn babies, or people who are very ill). This is called **herd immunity** 群体免疫. Smallpox was **eradicated** 根除 from the whole world in 1980 by vaccinating everyone around each case.



When most people are vaccinated, the pathogen cannot find enough hosts to spread



After vaccination, memory cells give a fast, large response if the real pathogen arrives, and the antibody level stays high for longer

Worked example. After a first dose of a vaccine, antibody levels rise slowly and stay low. After a second dose of the same vaccine, they rise faster and reach a much higher level. Explain. At the first dose the body has no memory cells for that antigen, so time is lost while the right lymphocyte is found and multiplies - the response is slow and small. The second dose meets the memory cells left over from the first, which recognise the antigen at once, so antibodies are made sooner and in far greater numbers. The marks are for **memory cells**: "the body is used to it" earns nothing.

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Passive immunity

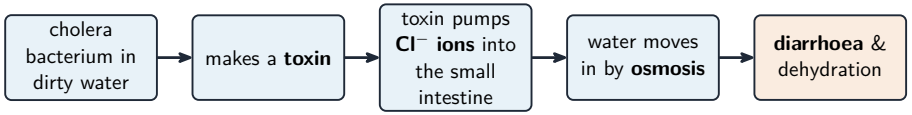
Passive immunity 被动免疫 is protection from antibodies made by **another** body, not your own. For example, a baby receives antibodies from its mother across the **placenta** 胎盘 and in **breast milk** 母乳. This is why **breast-feeding** 母乳喂养 helps protect **infants** 婴儿. Passive immunity is only short-term, because **no** memory cells are made.

Why breast-feeding matters. A newborn baby's immune system is not yet fully developed, so it cannot make many antibodies of its own. The antibodies in breast milk protect it against the pathogens the mother has met – which are the ones the baby is most likely to meet too – until its own immune system can respond. Antibodies can also be injected, for example after a snake bite or an exposure to tetanus, to give instant but short-term protection.

	Active immunity	**Passive immunity**
antibodies made by	your own lymphocytes	another person or animal
gained by	infection or vaccination	across the placenta, in breast milk, or by injection
memory cells?	yes	**no**
how fast it works	slowly at first (days)	immediately
how long it lasts	long-term (years)	short-term (weeks)

Cholera (Supplement)

Cholera 霍乱 is a disease caused by a **bacterium** 细菌 that spreads in contaminated water. The cholera bacterium makes a **toxin** 毒素. This toxin causes **chloride ions** 氯离子 to be pumped into the **small intestine** 小肠. Water then moves into the intestine by **osmosis** 渗透. The result is **diarrhoea** 腹泻, **dehydration** 脱水 (loss of water) and a loss of **ions** 离子 from the blood.



Cholera toxin pulls water into the gut by osmosis, causing diarrhoea and dehydration

Worked example. Explain why a person with cholera can die within a day, and how they can be treated. The toxin causes chloride ions to be secreted into the small intestine, lowering the water potential there, so water moves from the blood into the gut by osmosis and is lost as watery diarrhoea. The person loses so much water and so many ions from the blood that they become dangerously **dehydrated**. The treatment is to replace them: drinking **oral rehydration solution** 口服补液 (water with salts and glucose), or a drip into a vein if very ill. Cholera is prevented by a clean water supply and sewage treatment.

Common mistakes.

- Saying a vaccine contains antibodies. A vaccine contains weakened pathogens or their **antigens**; your own lymphocytes then make the antibodies and memory cells.
- Writing just "white blood cells" when the question asks which cells. **Lymphocytes** make antibodies; **phagocytes** engulf and digest pathogens. Name the right one.
- Saying memory cells make you immune because they "remember the disease". The marks are for: memory cells recognise the antigen and quickly make **many antibodies**, so the pathogen is destroyed before you become ill.
- Saying an antibody works against any pathogen. Its shape is complementary to **one** antigen, so a new antibody is needed for each kind of pathogen.
- Calling a baby's protection from breast milk long-term. The antibodies come from the mother and no memory cells are made, so passive immunity lasts only a short time.
- Saying cholera bacteria pump out water. The **toxin** makes chloride ions move into the small intestine, and **water follows by osmosis**.

Exam tips

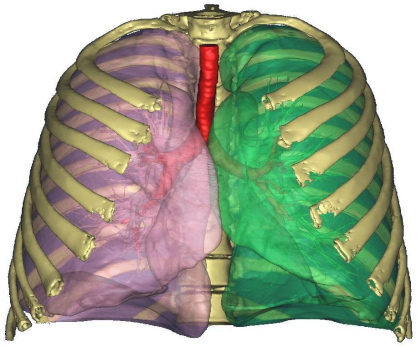
- Pathogen = organism that causes disease. Transmissible = can pass between hosts, by direct contact or indirectly.
- Five body defences: skin, nose hairs, mucus, stomach acid, white blood cells.
- An antibody's shape is **complementary** to one antigen (like an enzyme and its substrate).
- Active immunity (from infection or vaccination) makes **memory cells** → long-term. Passive immunity (placenta, breast milk) makes **no** memory cells → short-term.
- Cholera: toxin → chloride into the gut → water by osmosis → diarrhoea and dehydration.
- For each public-health measure, say which route of spread it breaks (water, food, hands, flies, sewage).
- Vaccination controls spread because vaccinated people do not become ill and cannot pass the pathogen on; if most are vaccinated, the chain of transmission breaks.

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Gas exchange in humans

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Gas exchange surfaces



Gas exchange happens across the huge surface of the lungs.

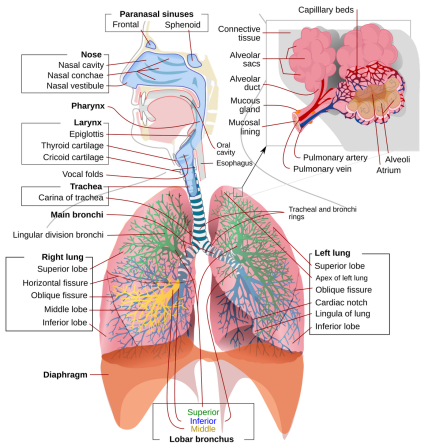
Gas exchange 气体交换 is how **oxygen** 氧气 gets into the blood and **carbon dioxide** 二氧化碳 gets out, by **diffusion** 扩散. A good gas exchange surface has four features:

- a large **surface area** 表面积 – so more gas can cross at once.
- a **thin** surface – so gases have only a short distance to diffuse.
- a good **blood supply** – to keep a steep difference in concentration.
- good **ventilation** 通气 with air – fresh air keeps the difference steep.

The breathing system

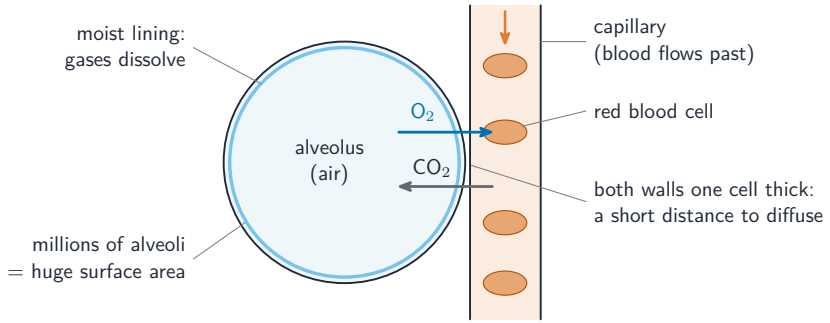
Air reaches the lungs through a series of tubes that branch and get narrower, like an upside-down tree. The table lists each part in the order air passes through it.

Part	Job
larynx 喉	the voice box, at the top of the windpipe
trachea 气管	the windpipe; carries air towards the lungs
bronchi 支气管	two tubes, one going to each lung
bronchioles 细支气管	smaller branching tubes inside the lungs
alveoli 肺泡	tiny air sacs where gas exchange happens; each is wrapped in **capillaries** 毛细血管



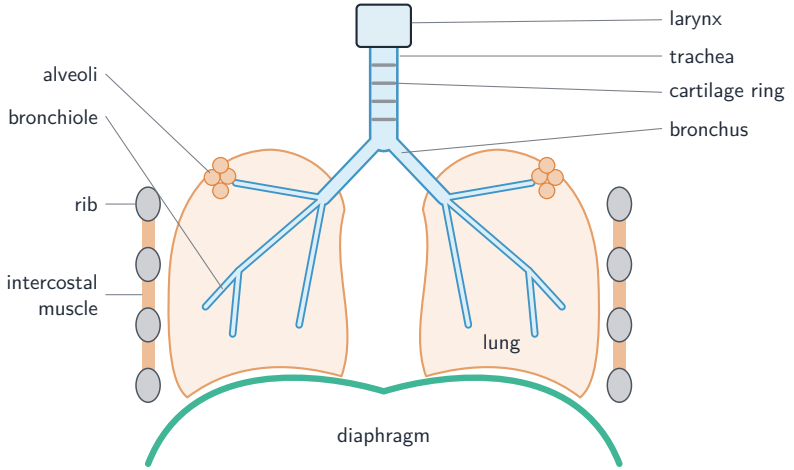
The lungs are the gas-exchange organs of the human body.

The alveoli make excellent gas exchange surfaces: there are millions of them (a huge surface area), each has a wall only one cell thick (a short distance), and each is surrounded by capillaries (a good blood supply).



At an alveolus, oxygen diffuses into the blood and carbon dioxide diffuses out

The lungs sit in the chest, protected by the **ribs** 肋骨. Below them is a sheet of muscle, the **diaphragm** 膈肌. Between the ribs are the **intercostal muscles** 肋间肌. **(Supplement)** The trachea is held open by rings of **cartilage** 软骨, so it cannot collapse when you breathe in.



Air travels from the trachea through the bronchi and bronchioles to the alveoli

How you breathe (Supplement)

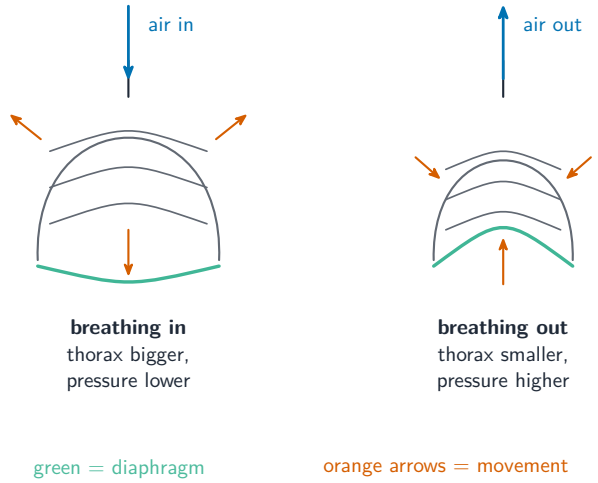
Breathing changes the volume and **pressure** 压力 inside the chest (the **thorax** 胸腔).

Breathing in (**inhaling** 吸气):

- the external intercostal muscles contract, pulling the ribs up and out.
- the diaphragm contracts and flattens (moves down).
- the thorax becomes bigger, so the pressure inside drops below the outside air pressure.
- air is pushed in.

Breathing out (**exhaling** 呼气) is the opposite: the muscles relax (and the internal intercostal muscles may contract), the thorax becomes smaller, the pressure rises, and air is pushed out.

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Breathing in makes the thorax bigger (lower pressure); breathing out makes it smaller

Two sets of intercostal muscles. On a diagram, the **external intercostal muscles** 肋间外肌 are the outer layer between the ribs, and the **internal intercostal muscles** 肋间内肌 are the inner layer. They are **antagonistic** 拮抗: when one set contracts, the other relaxes.

	Breathing in	**Breathing out (forced, as in exercise or coughing)**
external intercostal muscles	contract	relax
internal intercostal muscles	relax	contract, pulling the ribs down and in
ribs	move up and out	move down and in
diaphragm	contracts and flattens	relaxes and domes upwards
volume of thorax	increases	decreases
pressure in thorax	decreases (below air pressure)	increases (above air pressure)
air	moves in	moves out

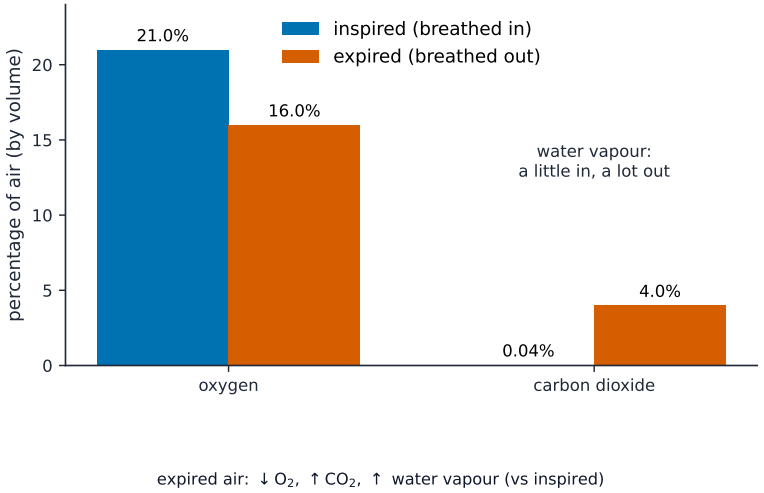
In quiet breathing out, the internal intercostals do little: the external intercostals and diaphragm simply relax, and the elastic lungs recoil. The internal intercostals contract only when you breathe out hard.

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> **Worked example.** Explain how the diaphragm and intercostal muscles cause air to enter the lungs. [4 marks] The external intercostal muscles **contract**, raising the ribs up and out; the diaphragm **contracts** and flattens. Both make the **volume** of the thorax larger, so the **pressure** inside falls below atmospheric pressure, and air moves into the lungs down the pressure difference. Each step is a mark: muscle → movement → volume → pressure → air.

Inspired and expired air

Gas	**Inspired air (breathed in)**	**Expired air (breathed out)**
oxygen	about 21%	about 16% (less)
carbon dioxide	about 0.04%	about 4% (more)
water vapour 水蒸气	a little	a lot (more)



expired air: ↓ O_2, ↑ CO_2, ↑ water vapour (vs inspired)

Expired air has less oxygen and much more carbon dioxide than inspired air

You can test for carbon dioxide with **limewater** 石灰水, which turns cloudy. Expired air turns limewater cloudy much faster than inspired air, showing it contains more carbon dioxide.

The investigation. Two boiling tubes each hold the same volume of limewater, joined to one mouthpiece by tubes arranged so that when you breathe **in**, air is drawn through tube A, and when you breathe **out**, air bubbles through tube B. After a few breaths, the limewater in B (expired air) turns milky, while A (inspired air) stays clear

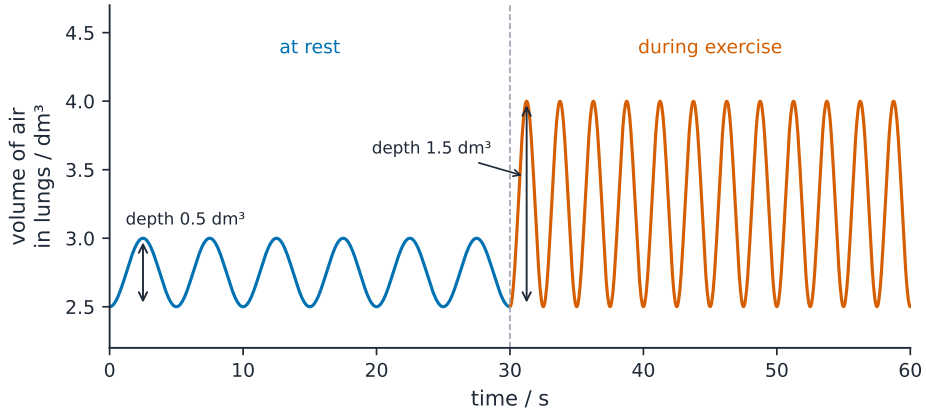
or turns cloudy only very slowly. Compare the time each takes to go cloudy, or the cloudiness after the same number of breaths. Breathe gently, and never suck limewater into your mouth.

(Supplement) Explaining the differences.

- **Less oxygen** in expired air: oxygen diffuses from the alveoli into the blood and is used by cells in **aerobic respiration**.
- **More carbon dioxide**: carbon dioxide made by respiration in the cells is carried by the blood to the lungs and diffuses into the alveoli.
- **More water vapour**: water **evaporates** from the moist lining of the alveoli into the air. (Water is also made by respiration.)
- Expired air is also **warmer**, because it is warmed by the body.

The nitrogen percentage hardly changes, because the body does not use nitrogen gas.

Breathing and exercise



Count the peaks for the rate; measure one peak's height for the depth

Reading a breathing trace. A machine called a **spirometer** 肺活量计 draws the volume of air in the lungs against time. Each peak is one breath. The **rate** is the number of peaks per minute. The **depth** is the height of one peak, from the bottom of a trough to the top of the next peak. In the trace above, at rest there are 6 peaks in 30 s, so the rate is $6 \times 2 =$ **12 breaths per minute**, with a depth of 0.5 dm^3. During exercise there are 12 peaks in 30 s (**24 per minute**), each 1.5 dm^3 deep.

Investigating physical activity. Count a student's breaths for one minute while they sit at rest (they should not know you are counting, as this changes their breathing). Then they exercise, for example stepping on and off a box for 2 minutes at a fixed pace, and you count their breaths for one minute straight afterwards. Keep counting each minute until the rate is back to the resting rate: this is the **recovery time**. Repeat with the same person and the same exercise, or with several people to compare. Controlled variables: the type, length and intensity of exercise, and the time the person rests beforehand.

During exercise your muscles respire faster and make more carbon dioxide. This raises the **concentration** 浓度 of carbon dioxide in the blood. **(Supplement)** Your **brain** 大脑 detects the rise and makes you breathe at a faster **rate** 速率 and a greater depth. This brings in more oxygen and removes the extra carbon dioxide quickly.

> **Worked example.** At rest a person takes 12 breaths per minute, moving 500 cm^3 of air per breath. During exercise this becomes 20 breaths per minute at 900 cm^3 per breath. How much air passes through the lungs each minute in each case? Multiply the rate by the depth. At rest: $12 \times 500 =$ **6000 cm^3 per minute**. During exercise: $20 \times 900 =$ **18 000 cm^3 per minute**, three times as much. Exercise raises **both** the rate and the depth of breathing - an answer that changes only the rate throws away half the marks.

(Supplement) The full explanation. Muscles contract more → they need more energy → more aerobic respiration → more carbon dioxide made, which diffuses into the blood → the brain detects the higher carbon dioxide concentration → it sends impulses to the intercostal muscles and diaphragm → they contract faster and more strongly → breathing becomes faster and deeper → more carbon dioxide is removed and more oxygen taken in. Breathing stays fast for a while after exercise, to repay the **oxygen debt** (see Respiration).

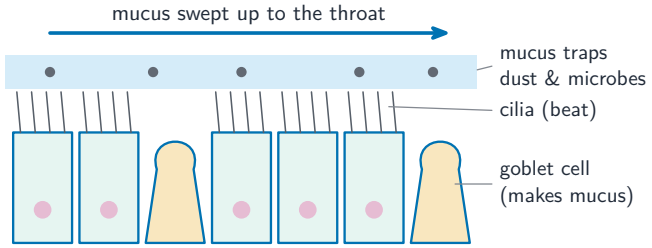
Keeping the airways clean (Supplement)

The airways are lined with two kinds of cell that trap and remove dirt:

- **goblet cells** 杯状细胞 make **mucus** 黏液, which traps **pathogens** 病原体 and dust **particles** 粒子.
- **ciliated cells** 纤毛细胞 have tiny hairs that sweep the mucus, with the trapped dirt, up to the throat, where it is swallowed.

Together they stop pathogens and particles reaching the alveoli, where they could cause infection or block gas exchange. Swallowed mucus goes to the stomach, where acid kills most of the pathogens. Tobacco smoke paralyses and damages the cilia, so mucus builds up in the airways; smokers cough to move it, and get more chest infections.

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Goblet cells make the mucus; cilia sweep it up to the throat.

Common mistakes.

- Mixing up breathing and respiration. Breathing moves air in and out of the lungs; respiration is the chemical reaction in every cell that releases energy from glucose.
- Saying expired air contains no oxygen. It still has about 16% oxygen; only about a quarter of the oxygen breathed in is taken up.
- (Supplement) Getting the order wrong: "air comes in, so the chest gets bigger". The muscles make the chest bigger **first**; this lowers the pressure inside, and then air is pushed in.
- (Supplement) Saying the diaphragm moves up when you breathe in. It contracts and **flattens** (moves down); it moves up when it relaxes as you breathe out.
- (Supplement) Saying the brain detects a lack of oxygen during exercise. The brain detects the **rise in carbon dioxide** in the blood.

Exam tips

- A gas exchange surface is large, thin, with a good blood supply and good ventilation.
- Air path: larynx → trachea → bronchi → bronchioles → alveoli.
- Breathing in: external intercostal muscles and diaphragm contract → thorax bigger → pressure lower → air in. Breathing out is the opposite.
- Expired air has **less** oxygen, **more** carbon dioxide and **more** water vapour. Limewater tests for carbon dioxide.
- Exercise → more carbon dioxide in the blood → brain → faster, deeper breathing.
- On a breathing trace, rate = peaks per minute; depth = height of one peak.
- (Supplement) Explain each difference in expired air with its cause: oxygen used in respiration, carbon dioxide made by respiration, water evaporating from the alveoli.
- (Supplement) External intercostals contract to breathe in; internal intercostals contract only for forced breathing out.

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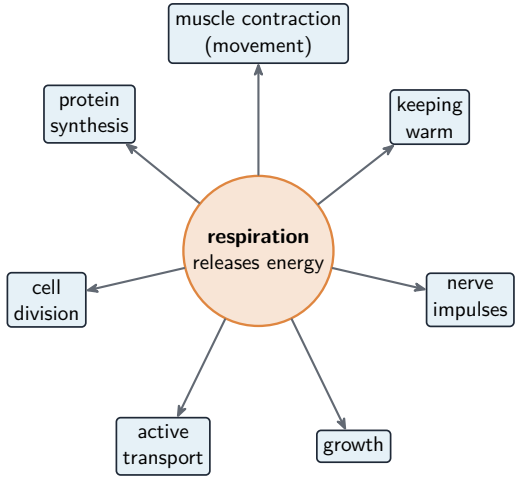
Respiration

IGCSE Biology

Respiration and energy

Respiration 呼吸作用 is the release of **energy** 能量 from food, and it happens in every living cell, all the time. (It is **not** the same as breathing.) Cells use this energy for many jobs:

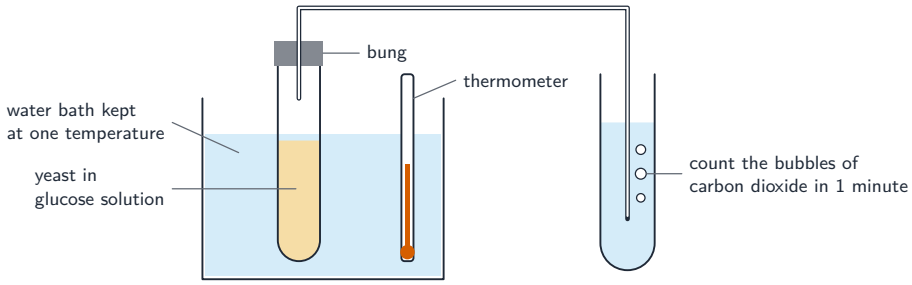
- **muscle** 肌肉 contraction (movement).
- **protein synthesis** 蛋白质合成 (building proteins).
- cell **division** 分裂 (making new cells).
- **active transport** 主动运输.
- growth.
- the passage of **nerve impulses** 神经冲动.
- keeping a constant body **temperature** 温度.



Cells use the energy from respiration for many different jobs

Investigating the effect of temperature on yeast

Yeast 酵母 is a single-celled fungus. When it respires, it gives off **carbon dioxide** 二氧化碳, so we can count the gas bubbles to see how fast it is respiring.



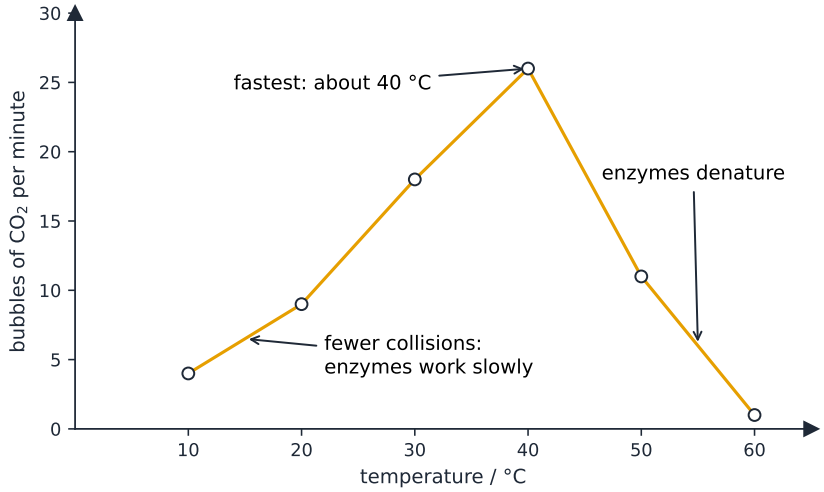
Count the bubbles of carbon dioxide given off in one minute

1. Mix yeast with glucose solution in a boiling tube and fit a bung with a delivery tube.
2. Stand the tube in a **water bath** 水浴 at one temperature, for example 20 °C. Wait 5 minutes so the yeast reaches that temperature.
3. Count the bubbles that come out of the delivery tube in 1 minute. Repeat the count and find the mean.
4. Repeat at other temperatures, such as 10, 30, 40, 50 and 60 °C.

Keep the other **variables** 变量 the same: the mass of yeast, the volume and concentration of the glucose solution, and the counting time.

The reactions of respiration are controlled by **enzymes** 酶. So the results follow the same pattern as enzyme activity:

- from cold to warm, the rate goes **up**: molecules move faster and collide more often.
- the rate is fastest at the **optimum** 最适 temperature.
- above it, the rate falls quickly, because the enzymes are **denatured** 变性.



The rate rises to a peak near 40 °C, then falls as the enzymes are denatured

> **Worked example.** A student's results are in the graph above. (a) At which temperature did the yeast respire fastest? (b) Explain the result at 60 °C. (c) Suggest one way to make the results more accurate. (a) 40 °C: it gave the most bubbles per minute (26). (b) Only 1 bubble per minute, because at 60 °C the yeast's enzymes are denatured, so respiration almost stops. (c) Collect the gas in a gas syringe and measure its **volume**, because bubbles can be different sizes; or repeat each temperature three times and take a mean.

Drawing the graph yourself. Practical questions often give a results table and ask you to plot it. The marks are for these points:

- Put the variable you **changed** (here, temperature) on the x-axis, and the one you **measured** (bubbles per minute) on the y-axis.
- Label each axis with the quantity **and its unit**, for example "temperature / °C" and "rate / bubbles per minute".
- Choose an **even scale** (for example, two large squares for every 10 °C) that makes the points fill **more than half** of the grid. The axes do not have to start at 0.
- Plot each point exactly, as a small cross.
- Join the points with **ruled** straight lines from point to point, or draw one smooth curve through them. Do not carry the line on past the first or the last point.
- Use a line graph when both variables are numbers. When the variable you changed is a set of **categories** (such as different foods), draw a **bar chart** 条形图 instead.

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Testing for carbon dioxide and heat

Two other ways to show that living things respire:

- **Carbon dioxide.** Bubble the gas into **limewater** 石灰水: it turns from clear to **milky** (cloudy). **Hydrogencarbonate indicator** 碳酸氢盐指示剂 is more sensitive: it changes from red to **yellow** as carbon dioxide is added. Small animals (such as woodlice) in a tube, kept off the indicator by gauze, turn it yellow; a tube with glass beads instead of animals is the control and stays red.
- **Heat.** Put **germinating** 萌发 (soaked, sprouting) peas in a vacuum flask with a thermometer, and boiled (dead) peas in a second flask as the control. Rinse both lots of peas in disinfectant first, so that bacteria growing on the dead peas do not respire and warm them. After a few days, the flask of living peas is **warmer**, because their respiration releases energy, some of it as heat.

> **Worked example.** Explain why the boiled peas are a control, and why they are washed in disinfectant. Boiling kills the peas and denatures their enzymes, so they cannot respire; any difference between the flasks must then be due to respiration in the living peas. The disinfectant kills microorganisms on the peas, which would otherwise respire and give off heat, making the dead peas warm up too.

Planning a respiration investigation

A 6-mark "plan an investigation" question is marked point by point. Use the same checklist every time:

Point	What to write (yeast and temperature)
what you **change** (independent variable)	the temperature of the water bath: at least five values, e.g. 10, 20, 30, 40 and 50 °C
what you **measure** (dependent variable)	the number of bubbles, or the volume of carbon dioxide in a gas syringe, in a fixed time
how you measure it	the same time each time, e.g. 1 minute, after 5 minutes to warm up
what you keep the **same** (controlled variables)	mass of yeast, volume and concentration of glucose solution, size of tube
a **control** 对照	a tube with boiled (dead) yeast, to show that living yeast makes the gas
repeats	three times at each temperature, then a mean
a **safety** point	care with hot water; wear eye protection

Write your plan as numbered steps. A good plan lets someone else repeat it without asking a question.

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Aerobic respiration

Aerobic respiration 有氧呼吸 uses **oxygen** 氧气 to break down **nutrient molecules** 营养物质 (mainly **glucose** 葡萄糖) and release energy.



Aerobic respiration releases energy steadily for sustained exercise.

Word equation:

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

(Supplement) Balanced chemical equation:

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

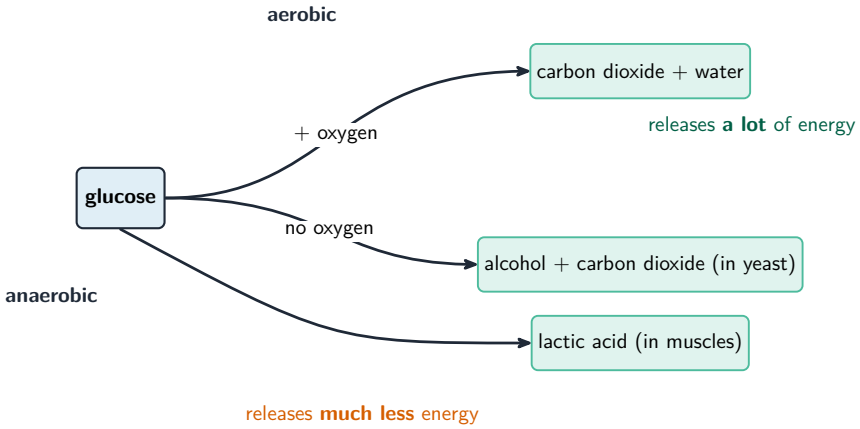
Aerobic respiration releases a **lot** of energy from each glucose molecule. Most of its reactions happen in the **mitochondria** 线粒体, so very active cells (muscle cells, sperm, root hair cells doing active transport) contain many mitochondria.

Anaerobic respiration

Anaerobic respiration 无氧呼吸 breaks down glucose to release energy **without** oxygen. It releases **much less** energy from each glucose molecule than aerobic respiration, because the glucose is not fully broken down.



A hard sprint relies on anaerobic respiration, building up lactic acid.



Aerobic respiration needs oxygen and gives a lot of energy; anaerobic gives much less

In yeast

$$\text{glucose} \rightarrow \text{alcohol} + \text{carbon dioxide}$$

(Supplement) Balanced chemical equation:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

The alcohol is **ethanol** 乙醇, C_2H_5OH.

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The carbon dioxide made by yeast makes bread rise, and the **alcohol** 酒精 is used to brew drinks (in baking it evaporates in the oven).

Comparing aerobic and anaerobic respiration

	Aerobic	Anaerobic in yeast	Anaerobic in muscles
oxygen needed?	yes	no	no
products	carbon dioxide and water	alcohol (ethanol) and carbon dioxide	lactic acid
energy released per glucose	a lot	much less	much less
glucose fully broken down?	yes	no	no

Worked example. State **two** differences between aerobic respiration and anaerobic respiration in muscles. Aerobic respiration uses oxygen, but anaerobic does not; aerobic respiration produces carbon dioxide and water, but anaerobic respiration in muscles produces lactic acid (and no carbon dioxide); aerobic respiration releases much more energy per glucose molecule. Each answer must say **both** sides of the difference – "aerobic uses oxygen" alone scores nothing.

In muscles (Supplement)

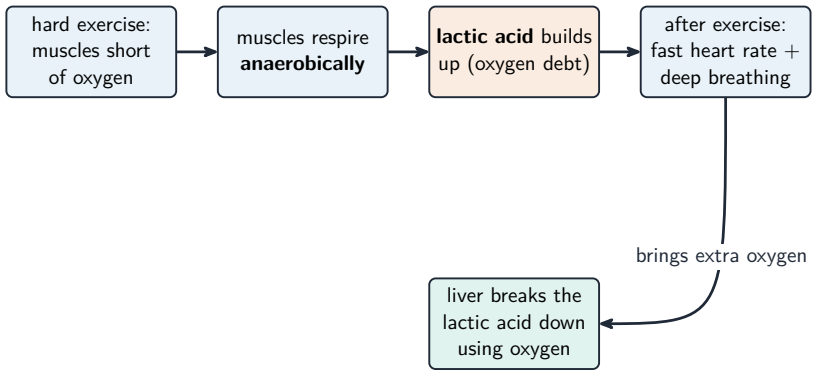
During hard exercise your muscles cannot get enough oxygen, so they respire anaerobically:

$$\text{glucose} \rightarrow \text{lactic acid}$$

The **lactic acid** 乳酸 builds up in the muscles and the blood. This creates an **oxygen debt** 氧债 – the extra oxygen the body will need later to break that lactic acid down.

After you stop exercising, the oxygen debt is repaid:

- your **heart rate** 心率 stays high, carrying the lactic acid in the blood from the muscles to the **liver** 肝脏.
- you keep breathing deeply and quickly, taking in extra oxygen.
- the liver uses this oxygen to break the lactic acid down by aerobic respiration.



Lactic acid from anaerobic respiration is broken down later, using extra oxygen

Worked example. A runner sprints hard for 20 seconds, then breathes deeply for several minutes after stopping. Explain why. During the sprint the muscles cannot get oxygen fast enough, so they respire **anaerobically** and lactic acid builds up, creating an **oxygen debt**. The deep breathing afterwards takes in the extra oxygen the liver needs to break that lactic acid down by aerobic respiration, while a high heart rate carries the acid from the muscles to the liver. The breathing repays a debt built up **during** the sprint - it is not simply "because the muscles are still working".

Common mistakes

- "Respiration is breathing." Breathing moves air in and out of the lungs. Respiration is a set of chemical reactions in **every** cell.
- "Plants photosynthesise instead of respiring." Plants respire all the time, day and night. In the light they also photosynthesise.
- "Respiration makes energy." Energy cannot be made. Respiration **releases** the energy stored in glucose.
- "Anaerobic respiration in muscles makes carbon dioxide." In muscles it makes only lactic acid. Yeast makes alcohol **and** carbon dioxide.
- An uneven scale on a graph, such as 10, 20, 40, 50 °C spaced equally. Each square must stand for the same amount all along the axis.

Exam tips

- Respiration releases energy in **all** living cells, all the time – it is not breathing.
- Aerobic: glucose + oxygen → carbon dioxide + water, and it gives **a lot** of energy. Learn the balanced equation too.

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- Anaerobic (no oxygen) gives **much less** energy. In yeast: glucose → alcohol + carbon dioxide ($C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$). In muscles: glucose → lactic acid.
- In the yeast experiment, the rate rises to an **optimum** temperature and then falls, because respiration depends on **enzymes**.
- Lactic acid causes an **oxygen debt**, repaid by a fast heart rate and deep breathing, with the liver breaking the lactic acid down.
- Carbon dioxide turns limewater milky and hydrogencarbonate indicator from red to yellow.
- In every respiration experiment, the control uses **dead** (boiled) organisms or glass beads, so that only respiration explains the difference.
- In a "difference" answer, compare both sides in one sentence: "aerobic … but anaerobic …".

Excretion in humans

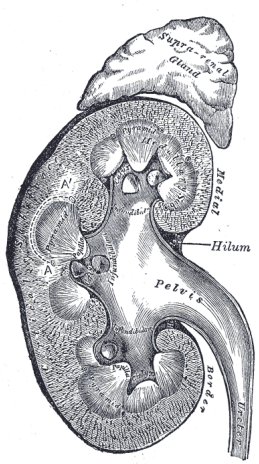
IGCSE Biology

Excretion

Excretion 排泄 is the removal of the waste products of metabolism, and of substances the body has in excess. Two main wastes are removed:

- **carbon dioxide** 二氧化碳 – made during respiration, and breathed out through the lungs.
- **urea** 尿素 – made in the **liver** 肝脏, and removed by the kidneys together with excess water and **ions** 离子.

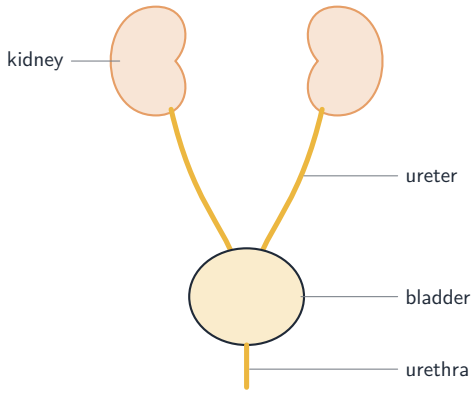
The urinary system



The kidneys filter the blood and make urine.

The **kidneys** 肾脏 clean the blood and make **urine** 尿液. The urine then passes through:

- the **ureters** 输尿管 – tubes from the kidneys to the bladder.
- the **bladder** 膀胱 – stores the urine.
- the **urethra** 尿道 – carries the urine out of the body.



The kidneys make urine, which flows down the ureters to the bladder and out of the urethra

Blood reaches each kidney in the **renal artery** 肾动脉 and leaves, cleaned, in the **renal vein** 肾静脉. So blood in the renal vein has **less urea** than blood in the renal artery, and less than in any other blood vessel. (It also has less oxygen and more carbon dioxide, because kidney cells respire.)

Identifying the parts. On a diagram of the whole system, the kidneys are the two bean-shaped organs at the back of the abdomen; the two long tubes leading down from them are the ureters; the bag they join is the bladder; the single short tube leading out of the bladder is the urethra.

How much urine?

The kidneys control the amount of water in the blood, so the volume and colour of urine change with the conditions:

Condition	Volume of urine	Urine is
drinking a lot of water	large	pale and dilute
a hot day, or exercise (much water lost in sweat)	small	dark and concentrated
eating a lot of salt	small at first (water is kept to dilute the salt)	concentrated, with many ions
eating a lot of protein	normal	more urea (more excess amino acids deaminated)

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Worked example. On a hot day a student plays football for two hours and drinks very little. Explain why their urine is small in volume and dark yellow. They lose a lot of water in sweat to keep cool, so their blood has less water. The kidneys respond by reabsorbing **more** water back into the blood, so less water is left in the urine. The same amount of urea is dissolved in less water, so the urine is more **concentrated** and darker.

If the kidneys stop working, a **dialysis** 透析 machine can do their job. The patient's blood flows through the machine, where waste and excess water pass out across a thin membrane, and the clean blood returns to the body.



A dialysis machine cleans the blood when the kidneys stop working

Inside the kidney (Supplement)

A kidney has two regions: an outer **cortex** 皮质 and an inner **medulla** 髓质.

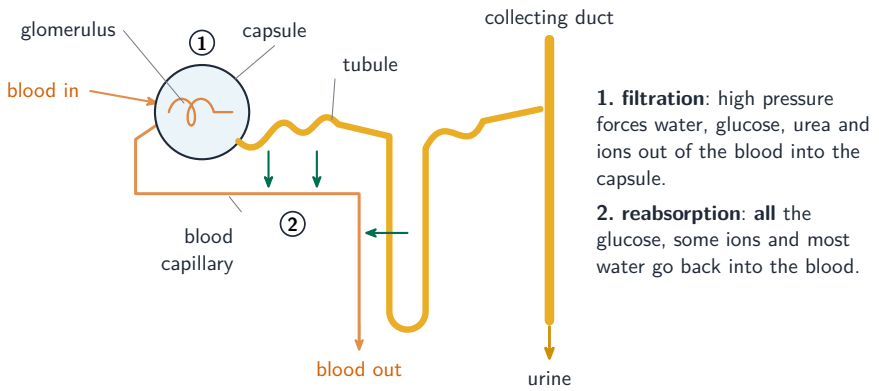
The nephron

Each kidney holds millions of tiny tubes called **nephrons** 肾单位. A nephron cleans the blood in two steps:

1. **Filtration** 过滤: at the **glomerulus** 肾小球 (a knot of capillaries), high pressure forces water, **glucose** 葡萄糖, urea and ions out of the blood and into the nephron.
2. **Reabsorption** 重吸收: in healthy kidneys, as the liquid flows along the nephron, the blood takes back **all** of the glucose, **some** of the ions, and **most** of the water.

What is left behind – urea, excess water and excess ions – becomes the urine.

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A nephron filters the blood, then reabsorbs the useful substances; what is left is urine

Worked example. A healthy person's urine contains urea and ions but **no** glucose, even though glucose is forced out of the blood at the glomerulus. Explain. Filtration does not choose: high pressure pushes water, glucose, urea and ions into the nephron together. The choosing happens at the next step - during **reabsorption** the blood takes back **all** of the glucose, so none is left to reach the urine. Glucose does appear in the urine of someone with untreated diabetes, because there is more of it than the nephron can reabsorb. Filtration removes; reabsorption selects.

Reading data on plasma, filtrate and urine

Exam questions often give a table like this and ask you to explain the numbers. **Filtrate** 滤液 is the liquid just after the glomerulus.

Substance	Blood plasma / g per dm^3	Filtrate / g per dm^3	Urine / g per dm^3
water	900	900	950
protein	80	0	0
glucose	1.0	1.0	0
ions (such as sodium)	7.2	7.2	6.0
urea	0.3	0.3	20

How to explain each row:

- **protein**: in the plasma but not in the filtrate. Protein molecules are too **large** to be forced out through the walls of the glomerulus, so they stay in the blood (as do the blood cells).

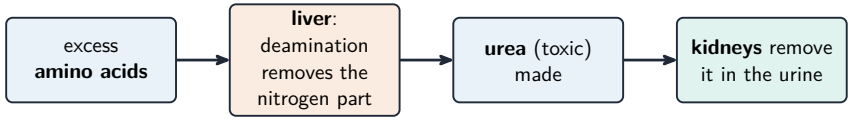
- **glucose**: the same in plasma and filtrate, because small molecules are filtered freely; **zero** in urine, because all of it is reabsorbed.
- **ions**: only some are reabsorbed; the rest, the excess, stays in the urine.
- **urea**: about 67 times more concentrated in urine than in filtrate ($20 \div 0.3 \approx 67$). Urea is not reabsorbed, but most of the **water** around it is, so the same urea is left in a much smaller volume.

> **Worked example.** Glucose is found in the urine of a person with untreated diabetes, and protein in the urine of a person with damaged kidneys. Explain each. In diabetes the blood glucose concentration is so high that the nephrons cannot reabsorb it all, so some is left in the urine. Protein in the urine means the glomerulus is damaged: large protein molecules, which should stay in the blood, are leaking into the filtrate.

The liver, amino acids and urea (Supplement)

The liver carries out the **assimilation** 同化 of **amino acids** 氨基酸: it joins them together into the **proteins** 蛋白质 that the body needs.

The body cannot store extra amino acids. The liver breaks the excess down by **deamination** 脱氨基作用 – it removes the **nitrogen** 氮-containing part of each amino acid. This part is then turned into urea.



The liver makes urea from excess amino acids; the kidneys excrete it

Urea must be excreted because it is **toxic** 有毒 (poisonous) if it is allowed to build up in the blood.

Putting it together. Follow one excess amino acid from a meal to the toilet: it is absorbed from the small intestine into the blood → carried to the liver in the hepatic portal vein → **deaminated** in the liver, and its nitrogen part made into urea → urea is carried by the blood to the kidneys → **filtered** out at the glomerulus and not reabsorbed → leaves in the urine, down the ureter, stored in the bladder, out through the urethra. The rest of the amino acid (without its nitrogen) can be respired for energy or turned into glycogen or fat.

Common mistakes.

- Calling the removal of undigested food (faeces) excretion. That food was never part of the body's metabolism, so it is not excretion; excretion removes **waste made by cells**, such as carbon dioxide and urea.

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- Saying the kidneys make urea. Urea is made in the **liver**; the kidneys only remove it from the blood.
- Mixing up the ureter and the urethra. The two **ureters** carry urine from the kidneys to the bladder; the one **urethra** carries it out of the body.
- Saying the glomerulus filters out only the waste. Filtration is not selective: water, glucose, urea and ions are all forced out. The useful substances are taken back later, by **reabsorption**.
- Saying "some glucose" is reabsorbed. In a healthy person **all** of the glucose is reabsorbed, so there is none in the urine.
- Saying deamination makes urea directly from proteins. The liver deaminates **excess amino acids**; the nitrogen part removed is then turned into urea.

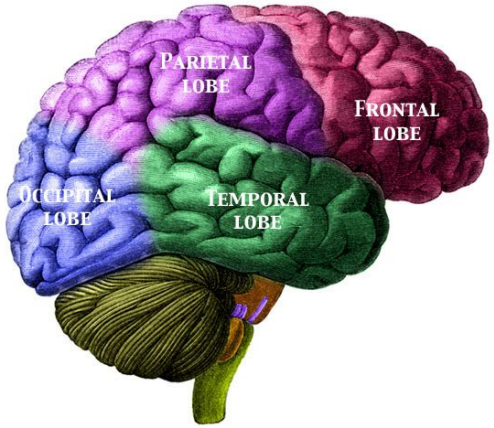
Exam tips

- Excretion removes metabolic wastes. Carbon dioxide leaves through the lungs; urea, excess water and excess ions leave through the kidneys.
- Urine path: kidney → ureter → bladder → urethra.
- Nephron: the glomerulus **filters** the blood; the nephron **reabsorbs** all the glucose, some ions and most of the water. What is left is urine.
- Urea is made in the **liver** from excess amino acids by **deamination**.
- We must excrete urea because it is **toxic** to the body.
- Proteins and blood cells are too large to be filtered, so they are not in the filtrate or the urine.
- The renal vein has the lowest urea concentration of any blood vessel.
- Less water drunk, or more sweating → more water reabsorbed → less, more concentrated urine.

Coordination and response

IGCSE Biology

The nervous system



The brain coordinates the body through the nervous system.

Your body must **coordinate** 协调 all its parts and react to changes. The **nervous system** 神经系统 does this using fast **electrical impulses** 电脉冲 that travel along **neurones** 神经元 (nerve cells). It has two parts:

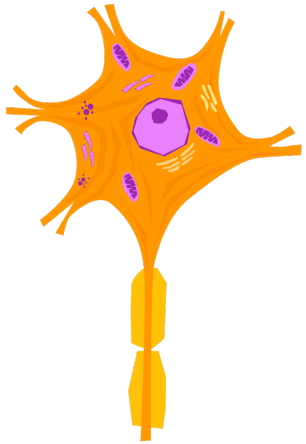
- the **central nervous system** 中枢神经系统 (CNS) – the **brain** 大脑 and the **spinal cord** 脊髓.
- the **peripheral nervous system** 周围神经系统 (PNS) – all the nerves outside the brain and spinal cord.

The nervous system coordinates and **regulates** 调节 the body's functions.

Neurones and the reflex arc

There are three kinds of neurone:

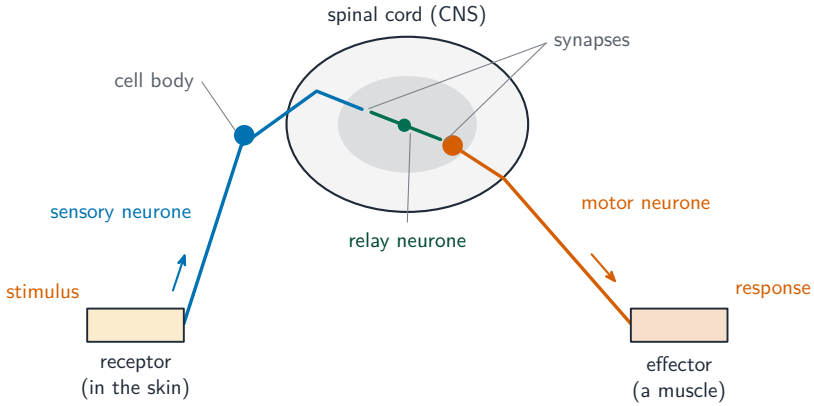
- **sensory neurones** 感觉神经元 – carry impulses from receptors to the CNS.
- **relay neurones** 中间神经元 – pass impulses on inside the CNS.
- **motor neurones** 运动神经元 – carry impulses from the CNS to effectors.



A neurone (nerve cell) carries electrical impulses around the body.

A **reflex** 反射 action is a fast, automatic **response** 反应 to a **stimulus** 刺激 (a change). It follows a fixed path, the **reflex arc** 反射弧:

receptor 感受器 → sensory neurone → relay neurone → motor neurone → **effector** 效应器 (a **muscle** 肌肉 or **gland** 腺体)



In a reflex arc the impulse passes from receptor → sensory → relay → motor neurone → effector

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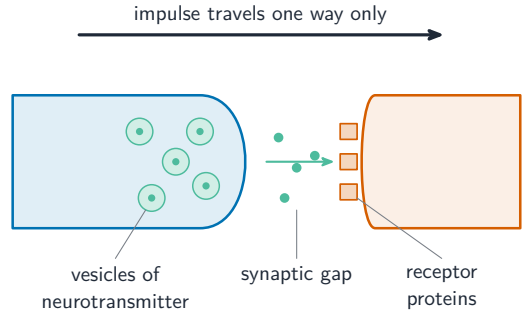
Synapses (Supplement)

A **synapse** 突触 is a junction (a tiny gap) between two neurones. At the end of one neurone are **vesicles** 囊泡 holding **neurotransmitter** 神经递质 molecules. Across the **synaptic gap** 突触间隙, the next neurone has **receptor proteins** 受体蛋白.

Events at a synapse:

1. an impulse arrives and makes the vesicles release neurotransmitter into the synaptic gap.
2. the neurotransmitter molecules **diffuse** 扩散 across the gap.
3. they bind to the receptor proteins on the next neurone.
4. this starts a new impulse in the next neurone.

Synapses make impulses travel in **one direction only**.



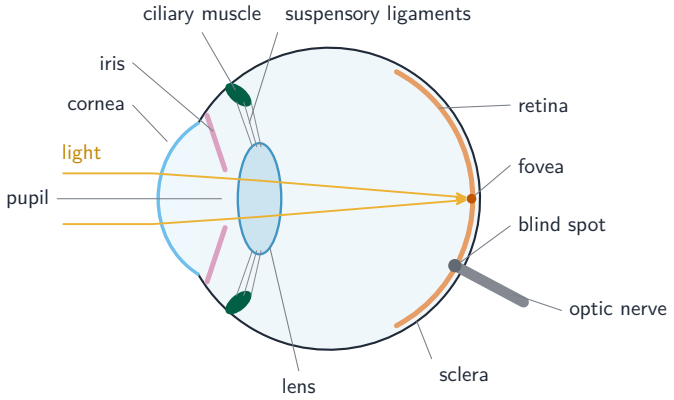
At a synapse, neurotransmitter diffuses across the gap, so impulses travel one way only

Sense organs and the eye

Sense organs 感觉器官 are groups of receptor cells that respond to one kind of stimulus – light, sound, touch, temperature or chemicals. The eye responds to light.

Parts of the eye

Part	Function
cornea 角膜	**refracts** 折射 (bends) the light as it enters
iris 虹膜	controls how much light enters the **pupil** 瞳孔
lens 晶状体	focuses the light onto the retina
retina 视网膜	contains light receptors, some sensitive to different colours
optic nerve 视神经	carries the impulses to the brain
blind spot 盲点	where the optic nerve leaves the eye; it has no receptors



Light is focused by the cornea and lens onto the retina; impulses leave by the optic nerve

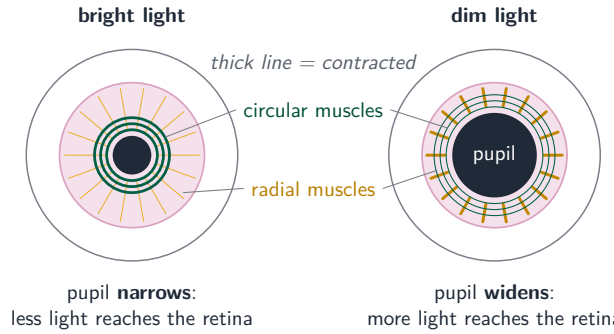


The front of a real eye: the black pupil is the hole that lets light in, and the coloured iris around it controls how wide the pupil opens

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The pupil reflex

In bright light the pupil gets **smaller**, to protect the retina. In dim light it gets **wider**, to let more light in. **(Supplement)** This is done by two sets of **antagonistic** 拮抗 muscles in the iris: the **circular muscles** 环肌 and the **radial muscles** 辐射肌. In bright light the circular muscles contract and the pupil narrows; in dim light the radial muscles contract and the pupil widens.

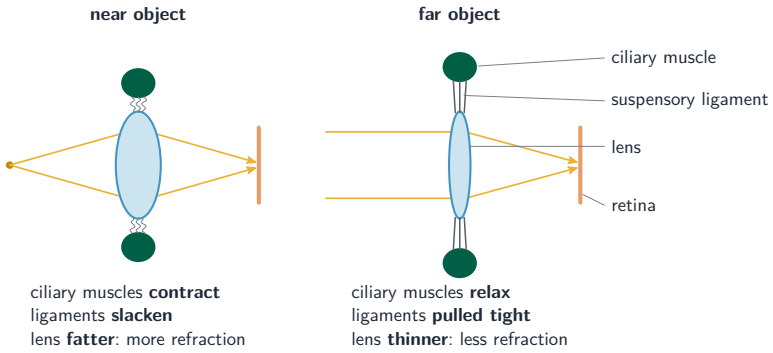


The pupil reflex: circular muscles narrow the pupil, radial muscles widen it

Accommodation (Supplement)

Accommodation 视觉调节 is changing the shape of the lens to focus on near or far objects, using the **ciliary muscles** 睫状肌 and the **suspensory ligaments** 悬韧带:

- near object: the ciliary muscles contract, the ligaments slacken, and the lens becomes fatter – more refraction.
- far object: the ciliary muscles relax, the ligaments pull tight, and the lens becomes thinner – less refraction.



Accommodation: a fat lens for near objects, a thin lens for far objects

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Rods and cones (Supplement)

The retina has two kinds of light receptor:

- **rods** 视杆细胞 – very sensitive, good for **vision** 视觉 in dim light (night vision); they do not detect colour.
- **cones** 视锥细胞 – three kinds, each absorbing a different colour, giving colour vision; they work best in bright light.

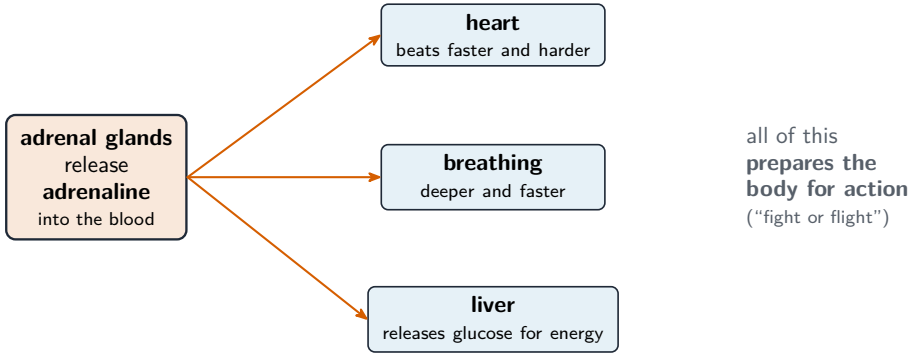
Cones are packed most densely at the **fovea** 中央凹, the part of the retina that gives the sharpest image.

Hormones

A **hormone** 激素 is a chemical, made by a gland and carried in the blood, that changes the activity of one or more **target organs** 靶器官. Hormones are made by **endocrine glands** 内分泌腺, which release them straight into the blood.

Gland	Hormone	Main effect
adrenal glands 肾上腺	**adrenaline** 肾上腺素	prepares the body for action
pancreas 胰腺	**insulin** 胰岛素 (and **glucagon** 胰高血糖素)	control blood **glucose** 葡萄糖
testes 睾丸	**testosterone** 睾酮	male development
ovaries 卵巢	**oestrogen** 雌激素	female development

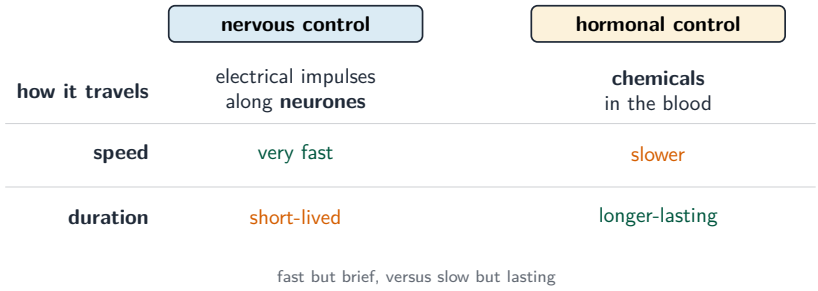
Adrenaline is released in 'fight or flight' situations, such as fear or danger. It increases the breathing rate, the **heart rate** 心率, the blood glucose **concentration** 浓度 and the pupil diameter, getting the body ready to act.



Adrenaline prepares the body for action by acting on several target organs

Nervous control vs hormonal control

	Nervous control	Hormonal control
speed	very fast	slower
duration 持续时间	short-lived	longer-lasting
how it travels	electrical impulses along neurones	chemicals in the blood



Nervous control is fast but brief; hormonal control is slower but longer-lasting

Homeostasis

Homeostasis 稳态 is keeping a constant internal **environment** 环境 inside the body – for example a steady temperature and a steady blood glucose level.

(Supplement) Homeostasis works by **negative feedback** 负反馈: when a value moves away from its **set point** 设定点, the body acts to bring it back. The change itself triggers the correction.

Every negative feedback loop has the same steps:

1. a **receptor** detects that the value has moved away from the set point;
2. a control centre (the brain, or a gland such as the pancreas) compares it with the set point;
3. **effectors** act to reverse the change;
4. when the value is back at the set point, the response stops.

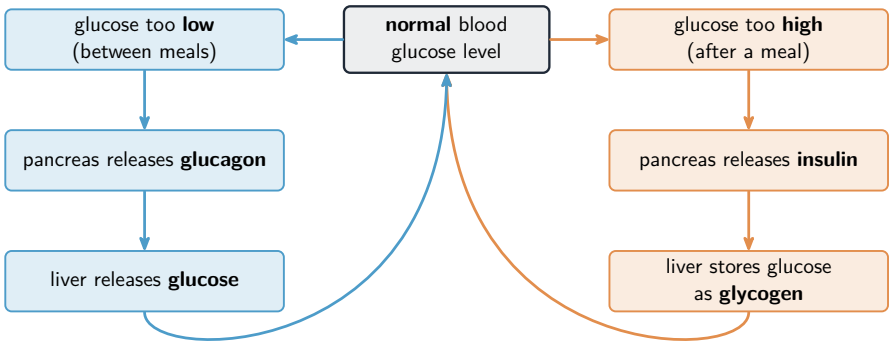
The word *negative* means the response goes the **opposite** way to the change: a rise causes a fall, and a fall causes a rise.

■ Controlling blood glucose

The **liver** 肝脏 and the pancreas keep blood glucose steady:

- **insulin** lowers blood glucose after a meal – the liver stores the glucose as **glycogen** 糖原.

- **(Supplement) glucagon** raises blood glucose between meals – the liver releases glucose.



Insulin lowers blood glucose and glucagon raises it, keeping it near a normal level

In **Type 1 diabetes** 糖尿病 the pancreas cannot make insulin, so blood glucose rises too high after meals. **(Supplement)** The treatment:

- **measure** the blood glucose concentration several times a day, with a small blood test or a sensor;
- **inject insulin** (or use an insulin pump), usually before meals, matching the dose to the food eaten;
- **control the diet**, especially the amount of carbohydrate, and eat at regular times;
- take care with **exercise**, which uses glucose: eat extra carbohydrate first, so blood glucose does not fall too low.

> **Worked example.** Blood glucose rises sharply after a meal, then falls back to normal over the next two hours. Name the organs and the hormone involved, and say what they do. The **pancreas** detects the rise and releases **insulin**. Insulin makes the **liver** take glucose out of the blood and store it as **glycogen**, so the level falls back to normal. Between meals the opposite loop runs: the pancreas releases glucagon and the liver releases glucose again. Keep the two words apart - insulin is the **hormone**, glycogen is the **store**. Swapping them is the classic error.

■ Controlling body temperature (Supplement)

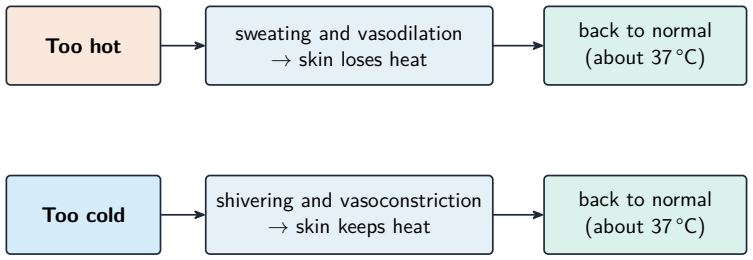
The brain detects the body **temperature** 温度 and keeps it steady. The skin helps:

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Structure	Role
sweat glands 汗腺	make sweat; as it evaporates it cools the skin (**sweating** 出汗)
hair erector muscles 立毛肌	raise the hairs to trap a layer of air
blood vessels 血管	change how much blood flows near the skin surface
fatty tissue 脂肪组织	gives **insulation** 隔热 to reduce heat loss
receptors and **sensory neurones**	detect the skin temperature and send impulses to the brain

When you are **too hot**: you sweat, and the **arterioles** 小动脉 widen (**vasodilation** 血管舒张) so more blood flows to the skin **capillaries** 毛细血管 and loses heat.

When you are **too cold**: you **shiver** 颤抖 (the muscles make heat), and the arterioles narrow (**vasoconstriction** 血管收缩) so less blood reaches the surface, keeping heat in.



Negative feedback: a change away from about 37 °C triggers the response that reverses it, bringing the body back to normal.

Worked example. A runner's body temperature rises to 38.5 °C during a race. Explain how negative feedback returns it to the set point. The brain detects that the blood temperature is **above the set point** of about 37 °C. It sends impulses to the effectors: the **sweat glands** make more sweat, which takes heat from the skin as it evaporates, and the **arterioles** to the skin widen (vasodilation), so more blood flows near the surface and loses heat. When the temperature is back at 37 °C, these responses stop. Do not say "the capillaries move to the surface": the arterioles **widen**; nothing moves.

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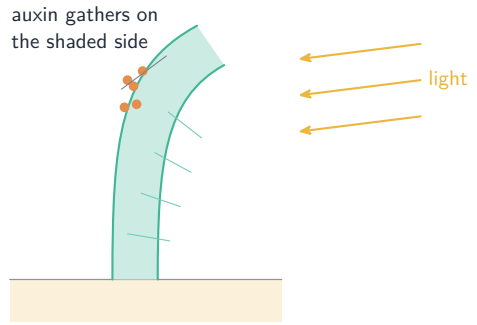
Tropisms

A **tropism** 向性 is a plant's growth response to a direction:

- **gravitropism** 向地性 – growth in response to **gravity** 重力 (roots grow down, shoots grow up).
- **phototropism** 向光性 – growth in response to the direction of light (shoots grow towards the light).

(Supplement) These responses are controlled by a chemical called **auxin** 生长素:

- auxin is made in the **shoot** 嫩枝 tip.
- it diffuses down through the plant.
- light or gravity makes the auxin spread unequally to one side.
- in shoots, auxin promotes growth: cells **elongate** 伸长 (grow longer). The side with more auxin grows faster, so the shoot bends.



Auxin gathers on the shaded side and makes those cells grow longer, bending the shoot to the light

(Supplement) Gravitropism of a shoot works the same way. Lay a shoot on its side and auxin collects on the **lower** side. The cells on the lower side elongate more, so the shoot bends **upwards**, away from gravity.

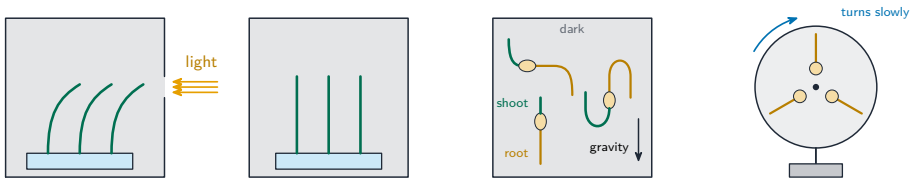
Investigating tropisms

Use young seedlings, such as bean or cress seedlings, grown in damp cotton wool.

Phototropism. Put one dish of seedlings in a box with a slit on one side, so light comes from **one direction** only. Put a second dish in a box with no light (or in light from all sides), as a **control**. After a few days, the shoots in the first box have grown **towards** the slit; the control shoots grow straight up.

Gravitropism. Pin germinating bean seeds to damp cotton wool with their roots pointing in different directions, and keep them in the **dark**, so light cannot affect the

result. After two days every root has bent to grow **downwards**, towards gravity, and every shoot upwards. As a control, fix seeds to a **clinostat** 回转器, a disc that turns slowly: gravity acts on all sides equally, and the roots grow straight.



(a) light from one side: shoots bend towards it

(b) control, no light: shoots grow straight up

(c) in the dark: roots grow down, shoots up

(d) clinostat control: roots grow straight

Investigating tropisms: one-sided light bends shoots towards it; gravity bends roots down and shoots up

Part	Response to light	Response to gravity
shoot	grows towards it	grows away from it (up)
root	grows away from it	grows towards it (down)

For a fair test, keep the type and age of the seedlings, the temperature and the water the same, and use several seedlings in each dish, so one odd seedling does not decide the result.

> **Worked example.** Some students cut the tips off five shoots and put them in light from one side, next to five shoots with tips. Predict the result and explain it. The shoots with tips bend towards the light. The shoots without tips **do not bend**, because auxin is made in the shoot tip: with no tip, no auxin reaches the cells below, so there is no unequal elongation.

Common mistakes.

- Mixing up **glucagon** (a hormone) and **glycogen** (the store of glucose in the liver). Check the spelling: the two words look alike but differ in three letters: glucagon has u, a, o where glycogen has y, o, e.
- Saying insulin turns glucose into glycogen. Insulin is a message carried in the blood; it makes the **liver** cells change glucose into glycogen.
- (Supplement) Saying an electrical impulse jumps across a synapse. The impulse makes neurotransmitter molecules **diffuse** across the gap; they bind to receptors and start a new impulse.
- (Supplement) Saying blood vessels move nearer to the skin when you are hot. The vessels do not move: the **arterioles** widen, so more blood flows through the capillaries near the surface.

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- (Supplement) Saying a shoot bends towards light because the lit side grows faster. Auxin collects on the **shaded** side, so the shaded side grows faster and the shoot bends towards the light.

Exam tips

- Nervous system: CNS (brain + spinal cord) and PNS (the nerves). Impulses travel along neurones.
- Learn the reflex arc in order: receptor → sensory → relay → motor → effector.
- At a synapse, neurotransmitter diffuses across the gap – this makes impulses go one way only.
- Eye: cornea and lens refract light; the lens changes shape (accommodation); rods for dim light, cones for colour.
- Hormones are slower but longer-lasting than nerves. Insulin lowers blood glucose; glucagon raises it.
- Too hot → sweating and vasodilation; too cold → shivering and vasoconstriction.
- Auxin from the shoot tip controls phototropism and gravitropism by making cells elongate.
- In a tropism investigation, name the control (a dark box, light from all sides, or a clinostat) and keep the seedlings in the dark for a gravity test.
- Negative feedback: a change away from the set point causes a response that **reverses** it.

Drugs

IGCSE Biology

What a drug is

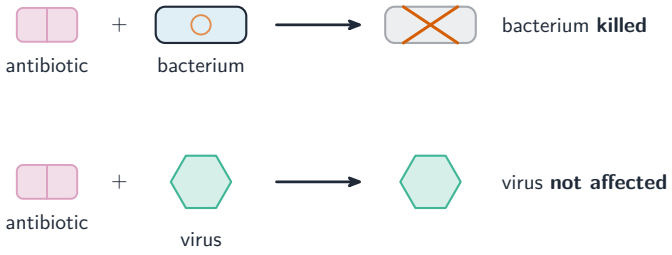


Cigarettes contain nicotine, an addictive drug.

A **drug** 药物 is any substance taken into the body that changes or affects the **chemical reactions** 化学反应 in the body. Many drugs are medicines that help to treat illness.

Antibiotics

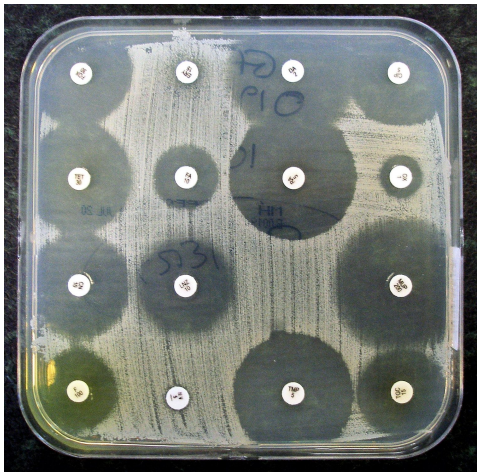
Antibiotics 抗生素 are drugs used to treat bacterial **infections** 感染. They **kill bacteria** 细菌, or stop them growing, but they do **not** affect **viruses** 病毒. This is why antibiotics cannot cure a cold or the flu, which are caused by viruses.



Antibiotics kill bacteria but have no effect on viruses

Why antibiotics do not affect viruses. An antibiotic works by damaging a part of the bacterial **cell**, for example its **cell wall** 细胞壁, or by stopping the bacterium's own reactions. A virus is not a cell. It has no cell wall and no reactions of its own; it can only reproduce **inside** our cells. So there is nothing in a virus for the antibiotic to attack.

To test which antibiotic works best, small paper discs soaked in different antibiotics are placed on a plate covered with bacteria. Where an antibiotic kills the bacteria, a clear ring with no growth appears around the disc. A bigger ring means the antibiotic is more effective.



Clear rings show where antibiotics have killed the bacteria on the plate

A student tests four antibiotics on the bacteria from one patient and measures the diameter of each clear ring:

Antibiotic	Diameter of clear ring / mm
A	24
B	0 (bacteria grow right up to the disc)
C	12
D	18

Worked example. (a) Which antibiotic should the doctor use? (b) What does the result for B show? (c) Suggest two things the student must keep the same. (a) **A**, because it has the largest clear ring, so it killed bacteria furthest from the disc. (b) The bacteria are **resistant** to antibiotic B: it does not kill them at all. (c) Any two of: the size of the paper discs; the concentration of antibiotic on each disc; the temperature and time the plate is left; the type and amount of bacteria spread on the plate. Measure the **diameter** through the centre of the disc, and repeat with more plates to check the result.

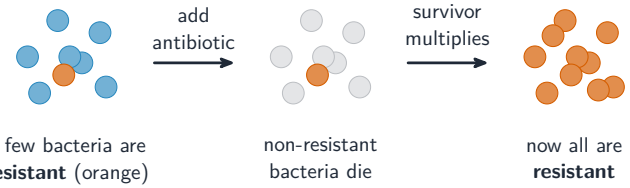
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Antibiotic resistance

Some bacteria are **resistant** 耐药 to an antibiotic – the antibiotic no longer kills them. These bacteria survive and multiply, so the antibiotic slowly becomes less effective for everyone.

(Supplement) To slow this down, antibiotics should be used **only when they are really needed**, and the full course should always be finished. Using antibiotics too often lets resistant bacteria, such as **MRSA**, spread.

Why this works: each time an antibiotic is used, the non-resistant bacteria are killed and any resistant ones are left to multiply. The **fewer** times antibiotics are used, the fewer chances resistant bacteria have to survive and take over. So doctors should not give antibiotics for viral infections such as colds, farmers should not use them just to make animals grow faster, and patients should not keep old antibiotics to take later.



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

> **Worked example.** A patient stops taking their antibiotic as soon as they feel better, and the infection comes back worse. Explain using resistance. In the starting population a few bacteria are **already resistant**, by chance. The antibiotic kills the non-resistant ones, so those few survive, multiply, and come to make up most of the population - and the antibiotic no longer works on it. Stopping early leaves behind exactly the bacteria that are hardest to kill. Say the resistant bacteria **already existed** and survived: writing that the antibiotic "made them resistant" is wrong and loses every mark.

Common mistakes

- "The **patient** becomes resistant to the antibiotic." It is the **bacteria** that are resistant, not the person.
- "The antibiotic **makes** bacteria resistant." The resistant bacteria were already there, by chance; the antibiotic kills the others, so the resistant ones are left to multiply.
- "Antibiotics kill all **microorganisms**." They kill bacteria only, not viruses.
- "A drug is an illegal substance." Medicines such as antibiotics and painkillers are drugs too.

Exam tips

- A drug is **any** substance that changes the body's chemical reactions – not only illegal drugs.
- Antibiotics kill **bacteria** only; they do **not** work on **viruses** (so they are useless against colds and flu).
- Overusing antibiotics leads to **resistant** bacteria like MRSA. Use them only when needed, and finish the whole course.

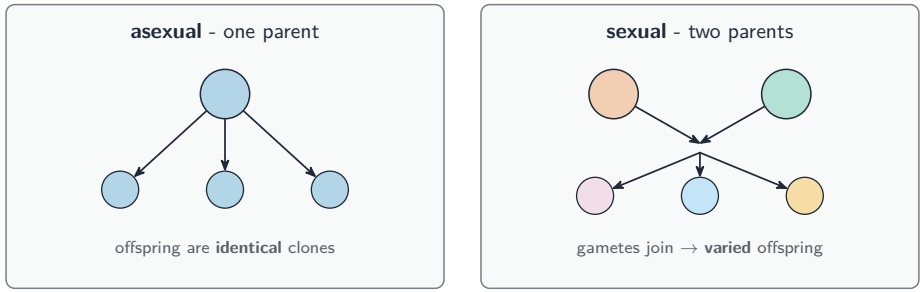
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Reproduction

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Two kinds of reproduction

Reproduction 生殖 makes new organisms of the same kind. There are two types.



Asexual reproduction needs one parent and gives identical clones; sexual reproduction needs two and gives varied offspring

Asexual reproduction

Asexual reproduction 无性生殖 needs only **one parent** 亲本. The **offspring** 后代 have exactly the same **genes** 基因 as the parent – they are genetically identical (clones).

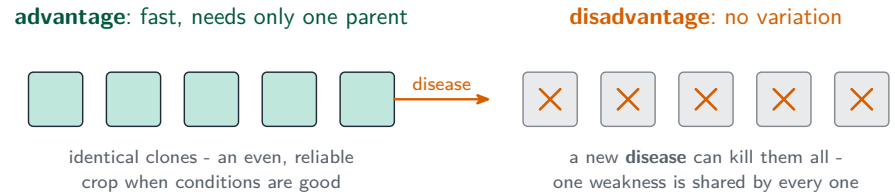
Examples you may be shown in a diagram or photo:

- **strawberry runners** – side shoots grow along the ground and root, giving new plants;
- **potato tubers** – each tuber can grow into a new plant;
- **bulbs**, such as onions and daffodils, which split into new bulbs;
- **bacteria** dividing into two (binary fission);
- **yeast** budding – a small bud grows on the parent cell and breaks off.

To spot asexual reproduction in information you are given, look for **one** parent and offspring that are **identical** to it, with no gametes or fertilisation.

- **Advantage**: it is fast and needs only one parent – useful when conditions are good and stable.
- **Disadvantage**: all the offspring are identical, so if the **environment** 环境 changes (for example a new disease) they may all die. (In crops, identical plants give an even harvest, but one disease can wipe out the whole crop.)

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Asexual reproduction is fast but gives no variation, so one disease can kill every identical offspring

Sexual reproduction

Sexual reproduction 有性生殖 needs **two** parents. It involves the **fusion** 融合 (joining) of the **nuclei** 细胞核 of two **gametes** 配子 (sex cells) to make a **zygote** 合子. This joining is called **fertilisation** 受精. The offspring get a mix of genes from both parents, so they show **variation** 变异 (they are genetically different).

- **Advantage**: variation means some offspring may survive if the environment changes.
- **Disadvantage**: it is slower and needs two parents.

(Supplement) The nuclei of gametes are **haploid** 单倍体 (one set of **chromosomes** 染色体); the nucleus of the zygote is **diploid** 二倍体 (two sets).

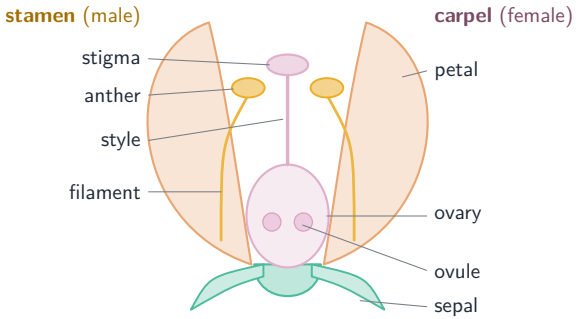
(Supplement) Comparing the two, in the wild and in crops.

	Asexual	Sexual
in the wild: advantage	quick; one plant can fill a good habitat fast; no need for a mate or pollinators	variation, so some individuals may survive a new disease or a change in climate
in the wild: disadvantage	no variation, so one disease or change can kill the whole population; offspring grow close together and compete	slower; needs two parents (or pollinators or wind), and energy goes into flowers or finding a mate
in crop production	the farmer gets identical plants with the same good features, ready at the same time; but one disease can destroy the whole crop	breeders can combine good features from two parents into new varieties; but the offspring vary, so not all keep the wanted features

Sexual reproduction in plants

Parts of an insect-pollinated flower

Part	Function
sepals 萼片	protect the flower bud before it opens
petals 花瓣	large and colourful, to attract **insects** 昆虫
stamens 雄蕊	the male parts; each is a **filament** 花丝 holding up an **anther** 花药
anther	makes **pollen grains** 花粉粒
carpel 雌蕊	the female part; made of a **stigma** 柱头, a **style** 花柱 and an **ovary** 子房
stigma	catches pollen grains
ovary	holds the **ovules** 胚珠, which become seeds



An insect-pollinated flower: the male stamens and the female carpel



A real lily: the long stamens make pollen and the central stigma receives it

Pollination

Pollination 传粉 is the transfer of pollen grains from an anther to a stigma.

- **insect-pollinated** flowers have bright petals, scent and nectar, and sticky or spiky pollen, to attract insects and stick to them.
- **wind-pollinated** flowers have small dull petals, anthers and stigmas that hang outside, and light, smooth pollen that blows in the wind.

	Insect-pollinated	Wind-pollinated
anthers	inside the flower, firmly attached	hang outside on long filaments, loosely attached, so the wind shakes pollen out
stigmas	inside the flower, sticky	large and feathery, hanging outside, to catch pollen from the air
pollen grains	larger, sticky or spiky, so they cling to insects; fewer	small, smooth and light, so they blow far; made in huge numbers, because most are wasted

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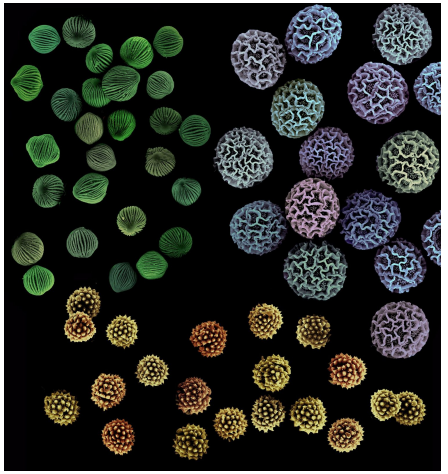
A bee carries pollen from one flower to another – insect pollination in action



insect-pollinated
bright petals, scent + nectar;
sticky, spiky pollen

wind-pollinated
small dull petals; anthers &
stigma hang out; light pollen

Insect-pollinated flowers are showy; wind-pollinated flowers are small with parts hanging out



Pollen grains seen under an electron microscope (colour added); each plant has its own pattern

(Supplement) Self-pollination 自花传粉 is pollen landing on the stigma of the same flower (or another flower on the same plant). **Cross-pollination** 异花传粉 is pollen carried to a flower on a **different** plant of the same species. Cross-pollination gives more **variation**, helping the population cope with change, but it relies on **pollinators** 传粉者 or wind. Self-pollination is more reliable but gives less variation.

■ Fertilisation and germination

Fertilisation happens when a pollen nucleus fuses with a nucleus in an ovule. **(Supplement)** First a **pollen tube** 花粉管 grows down the style into the ovary, carrying the pollen nucleus to the ovule. The tube enters the ovule through a tiny hole, the **micropyle** 珠孔, and the pollen nucleus fuses with the ovule's nucleus. The fertilised ovule becomes a seed, and the ovary becomes the fruit.

A **seed** 种子 will only **germinate** 萌发 (begin to grow) when it has water, **oxygen** 氧气 and a suitable **temperature** 温度.

Investigating germination. Set up four test tubes, each with ten seeds (cress or beans) on cotton wool, and change **one** condition in each:

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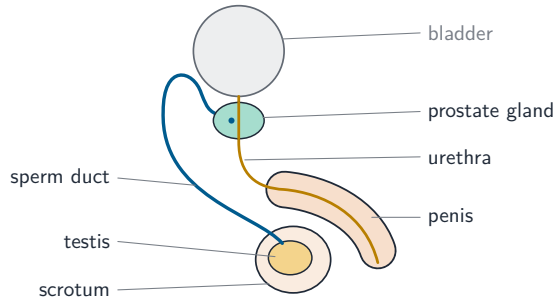
Tube	Conditions	Result after a few days
A (control)	moist cotton wool, air, 20 °C	seeds germinate
B	**dry** cotton wool, air, 20 °C	no germination: no water
C	seeds in **boiled, cooled** water with a layer of oil on top, 20 °C	no germination: no oxygen (boiling removes it, and the oil stops more dissolving)
D	moist cotton wool, air, in a fridge at 4 °C	no germination, or very slow: too cold

Use the same type and number of seeds in each tube, and count how many germinate. Water is needed to activate the **enzymes** and swell the seed; oxygen is needed for **respiration** to release energy for growth; a suitable temperature lets the enzymes work. Light is **not** needed: seeds germinate in the dark, using the food stored in the seed.

Sexual reproduction in humans

The male reproductive system

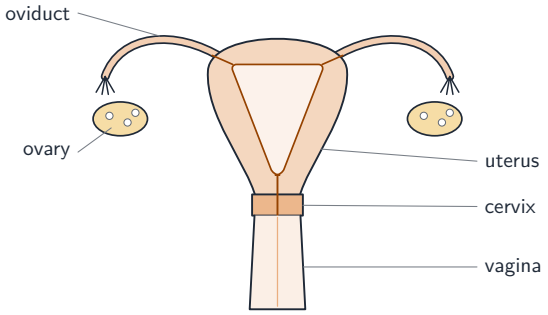
Part	Function
testes 睾丸	make **sperm** 精子 and **testosterone** 睾酮
scrotum 阴囊	holds the testes outside the body, kept slightly cool
sperm ducts 输精管	carry sperm away from the testes
prostate gland 前列腺	adds fluid to make semen
urethra 尿道	carries semen (and urine) out through the penis
penis 阴茎	passes sperm into the female



The male reproductive system (simplified side view)

The female reproductive system

Part	Function
ovaries 卵巢	make **egg cells** 卵细胞 and **oestrogen** 雌激素
oviducts 输卵管	carry the egg towards the uterus; fertilisation happens here
uterus 子宫	where the baby develops
cervix 子宫颈	the ring of muscle at the base of the uterus
vagina 阴道	receives the penis; also the birth canal



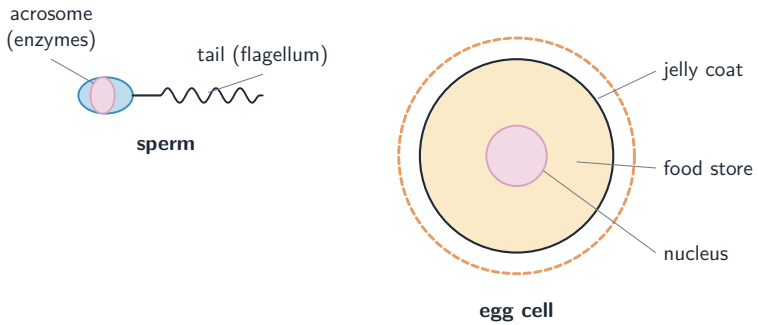
The female reproductive system (front view)

Gametes and fertilisation

Fertilisation is the fusion of the nuclei of a male gamete (sperm) and a female gamete (egg cell). The two gametes are adapted to their jobs:

	Sperm	Egg cell
size	very small	large
number	millions	few (about one a month)
can it move?	yes – swims with a **flagellum** 鞭毛	no – it is carried along
special features	many **mitochondria** 线粒体 for energy; **enzymes** 酶 in the **acrosome** 顶体 to break into the egg	a store of food; a **jelly coat** 胶质层 that changes after fertilisation to keep other sperm out

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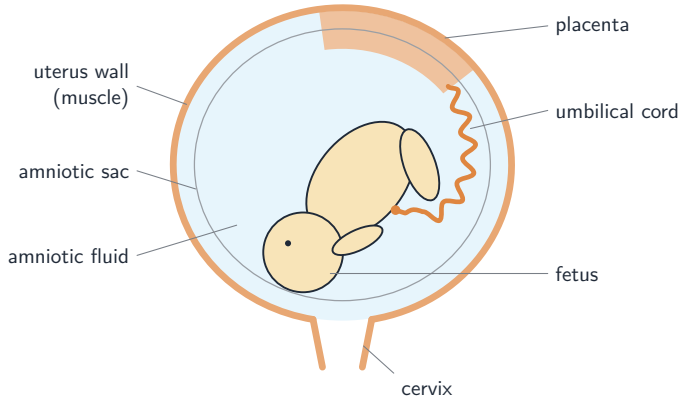
sperm: small, millions, swims | egg: large, few, carried

The sperm is small and swims; the egg cell is large and stores food

Pregnancy and the fetus

After fertilisation the zygote divides to form an **embryo** 胚胎 – a ball of cells that **implants** 植入 into the lining of the uterus. As it grows it becomes a **fetus** 胎儿. These structures support it:

- the **placenta** 胎盘 – where dissolved nutrients, gases and wastes are exchanged between the mother's blood and the fetus's blood (the two never mix).
- the **umbilical cord** 脐带 – joins the fetus to the placenta.
- the **amniotic sac** 羊膜囊 – a bag around the fetus, filled with **amniotic fluid** 羊水 that cushions it.



The fetus develops in the uterus, supported by the placenta, cord and amniotic sac

(Supplement) Some **pathogens** 病原体 and **toxins** 毒素 can cross the placenta and harm the fetus.

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Sex hormones

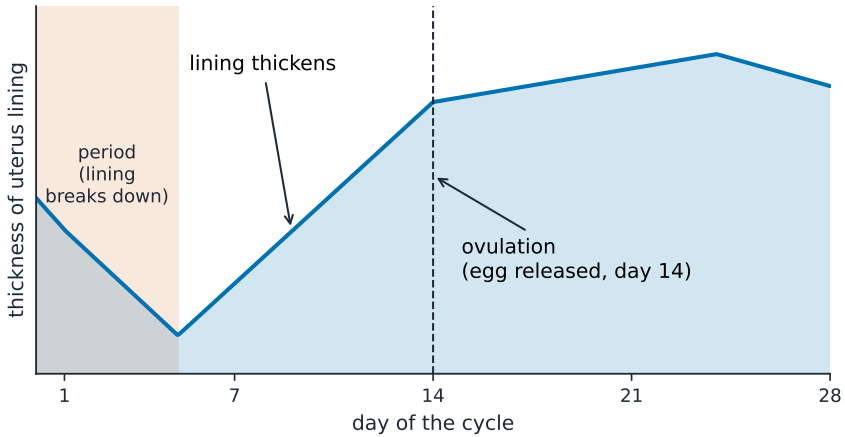
Puberty

At **puberty** 青春期, sex **hormones** 激素 make the body develop **secondary sexual characteristics** 第二性征 – such as body hair, a deeper voice in boys, and breasts in girls. **Testosterone** does this in boys; **oestrogen** does it in girls.

The menstrual cycle

The **menstrual cycle** 月经周期 (about 28 days) prepares the uterus for a possible pregnancy:

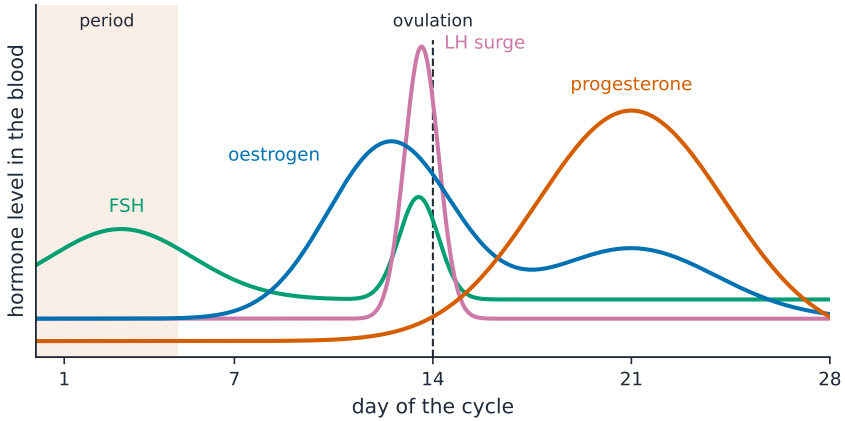
- the lining of the uterus thickens.
- around day 14 an ovary releases an egg (**ovulation** 排卵).
- if the egg is not fertilised, the lining breaks down and leaves the body (a period), and the cycle starts again.



~28 days · ovulation ~day 14 · lining thickens, then sheds if no pregnancy

The lining thickens, an egg is released at day 14, and a period follows if there is no pregnancy

(Supplement) Four hormones control the cycle: **FSH** (makes an egg mature and the ovary release oestrogen), **LH** (triggers ovulation), **oestrogen** (repairs and thickens the lining), and **progesterone** 孕酮 (keeps the lining thick). Oestrogen and progesterone are made in the ovaries; during **pregnancy** 怀孕, progesterone keeps the lining in place.



pituitary: FSH, LH · follicle in the ovary: oestrogen · corpus luteum: progesterone

(Supplement) FSH starts the cycle, oestrogen peaks before ovulation, an LH surge releases the egg, and progesterone peaks while the lining waits for an embryo

(Supplement) The hormones in order.

1. FSH from the **pituitary gland** 垂体 makes an egg mature inside a **follicle** 卵泡 in the ovary.
2. The follicle makes oestrogen. Oestrogen thickens the lining again after the period.
3. A sudden rise in LH, also from the pituitary, makes the follicle burst and release the egg (ovulation).
4. The empty follicle becomes the **corpus luteum** 黄体, which makes progesterone. Progesterone keeps the lining thick, ready for an embryo.
5. If no embryo implants, the corpus luteum breaks down, progesterone falls, and the lining is shed: the next period begins.

In pregnancy the corpus luteum keeps making progesterone at first. Later the **placenta** takes over and makes both progesterone and oestrogen, so the lining is never shed and no new eggs are released.

Common mistakes.

- Saying the ovary makes FSH or LH. They come from the pituitary gland; the ovary makes oestrogen and progesterone.
- Saying oestrogen releases the egg. The **LH surge** releases it.
- Saying a period happens because progesterone rises. It happens because progesterone **falls**.

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> **Worked example.** A woman has a regular 28-day cycle, and her period starts on the 1st of the month. On roughly which date is she most likely to conceive? Ovulation happens about **day 14**, so counting 14 days on from the start of the period points to about the **14th**, and the days either side of it are the most fertile. Day 1 is the day the period **starts**, not the day it ends - counting from the wrong day is what makes most cycle questions go wrong.

Sexually transmitted infections

A **sexually transmitted infection** 性传播感染 (STI) is an **infection** 感染 spread through sexual contact.

HIV is a **virus** 病毒 that causes an STI, and it can lead to **AIDS**, in which the immune system stops working properly. HIV is passed on in infected body fluids – for example by sharing needles, during sex, or from mother to baby (across the placenta or in breast milk).

The spread of STIs is controlled by using condoms, having fewer partners, testing and treating infected people, and not sharing needles.

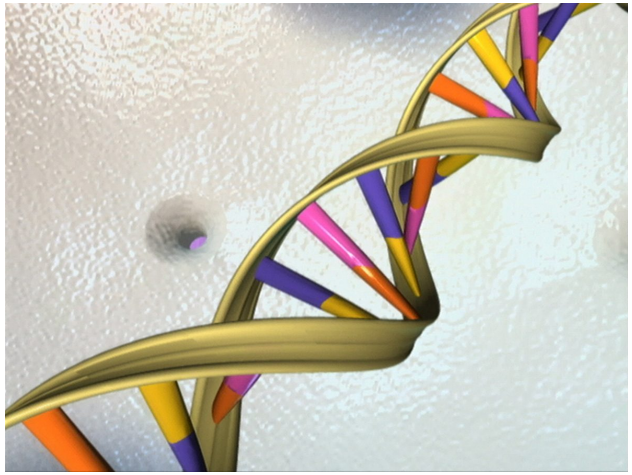
Exam tips

- Asexual: one parent, identical offspring (no variation). Sexual: two parents, gametes fuse, offspring show variation.
- Fertilisation = fusion of two gamete nuclei → zygote. (Supplement: gametes haploid, zygote diploid.)
- Learn the flower parts and which are male (stamen) and female (carpel). Compare insect- and wind-pollinated flowers.
- Sperm: small, many, moving (flagellum). Egg: large, few, with a food store.
- Menstrual cycle: lining thickens → ovulation (day 14) → period if no fertilisation. (Supplement: FSH, LH, oestrogen, progesterone.)
- HIV is a virus that causes an STI and can lead to AIDS; it spreads through body fluids.

Inheritance

IGCSE Biology

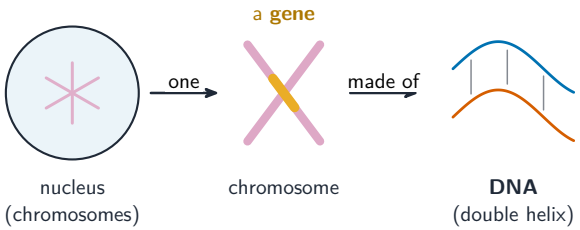
Chromosomes, genes and DNA



DNA carries inherited information in its double-helix structure.

Chromosomes 染色体 are made of **DNA**, which carries the genetic information in units called **genes** 基因.

- A **gene** is a length of DNA that **codes** 编码 for one **protein** 蛋白质.
- An **allele** 等位基因 is an alternative form of a gene. For example, a gene for eye colour may have a brown allele and a blue allele.

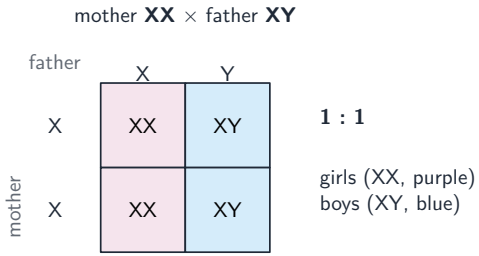


A chromosome is made of DNA and carries genes; a gene is a length of the DNA

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Sex chromosomes

Sex is inherited through the **sex chromosomes** 性染色体. Females are **XX** and males are **XY**. An egg always carries an X; a sperm carries either an X or a Y, so the sperm decides the baby's sex. This gives a 1:1 **ratio** 比例 of girls to boys.



XX × XY gives a 1:1 ratio of girls to boys; the sperm decides the sex

How DNA controls the cell (Supplement)

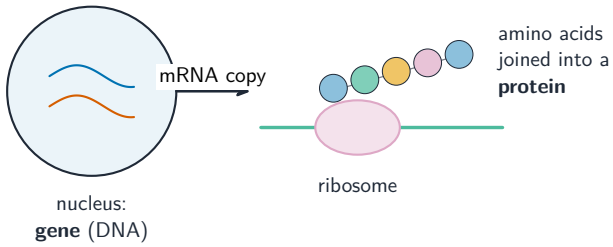
The **base sequence** 碱基序列 of a gene sets the order of **amino acids** 氨基酸 in a protein. A different order of amino acids folds the protein into a different shape, and the shape decides its job. So DNA controls the cell by controlling which proteins are made – including **enzymes** 酶, membrane carriers and **receptor proteins** 受体蛋白 for **neurotransmitters** 神经递质.

Most body cells hold the **same** genes, but each cell only **expresses** 表达 (switches on) the genes it needs, so it makes only the proteins for its own job.

Making a protein (Supplement)

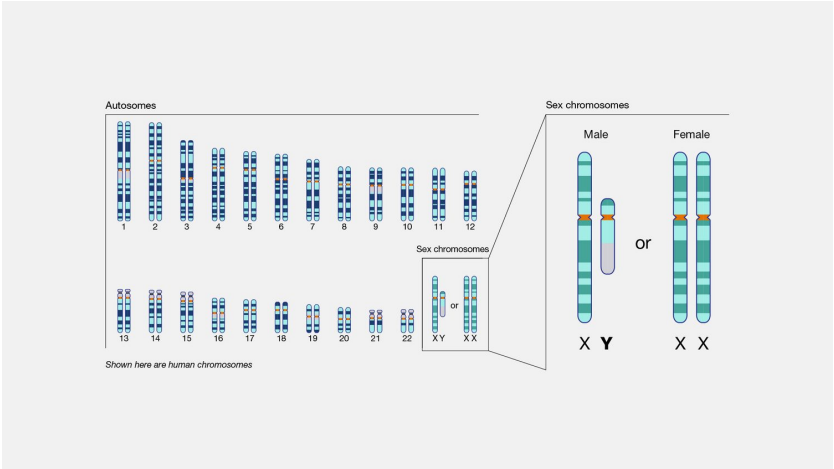
In the eukaryotic cell model here, the gene stays in the **nucleus** 细胞核, but proteins are made in the **cytoplasm** 细胞质. The link between them is **messenger** 信使 RNA (mRNA):

1. mRNA is made in the nucleus as a copy of the gene.
2. the mRNA moves out into the cytoplasm and passes through a **ribosome** 核糖体.
3. the ribosome reads the mRNA's **bases** 碱基 and joins amino acids in the matching order to build the protein.



mRNA copies a gene, then a ribosome reads it to build a protein from amino acids

Cell division (Supplement)



A karyotype shows the full set of chromosomes in a human cell.

Body cells are **diploid** 二倍体 (two sets of chromosomes; humans have 23 pairs). Gametes are **haploid** 单倍体 (one set). Cells make new cells by nuclear **division** 分裂, of two kinds.

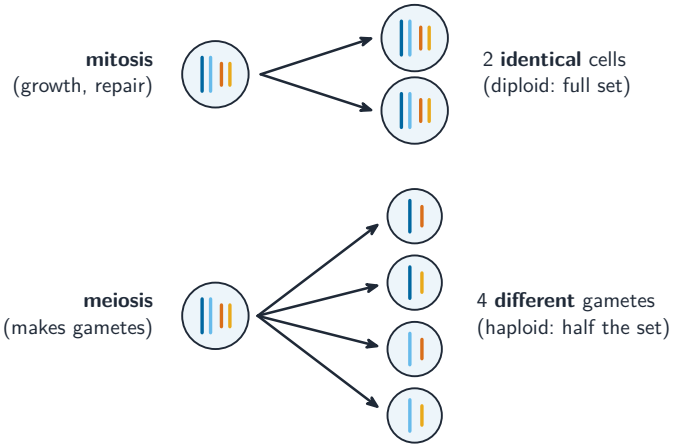
Mitosis 有丝分裂:

- makes two cells that are genetically **identical** to the parent cell.
- the chromosomes are copied exactly (**replication** 复制) before division, so each **daughter cell** 子细胞 keeps the full chromosome number.
- it is used for growth, repair of tissues, replacing old cells, and **asexual reproduction** 无性生殖.
- **stem cells** 干细胞 are unspecialised cells that divide by mitosis; their daughter cells can then become specialised.

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Meiosis 减数分裂:

- makes **gametes** 配子.
- it is a **reduction division**: the chromosome number is halved, from diploid to haploid.
- the cells it makes are genetically **different** from one another.

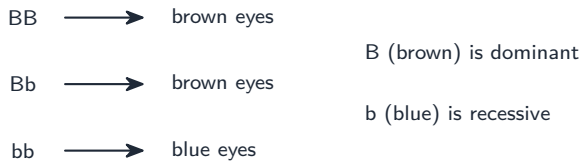


Mitosis makes two identical diploid cells; meiosis makes four different haploid gametes

Inheritance: key words

Inheritance 遗传 is the passing of genetic information from one generation to the next. Learn these words:

Word	Meaning
genotype 基因型	the alleles an organism has (its genetic make-up)
phenotype 表现型	the features you can observe
dominant 显性 allele	shown in the phenotype even if only one copy is present (written as a capital letter, e.g. B)
recessive 隐性 allele	shown only when **no** dominant allele is present (small letter, e.g. b)
homozygous 纯合子	two **identical** alleles (BB or bb); these breed true, or **pure-breeding** 纯种
heterozygous 杂合子	two **different** alleles (Bb); not pure-breeding



A dominant allele shows with one copy; a recessive needs two

Monohybrid crosses

To predict the offspring of a **cross** 杂交 involving one gene, use a genetic diagram or a **Punnett square** 庞纳特方格:

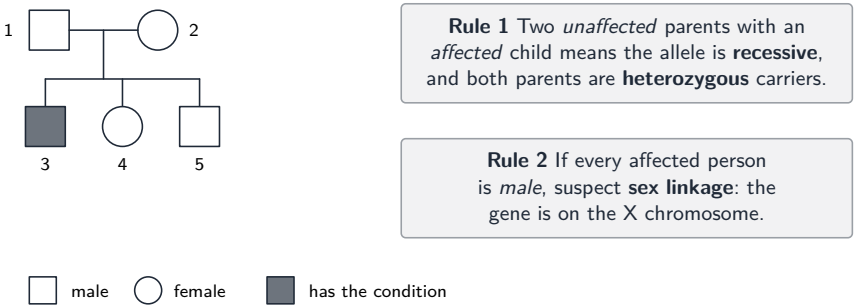
- write each parent's genotype, then the gametes (each gamete carries one allele).
- combine them in a grid to find the possible offspring genotypes and phenotypes.

Two heterozygous parents (Bb × Bb) give a **3:1** ratio of dominant to recessive. A heterozygous crossed with a homozygous recessive (Bb × bb) gives a **1:1** ratio.

A full genetic diagram has five lines. Examiners give a mark for each, so set it out like this every time:

Line	Bb × Bb
parents' phenotypes	brown eyes × brown eyes
parents' genotypes	Bb × Bb
gametes	B and b × B and b
offspring genotypes	BB, Bb, Bb, bb
offspring phenotypes and ratio	3 brown : 1 blue

Reading a pedigree diagram. A **pedigree diagram** 系谱图 is a family tree for one feature. Squares are males and circles are females; a shaded shape has the feature; a horizontal line joins two parents, and a vertical line leads down to their children.



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

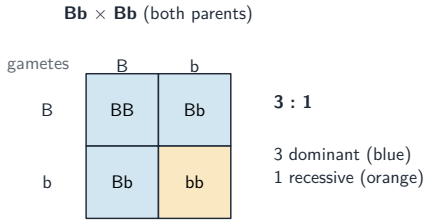
Rule 2 If every affected person is *male*, suspect **sex linkage**: the gene is on the X chromosome.

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

Use these steps:

1. **Is the feature dominant or recessive?** Find two parents who are the **same** as each other but have a child who is **different**. The child's feature is the recessive one, and both parents are heterozygous.
2. **Fill in the certain genotypes.** Everyone showing the recessive feature is homozygous recessive (for example, rr).
3. **Work out the rest.** A person with the dominant feature has at least one dominant allele. If one of their parents or children shows the recessive feature, they must also carry the recessive allele, so they are heterozygous. If there is no such evidence, write both possibilities (RR or Rr).

Worked example (pedigree). In the diagram above, the feature is shown only by person 3. Is it caused by a dominant or a recessive allele? Give the genotypes of persons 1 and 2. Persons 1 and 2 do not have the feature, but their son, person 3, does. If the allele were dominant, one parent would have to show it. So it is **recessive**. Person 3 is **nn**; he received one n from each parent, and each parent shows the dominant phenotype, so persons 1 and 2 are both **Nn**. Persons 4 and 5 could be NN or Nn. In an exam answer, always quote the evidence: "because 1 and 2 are unaffected but their child 3 is affected".



A Punnett square for Bb × Bb gives a 3:1 ratio of dominant to recessive

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(Supplement) A **test cross** 测交 finds an unknown genotype: cross the unknown with a homozygous recessive. If any offspring show the recessive feature, the unknown must have been heterozygous.

The reason is that the homozygous recessive parent can only give recessive alleles, so the offspring show **whatever allele the unknown parent gave**:

- if the unknown is **BB**: BB × bb gives all Bb, so **all** offspring show the dominant feature;
- if the unknown is **Bb**: Bb × bb gives Bb and bb, so about **half** the offspring show the recessive feature (a 1:1 ratio).

A large number of offspring makes the result more reliable: a few dominant offspring alone do not prove the parent is BB.

> **Worked example.** Brown eyes (B) are dominant to blue (b). Two brown-eyed parents have a blue-eyed child. Give the parents' genotypes, and the chance that their next child has blue eyes. Start from the child: blue is recessive, so the child must be **bb**, and it got one b from each parent. So each parent carries a b. But both parents show brown eyes, so each must also carry a B: both parents are **Bb**. The Punnett square for Bb × Bb gives BB, Bb, Bb and bb, so the chance of a blue-eyed child is **1 in 4 (25%)**. Always work backwards from the recessive individual - a recessive phenotype pins a genotype exactly, and the rest follows. The 25% applies to **each** child on its own: three brown-eyed children do not make the fourth blue.

Codominance and blood groups (Supplement)

In **codominance** 共显性, **both** alleles in a heterozygous organism show in the phenotype.

The ABO **blood groups** 血型 are an example. The alleles are I^A, I^B and I^o. The alleles I^A and I^B are codominant, while I^o is recessive:

- I^AI^A or I^AI^o → group A
- I^BI^B or I^BI^o → group B
- I^AI^B → group AB (both alleles shown)
- I^oI^o → group O

> **Worked example (codominance).** A man is blood group A, genotype I^AI^o; a woman is group B, genotype I^BI^o. What blood groups can their children have, and in what ratio?

gametes	I^B	I^o
I^A	I^AI^B (AB)	I^AI^o (A)
I^o	I^BI^o (B)	I^oI^o (O)

All four blood groups are possible, in the ratio **1 AB : 1 A : 1 B : 1 O**. So two parents of group A and B can have a child of group O, but only if both carry I^o.

Sex linkage (Supplement)

A **sex-linked** 伴性遗传 characteristic is controlled by a gene on a sex chromosome (usually the X). Because males have only one X chromosome, a recessive allele on it always shows in males, so the feature is more common in males than in females.

Red-green colour blindness 色盲 is an example: the recessive allele is on the X chromosome, so it is much more common in boys than in girls.

Write sex-linked alleles **on the X chromosome**: X^B is normal colour vision and X^b is colour blindness. The Y chromosome carries no allele for this gene. So a girl can be X^BX^B (normal), X^BX^b (normal, but a **carrier** 携带者) or X^bX^b (colour-blind); a boy is either X^BY (normal) or X^bY (colour-blind).

mother X^BX^b (a carrier) × father X^BY

	X^B	X^b
X^B	X^BX^B girl, normal	X^BX^b girl, carrier
Y	X^BY boy, normal	X^bY **boy, colour-blind**

A boy has **one** X, so a single recessive allele on it always shows. A girl needs **two**, which is far rarer – hence "more common in one sex".

Here half the sons are colour-blind and none of the daughters are, although half the daughters are carriers. Always write the chromosomes, never bare letters.

A carrier mother and a normal father: half the sons are colour-blind, and half the daughters are carriers

> **Worked example (sex linkage).** A carrier mother (X^BX^b) and a father with normal vision (X^BY) have children. Find the chance that a son is colour-blind. The gametes are X^B and X^b from the mother, and X^B and Y from the father. The offspring are X^BX^B, X^BX^b, X^BY and X^bY. The sons are X^BY and X^bY, so the chance that **a son** is colour-blind is **1 in 2**; the chance that **any child** is a colour-blind boy is 1 in 4. Read the question carefully to see which it asks for. A son always gets his X from his **mother**, so a colour-blind father cannot pass the allele to his sons.

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Common mistakes.

- Mixing up gene and allele. A **gene** is the length of DNA for one protein (eye colour); an **allele** is one form of it (blue or brown).
- Writing a Punnett square without the gametes. Show each parent's genotype, then the **gametes** (one allele each), then the offspring.
- Reading a 3:1 ratio as a promise. It gives the **chance** for each child: a 1 in 4 chance of blue eyes does not mean exactly one child in four will have them.
- Using different letters for the two alleles, such as B and r. Use the same letter for one gene: capital for dominant, small for recessive (B and b).
- Thinking a dominant allele is more common or "stronger". Dominant only means it shows with one copy; a dominant allele can be rare.
- Saying mitosis makes gametes. Mitosis makes **identical diploid** cells for growth and repair; **meiosis** makes the haploid gametes, which are all different.
- Saying the mother decides a baby's sex. Every egg carries an X; the **sperm** carries X or Y, so it decides.
- Calling group AB "a blend" of A and B. In codominance **both** alleles show fully in the phenotype: $I^A I^B$ is group AB, not something in between.

Exam tips

- Gene = a length of DNA coding for a protein. Allele = one form of a gene.
- Genotype = the alleles present; phenotype = what you see. Homozygous = two same; heterozygous = two different.
- Dominant shows with one copy; recessive needs two copies.
- Learn to draw a Punnett square. Bb × Bb → 3:1; Bb × bb → 1:1.
- (Supplement) Codominance: both alleles show (blood group AB). Sex linkage: a gene on the X, more common in boys (colour blindness).
- Set out every cross in five lines: parents' phenotypes, parents' genotypes, gametes, offspring genotypes, offspring phenotypes with the ratio.
- In a pedigree, two parents who are alike with a child who is different show that the child's feature is **recessive**, and both parents are heterozygous. Quote the individuals you used as evidence.
- (Supplement) Write sex-linked genotypes as $X^B X^b$ and $X^b Y$, never as bare letters.

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Variation and selection

IGCSE Biology

Variation

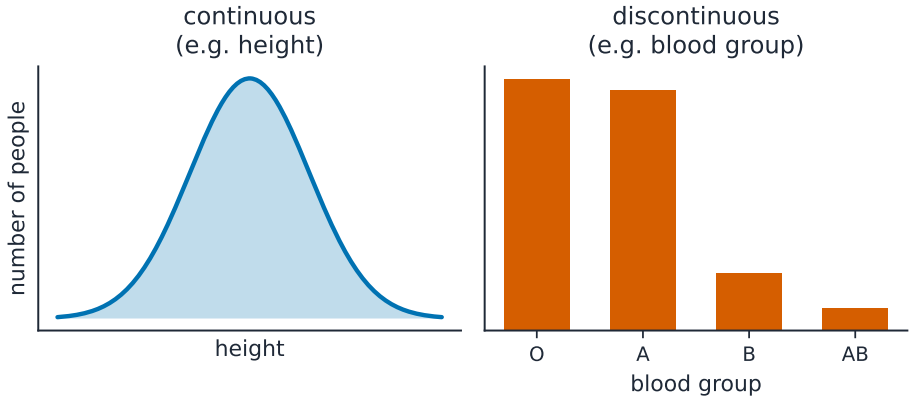


People show wide variation in many inherited features.

Variation 变异 means the differences between individuals of the same **species** 物种. There are two types:

- **continuous variation** 连续变异 – a smooth range of **phenotypes** 表现型 between two extremes (for example body length and body mass).
- **discontinuous variation** 不连续变异 – a few separate phenotypes with nothing in between (for example **ABO blood groups** 血型, or seed shape in peas).

Discontinuous variation is usually caused by **genes** 基因 only. Continuous variation is caused by **both** genes and the **environment** 环境 – for example, your height depends on your genes and also on your diet.



Continuous variation is a smooth range; discontinuous variation falls into separate groups

Investigating variation. To study continuous variation, measure one feature in many individuals of the same species, for example the length of 30 leaves from one tree, or the hand span of everyone in your class. Group the measurements into equal **classes** (such as 60–69 mm, 70–79 mm), make a **tally** 计数 chart, and draw a **histogram** 直方图 with the bars touching, because the data are continuous. Most values fall near the middle and few at the extremes. For discontinuous variation, count how many individuals fall into each category, for example who can and cannot roll their tongue, and draw a **bar chart** 条形图 with gaps between the bars. Measure **many** individuals, chosen at random, so the pattern is reliable.

Mutation

A **mutation** 突变 is a genetic change. Mutations are the way **new alleles** 等位基因 are made, so they are the original source of all variation. **(Supplement)** A **gene mutation** 基因突变 is a random change in the **base sequence** 碱基序列 of DNA.



A mutation changes the DNA bases, making a new allele

Ionising radiation 电离辐射 (such as X-rays) and some chemicals raise the **rate** 速率 of mutation. **(Supplement)** Other sources of genetic variation are **meiosis** 减数分裂, random mating and random **fertilisation** 受精.

Adaptive features

An **adaptive feature** 适应特征 is an **inherited** 遗传 feature that helps an organism to **survive** 生存 and **reproduce** 生殖 in its **environment**.



A camel is adapted to desert life: it stores fat in its humps and can survive a long time without water

Interpreting an adaptive feature. Exam questions show a picture or give facts about an organism and ask how it is adapted. Name the **feature**, then say **how it helps** the organism survive in **that** environment. For example, a polar bear has thick white fur and a thick layer of fat (feature), which **insulate** it so it loses less heat in the Arctic cold, and its white colour **camouflages** it against the snow, so it can get close to its prey (how it helps).

(Supplement) Plants that live in water and in very dry places show clear adaptive features. Always link each feature to its effect.

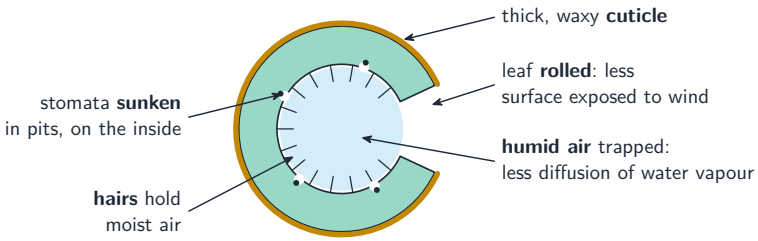
Hydrophytes 水生植物 (water plants, such as the water lily):

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Feature	How it helps
large **air spaces** in the leaves and stems	make the leaves float near the light; store oxygen and carbon dioxide
stomata on the upper surface of floating leaves	open to the air for gas exchange (the lower surface is in water)
thin or no waxy cuticle	water loss is not a problem, so no waterproof layer is needed
little xylem and little support tissue	the water supports the plant, and water is all around it

Xerophytes 旱生植物 (plants of dry places, such as cacti and marram grass) reduce water loss by **transpiration** 蒸腾作用 and store water:

Feature	How it helps
thick, waxy **cuticle**	waterproof, so less water evaporates from the leaf surface
few, small stomata; often **sunken** in pits	less water vapour diffuses out; humid air is trapped in the pit
hairs on the leaf	trap a layer of moist air, so the water vapour gradient is smaller
rolled leaves (marram grass)	stomata are inside, in still, humid air, sheltered from the wind
leaves reduced to **spines** (cactus)	a much smaller surface area loses less water; spines also stop animals eating the plant
swollen, fleshy stem	stores water
long, deep or widespread roots	reach water deep underground or absorb rain quickly from a wide area



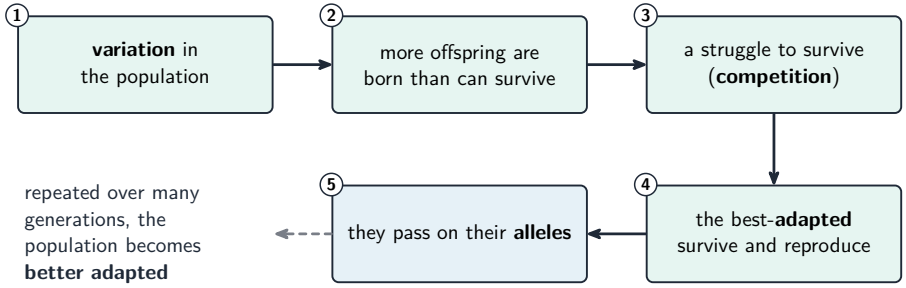
Marram grass, a xerophyte: its rolled leaf keeps the stomata inside, in humid air, behind a thick waxy cuticle

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Natural selection

Natural selection 自然选择 explains how a species becomes better suited to its environment:

1. there is genetic variation in a population (caused by mutation).
2. organisms produce **many offspring** 后代 – more than can survive.
3. there is a struggle to survive, with **competition** 竞争 for **resources** 资源 such as food and space.
4. the individuals that are better **adapted** 适应 are more likely to survive and reproduce.
5. they pass on their alleles, so the helpful alleles become more common in the next generation.



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



The dark (melanic) form of the peppered moth – the form favoured on soot-darkened bark

(Supplement) Over many generations this makes the population more suited to its environment; this process is called adaptation. A clear example is **antibiotic** 抗生素-resistant **bacteria** 细菌: a few bacteria carry a **resistant** 耐药 allele and survive the antibiotic, then multiply, until the whole population is resistant.

Set out antibiotic resistance as a chain:

1. In a population of bacteria there is **variation**: by a random **mutation**, a few bacteria have an allele that makes them resistant to an antibiotic.
2. The antibiotic kills the **non-resistant** bacteria.
3. The resistant bacteria **survive**, so there is less competition for them.
4. They **reproduce** (bacteria divide very quickly), passing on the resistance allele.
5. Over many generations, most of the population is resistant: a **resistant strain** 耐药菌株, which the antibiotic can no longer treat.

This is why doctors avoid giving antibiotics when they are not needed (for example for a viral infection) and why patients should **finish the whole course**: both stop resistant bacteria from being selected and spread.

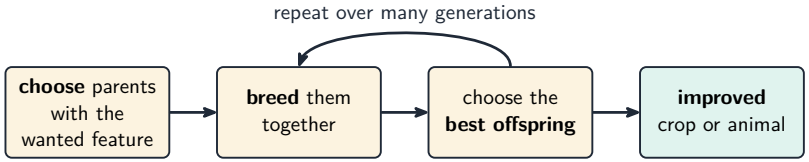
> **Worked example.** A moth species is mostly pale. Soot darkens the tree trunks the moths rest on, and within a few decades most of the moths are dark. Explain by natural selection. **Variation** is already there: a few dark moths exist by chance, caused by **mutation**. On sooty bark the dark moths are better camouflaged, so birds eat fewer of them and they are more likely to **survive**. The survivors **reproduce** and pass the allele for dark colour to their offspring, so it becomes more common each generation until most moths are dark. Follow the chain: variation, survival, reproduction, the allele becomes more common. The moths did not turn dark in order to hide - the dark ones simply survived more often.

Selective breeding

In **selective breeding** 选择育种 (also called **artificial selection** 人工选择), humans choose which organisms breed:

1. choose the individuals that have the features you want.
2. cross them to produce the next generation.
3. choose the offspring that show those features, and repeat over many generations.

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humans choose which breed (not the environment)

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

It improves **crops** 农作物 (higher yield) and farm animals (cows giving more milk).

> **Worked example (selective breeding in context).** *A farmer wants a wheat variety that is resistant to a fungal disease. Outline how this could be done.* "Choose wheat plants that show the most resistance to the disease. Cross (breed) these plants with each other. Grow the seeds and select the offspring that are most resistant. Breed these together, and repeat for many generations until all the plants are resistant." To combine two features (such as disease resistance and a high **yield** 产量), cross a resistant plant with a high-yield plant, then select offspring that show **both** features.

(Supplement) The key difference: in natural selection the **environment** decides which individuals survive; in artificial selection **humans** decide.

	Natural selection	**Artificial selection**
what selects	the environment	humans
which features are favoured	those that help the organism survive and reproduce	those that are useful to humans (even if they do not help the organism survive in the wild)
speed	usually slow, over very many generations	faster, because only chosen individuals breed
result	a population better adapted to its environment	a new variety or breed



Dairy cattle: generations of selective breeding for milk yield

Common mistakes.

- Saying organisms change **in order to** survive, or "adapt because they need to". A single organism cannot choose its alleles. The variation is already there by chance (mutation); the environment then selects which individuals survive.
- Saying the antibiotic **causes** the resistance mutation. The resistant allele was already there by chance; the antibiotic kills the others, so the resistant bacteria are left to multiply.
- Stopping at "the best-adapted survive". The marks need the whole chain: they **reproduce** and **pass on their alleles**, so the allele becomes more common in the next generation.
- Saying "survival of the strongest". The organism that survives is the one **best suited** to its environment, such as the best-camouflaged moth, not the biggest or strongest.
- Calling height discontinuous because you can group it into bars. Height has a smooth range of values, so it is **continuous**; blood group has a few separate groups, so it is discontinuous.
- Saying the environment causes discontinuous variation. Discontinuous variation is usually caused by **genes only**.
- Mixing up natural and artificial selection. In natural selection the **environment** decides who breeds; in selective breeding **humans** decide.

Exam tips

- Continuous variation = a range (genes + environment); discontinuous = separate groups (genes only).
- Mutation makes new alleles – the source of all variation. Radiation and some chemicals raise the mutation rate.
- Natural selection: variation → too many offspring → struggle and competition → the best-adapted survive and reproduce → they pass on their alleles.
- Antibiotic resistance in bacteria is natural selection in action.
- Selective breeding: humans, not the environment, pick which parents breed.
- For an adaptive feature, give the feature **and** explain how it helps in that environment. (Supplement) For xerophytes, link each feature to **less water loss** or **water storage**.
- For antibiotic resistance, start with a random **mutation** and end with the resistant bacteria **reproducing** and passing on the allele.

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Organisms and their environment

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Energy flow

The **Sun** is the main source of **energy** 能量 for almost all life. Plants capture light energy by **photosynthesis** 光合作用 and store it as chemical energy in food. This energy then passes from organism to organism as they feed. At every step, some energy is lost (mostly as heat from **respiration** 呼吸作用) to the **environment** 环境. Energy flows **one way** – it is not recycled.

Follow the energy through its forms: **light energy** from the Sun → **chemical energy** in the plant's glucose and other organic molecules → chemical energy in the animals that eat it → and finally **heat** (thermal energy) that passes to the environment and cannot be used by living things again.

Food chains and food webs



A savanna ecosystem: organisms linked by feeding relationships.

A **food chain** 食物链 shows the transfer of energy from one organism to the next, starting with a producer. Each arrow points in the direction the energy flows:

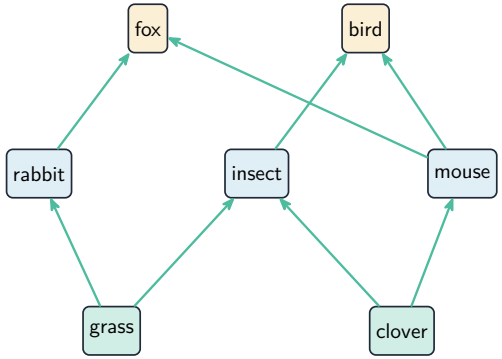
grass → rabbit → fox



each arrow shows energy flowing to the next organism

A food chain: arrows show energy passing from producer to consumers

A **food web** 食物网 is many food chains linked together. In a web, one animal can be at **more than one** trophic level: a bird that eats insects is a secondary consumer, but if it also eats seeds it is a primary consumer too.



A food web is several food chains linked together

Producers, consumers and decomposers

Type	Meaning
producer 生产者	makes its own food (organic **nutrients** 营养物质), usually by photosynthesis
consumer 消费者	gets its energy by feeding on other organisms
herbivore 食草动物	a consumer that eats plants
carnivore 食肉动物	a consumer that eats other animals
decomposer 分解者	gets its energy from dead or waste material, causing **decomposition** 分解

Consumers are named by their position: a **primary** consumer eats the producer; a **secondary** consumer eats the primary consumer; then come **tertiary** and **quaternary** consumers.

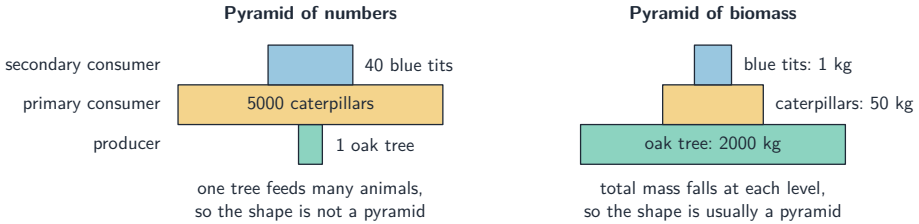
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Worked example (interpreting a food web). In the food web above, a disease kills most of the rabbits. Suggest what happens to the grass and to the mice. With fewer rabbits eating it, the **grass** increases. The foxes have fewer rabbits to eat, so they eat **more mice**, and the mouse population falls. With fewer mice, the birds may eat more insects. (Another answer can also score: more grass gives the insects more food, so they could increase.) Give one clear effect, say **why** using the feeding links, and name the organisms.

Trophic levels and pyramids

A **trophic level** 营养级 is the position of an organism in a food chain (producers first, then primary consumers, and so on). You can show a food chain as a **pyramid** 金字塔:

- a **pyramid of numbers** counts the organisms at each level.
- a **pyramid of biomass** 生物量 shows the total mass at each level – usually a better picture, because it does not depend on how big the organisms are.
- **(Supplement)** a **pyramid of energy** shows the energy at each level – the most useful picture of all.

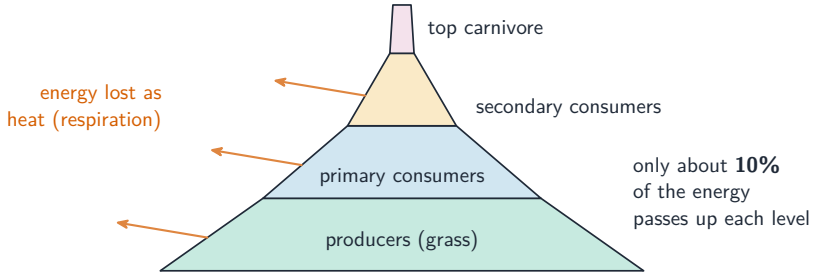


The same food chain as a pyramid of numbers and as a pyramid of biomass: one large tree makes the numbers pyramid an odd shape

Drawing a pyramid. Draw one horizontal bar per trophic level, with the **producer at the bottom**. Make each bar's width in proportion to the number (or biomass, or energy), centre the bars, and label each level.

Why choose one pyramid over another?

Pyramid	Advantage	Disadvantage
numbers	easy to count	ignores size: one tree counts the same as one caterpillar, so the shape can be odd
biomass	allows for size, so it is usually a true pyramid	organisms must be dried and weighed (killed); it shows mass at **one time** only, which can change with the season
(Supplement) energy	shows the energy passed on **over time** (for example, kJ per m^2 per year); always a true pyramid; levels and different ecosystems can be compared fairly	the data are hard and slow to collect



Only about 10% of energy passes up each level, so the levels get smaller

Energy loss along a chain (Supplement)

Only about 10% of the energy at one trophic level passes to the next. The rest is not passed on, because:

- not all of the organism is **eaten** (roots, bones, fur);
- not all that is eaten is **digested**: some passes out in faeces;
- energy is used in **respiration** and lost as **heat**, and used for movement;
- some is lost in **excretion** (urine).

The **efficiency** 效率 of a transfer is:

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$$\text{efficiency} = \frac{\text{energy passed to the next level}}{\text{energy in the level below}} \times 100\%$$

Because so much energy is lost, food chains usually have **fewer than five** trophic levels. It is more energy-efficient for people to eat **crop plants** 农作物 directly than to eat animals that were fed on those crops, because each extra level wastes energy.

> **Worked example.** The producers in a field trap 40 000 kJ of energy. Roughly how much reaches a secondary consumer, and why do food chains stay short? About 10% passes on at each step. Primary consumers receive 10% of 40 000 = **4000 kJ**. Secondary consumers receive 10% of 4000 = **400 kJ** - only 1% of what the plants trapped. After a few levels too little energy is left to support another one, which is why chains rarely pass five levels. Apply the 10% **again at every step**, not once for the whole chain.

> **Worked example (efficiency from data).** A field of grass gains 21 000 kJ per m^2 per year. The cows that graze it gain 2100 kJ per m^2 per year, and the farmer's family who drink the milk gain 170 kJ. Calculate the efficiency of the grass-to-cow transfer. Efficiency = 2100 ÷ 21 000 × 100 = **10%**. From cows to people it is 170 ÷ 2100 × 100 = **8.1%**. If the family ate a crop grown on the same field instead, they would skip the cow's 90% loss: this is why eating plants feeds more people from the same land.

Human impact

Humans can damage food webs by:

- **overharvesting** 过度捕捞 – taking too many of one species (such as overfishing), so its numbers crash.
- introducing a **foreign species** 外来物种 – a new species may have no predators and may crowd out native species.

Explain each one through the food web. **Overharvesting**: when too many cod are fished, their prey (smaller fish) increase, and the seals and seabirds that eat cod lose food and decline. **Foreign species**: cane toads were brought to Australia to eat beetles on sugar cane. They had no natural predators there, so their numbers grew fast; they eat many native animals, and their poison kills native predators that try to eat them.

Nutrient cycles

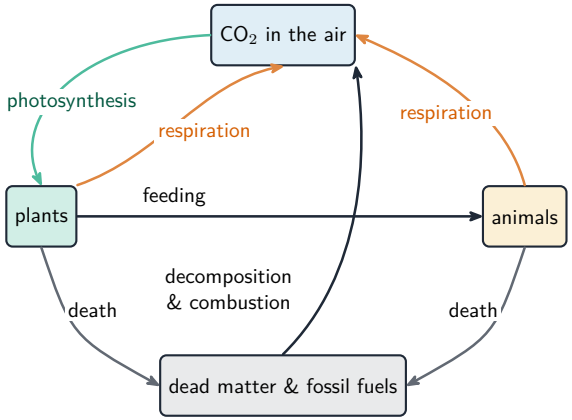
Unlike energy, nutrients are **recycled** – used again and again.

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The carbon cycle

In the **carbon cycle** 碳循环:

- photosynthesis removes **carbon dioxide** 二氧化碳 from the air.
- respiration and **combustion** 燃烧 (burning) return carbon dioxide to the air.
- feeding passes carbon from one organism to the next.
- decomposition returns carbon to the air and soil.
- over millions of years, dead organisms can form **fossil fuels** 化石燃料 (coal and oil), which release carbon dioxide when they are burned.



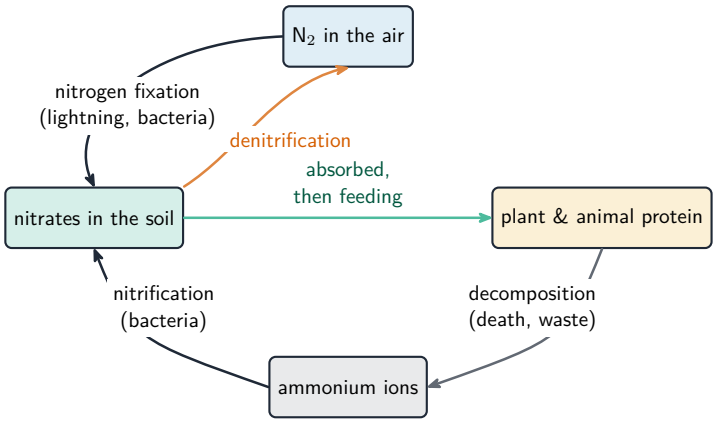
The carbon cycle: photosynthesis removes CO_2; respiration, combustion and decay return it

The nitrogen cycle (Supplement)

The **nitrogen cycle** 氮循环 recycles nitrogen for making **proteins** 蛋白质. **Microorganisms** 微生物 do most of the work:

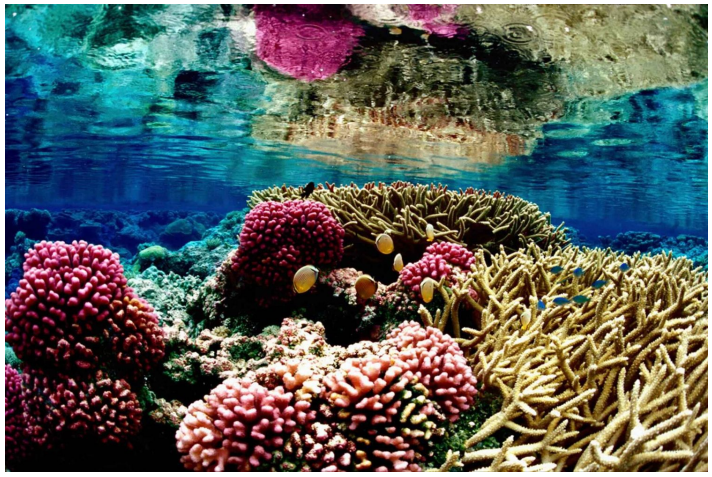
- **decomposition**: decomposers break dead protein down into **ammonium ions** 铵离子.
- **nitrification** 硝化作用: bacteria change ammonium ions into **nitrate ions** 硝酸根离子.
- **nitrogen fixation** 固氮作用: lightning and some **bacteria** 细菌 turn nitrogen gas into compounds that plants can use.
- plants absorb nitrate ions to make **amino acids** 氨基酸 and proteins; animals get them by feeding and **digestion** 消化.
- **deamination** 脱氨基作用 (in the liver) and decomposition release nitrogen compounds again.

- **denitrification** 反硝化作用: some bacteria turn nitrate ions back into nitrogen gas.



The nitrogen cycle: microorganisms move nitrogen between the air, soil and living things

Populations



A coral reef is a rich ecosystem supporting many interdependent species.

- a **population** 种群 is a group of organisms of one **species** 物种, living in the same area at the same time.
- a **community** 群落 is all the populations of different species in one place.

- an **ecosystem** 生态系统 is the community together with its **environment**, all interacting.

Population growth

The growth of a population depends on the food supply, **competition** 竞争, **predation** 捕食 (being eaten) and disease.

When a population grows in a place with limited **resources** 资源, its growth follows an S-shaped curve with four phases:

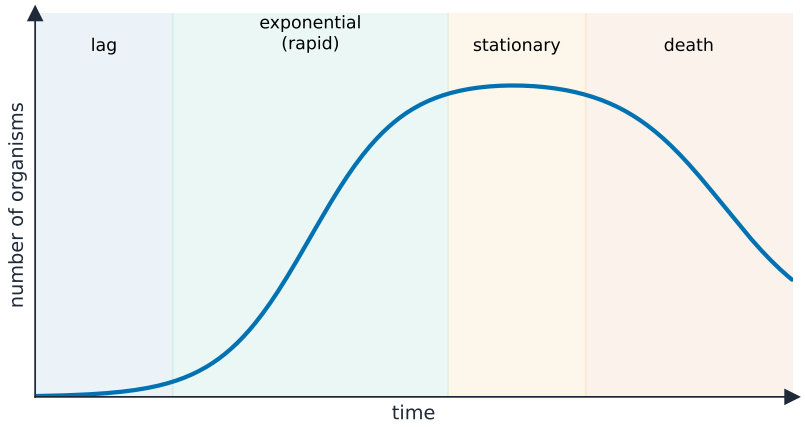
Phase	What happens
lag phase 延迟期	slow growth at first, while numbers are still small
exponential phase 对数期	very fast growth, with plenty of food and space
stationary phase 稳定期	growth stops; births ≈ deaths (a **limiting factor** 限制因素 such as food holds it back)
death phase 衰亡期	numbers fall as food runs out, wastes build up, or disease spreads

(Supplement) Explain each phase by comparing **births and deaths**, and name the limiting factor:

- **lag**: few individuals are breeding, and they are still adapting (bacteria make new enzymes; animals must mature), so births only slightly exceed deaths.
- **exponential (log)**: food, space and oxygen are plentiful and there is little competition, so births far exceed deaths and the numbers double again and again.
- **stationary**: a **limiting factor** – such as food, space, oxygen, or a build-up of toxic waste – slows births or raises deaths until births equal deaths. Competition for the resource increases.
- **death**: the resource runs out or waste becomes toxic, so deaths exceed births.

Predators and disease also cut the growth rate; in real ecosystems predator and prey numbers often rise and fall in a repeating cycle, with the predator peak shortly after the prey peak.

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lag → exponential → stationary (births = deaths) → death

A population in a limited space grows in four phases: lag, exponential, stationary, death

Common mistakes.

- Drawing food-chain arrows from the eater to the food. The arrow shows the direction energy flows, so it points **into** the organism that eats: grass → rabbit → fox.
- Saying energy is recycled. Energy flows one way and leaves as heat; only **nutrients** such as carbon and nitrogen go round a cycle.
- Saying the lost energy is "used up" or "destroyed". It is lost to the surroundings as heat from respiration, and in waste and uneaten parts.
- Applying the 10% once for the whole chain. Take 10% again at **each** step: 40 000 kJ → 4000 kJ → 400 kJ.
- Leaving decomposers out of the carbon cycle. Decomposers **respire**, and that respiration returns the carbon in dead matter to the air as carbon dioxide.
- Saying plants absorb nitrogen gas from the air. Plants absorb **nitrate ions** from the soil through their roots; only nitrogen-fixing bacteria (and lightning) can use nitrogen gas.
- Mixing up the bacteria. **Nitrogen-fixing** bacteria turn nitrogen gas into nitrogen compounds, **nitrifying** bacteria turn ammonium ions into nitrates, and **denitrifying** bacteria turn nitrates back into nitrogen gas.
- Calling the flat part of the population curve "no births". In the stationary phase births still happen; they are simply **equal** to deaths.

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Exam tips

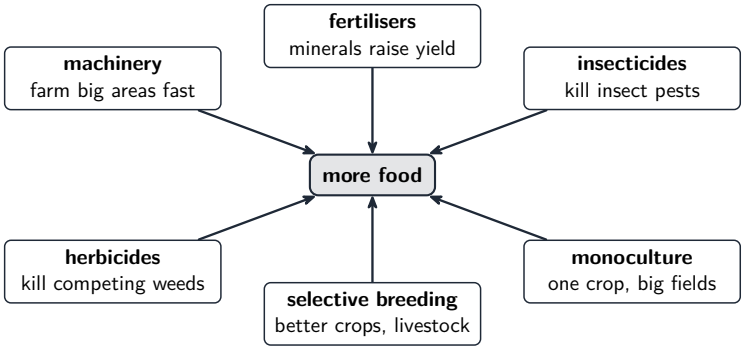
- Energy enters from the Sun, flows one way along the chain, and is lost as heat at each step. Nutrients are recycled.
- Food chain starts with a producer; arrows show energy flow. Learn producer, consumer, herbivore, carnivore, decomposer.
- Only ~10% of energy passes up each trophic level, so chains are short and eating plants is more efficient.
- Carbon cycle: photosynthesis ↔ respiration and combustion; nitrogen cycle (Supplement): fixation, nitrification, denitrification by microorganisms.
- Draw a pyramid with the **producer at the bottom** and bar widths in proportion. A pyramid of numbers can be an odd shape (one tree); a pyramid of biomass usually cannot.
- For efficiency, divide the energy **passed on** by the energy **in the level below**, then × 100.
- For a food web question, say what changes, then **why**, using the feeding links between named organisms.
- Population: one species, one area, one time. Learn the four phases of the S-shaped growth curve.

Human influences on ecosystems

IGCSE Biology

Increasing food supply

To grow more food, humans use:



Ways farmers increase food production

- **agricultural machinery** to farm larger areas of land quickly.
- chemical **fertilisers** 化肥 to improve **yields** 产量.
- **insecticides** 杀虫剂 to kill insect pests.
- **herbicides** 除草剂 to kill **weeds** 杂草 that compete with the crops.
- **selective breeding** 选择育种 to improve **crop plants** 农作物 and **livestock** 牲畜.

A **monoculture** 单一栽培 (growing one crop over a large area) gives a big, easy harvest, but one pest or disease can destroy the whole crop, and it lowers **biodiversity** 生物多样性. Intensive livestock farming (many animals in a small space) gives cheap meat, but raises worries about animal welfare and the spread of disease.

Habitat destruction

Biodiversity is the number of different **species** 物种 living in an area. Humans destroy **habitats** 栖息地 (the places where organisms live) by:

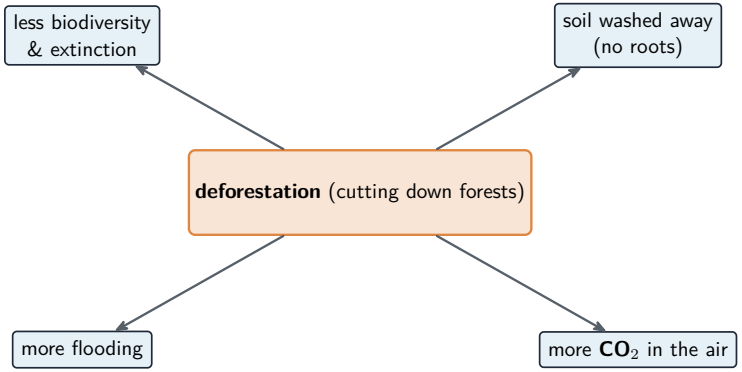
- clearing land for housing, crops and livestock.
- extracting natural **resources** 资源, such as by mining.
- **pollution** 污染 of fresh water and the sea.



Clearing forest destroys habitats and reduces biodiversity.

By changing **food webs** 食物网 and **food chains** 食物链, humans harm habitats. **Deforestation** 森林砍伐 (cutting down forests) is a major example. It causes:

- lower biodiversity and the **extinction** 灭绝 of species.
- loss of soil (no roots to hold it, so it washes away).
- more flooding.
- more **carbon dioxide** 二氧化碳 in the air, because there are fewer trees to take it in.



Deforestation lowers biodiversity, washes away soil, causes flooding and adds CO_2

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Pollution



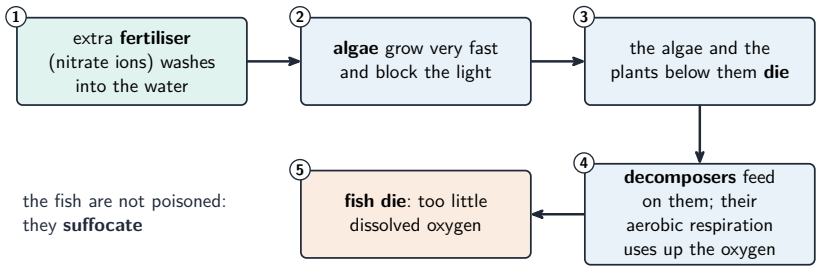
Plastic pollution is a major human impact on ecosystems.

Water pollution

Untreated **sewage** 污水 and excess fertiliser washed into rivers and lakes damage water **ecosystems** 生态系统.

(Supplement) Excess fertiliser causes **eutrophication** 富营养化:

1. the fertiliser adds **nitrate ions** 硝酸根离子 and other ions to the water.
2. **producers** 生产者 such as algae grow very fast.
3. they soon die, and **decomposition** 分解 increases.
4. **decomposers** 分解者 use up the **oxygen** 氧气 in **aerobic respiration** 有氧呼吸.
5. the dissolved oxygen falls, so fish and other organisms die.



Eutrophication: extra fertiliser makes algae bloom, then the water loses its oxygen and fish die

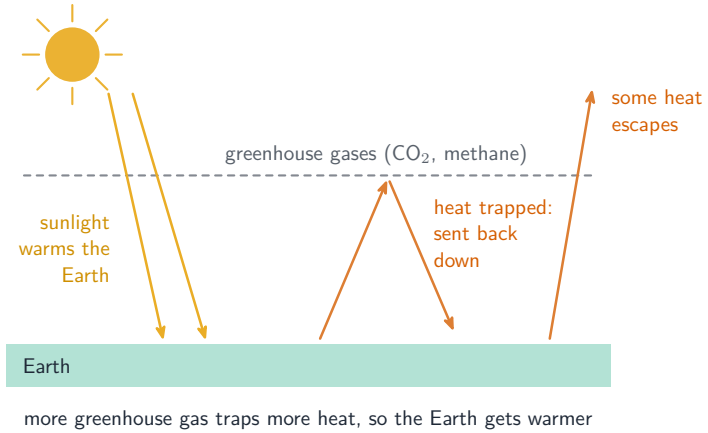
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> **Worked example.** A farmer spreads fertiliser on a field; weeks later the fish in a nearby river die. Put the steps in order and explain. Rain washes **nitrate ions** off the field into the river. The extra nitrate makes algae grow very fast and cover the surface. The algae block the light, so the plants below die. **Decomposers** multiply as they feed on the dead algae and plants, and their **aerobic respiration** uses up the oxygen dissolved in the water. With too little oxygen left, the fish die. The fish are **not** poisoned by the fertiliser - they suffocate, and it is the decomposers that actually remove the oxygen.

Plastics and air pollution

Non-biodegradable 不可降解 **plastics** 塑料 do not rot away. They build up in the sea and on land, harming wildlife – animals may eat them or get trapped.

Methane 甲烷 and carbon dioxide are greenhouse gases. Too much of them strengthens the **greenhouse effect** 温室效应 (the enhanced greenhouse effect), which causes **climate change** 气候变化.



Greenhouse gases trap heat leaving the Earth, so the Earth gets warmer

Conservation

Sustainable resources

A **sustainable** 可持续 resource is produced as fast as it is used up, so it never runs out. Forests and **fish** 鱼类 stocks can both be managed in this way.

(Supplement) Forests are **conserved** 保护 by education, protected areas, **quotas** 配额 (limits on how much is taken) and replanting. Fish stocks are conserved by **closed seasons** 禁渔期, protected areas, controlled net mesh sizes (so young fish can escape), quotas and monitoring.

Saving endangered species

A species becomes **endangered** 濒危 or extinct when its numbers fall, because of climate change, habitat destruction, **hunting** 狩猎, **overharvesting** 过度捕捞, pollution and **introduced species** 外来物种.

Endangered species can be saved by:

- monitoring and protecting the species and its habitat.
- education.
- **captive breeding** 圈养繁殖 programmes, which breed animals in zoos. **(Supplement)** These may use **artificial insemination** 人工授精 (AI) or **in vitro fertilisation** 体外受精 (IVF).
- **seed banks** 种子库, which store seeds safely.



The giant panda was once endangered; protected habitats and captive-breeding programmes have helped its numbers recover

(Supplement) We conserve nature to keep up biodiversity, reduce extinction, protect ecosystems, and keep ecosystem functions going – such as recycling nutrients and providing food, **drugs** 药物, fuel and useful **genes** 基因. If a population becomes too small, it loses **genetic variation** 变异, which makes it harder for the species to survive future change.

Common mistakes.

- Saying the algae use up the oxygen in eutrophication. The algae **die**; the **decomposers** feeding on them use up the oxygen by aerobic respiration, and that is why the fish die.
- Saying fertiliser poisons the fish. Fertiliser is not toxic to fish; it kills them only indirectly, through the chain of extra algae, extra decomposers and less dissolved oxygen.

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- Confusing the greenhouse effect with the hole in the ozone layer. Greenhouse gases **trap heat** leaving the Earth; the greenhouse effect itself is natural, and it is the **enhanced** effect from extra gases that causes climate change.
- Saying deforestation adds carbon dioxide only because the trees are burned. It also means fewer trees **take in** carbon dioxide by photosynthesis.
- Calling any resource that is reused "sustainable". A sustainable resource is **produced as fast as it is used**, so its stock does not fall.
- Saying captive breeding alone saves a species. The habitat must also be protected, or the animals have nowhere to be released.

Exam tips

- More food: machinery, fertilisers, insecticides, herbicides, selective breeding. Monocultures and intensive farming each have advantages and disadvantages.
- Deforestation: less biodiversity, extinction, soil loss, flooding, more carbon dioxide.
- Eutrophication (Supplement): fertiliser → more producers → more decomposers → less dissolved oxygen → organisms die.
- Greenhouse gases (carbon dioxide, methane) → enhanced greenhouse effect → climate change.
- Conservation: sustainable use, protected areas, quotas, captive breeding and seed banks. Small populations lose genetic variation.

Biotechnology and genetic modification

IGCSE Biology

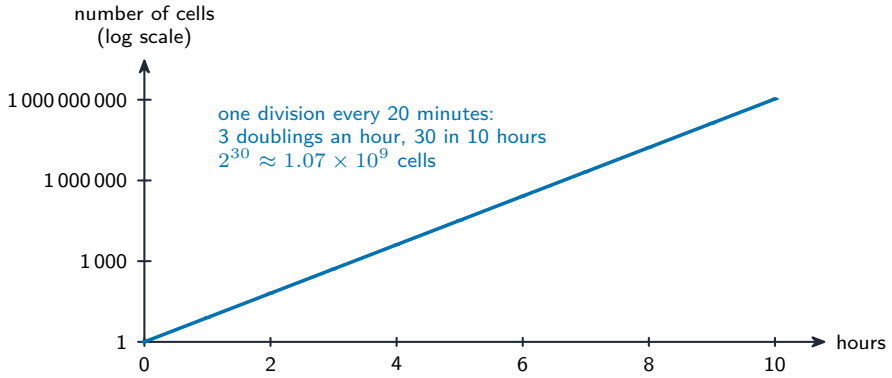
Why bacteria are useful

Biotechnology 生物技术 uses living things (or their **enzymes** 酶) to make useful products. **Bacteria** 细菌 are especially useful because:

- they reproduce very fast (a high **rate** 速率 of reproduction).
- they can make complex **molecules** 分子.
- **(Supplement)** there are few **ethical** 伦理 concerns about growing them, and they contain **plasmids** 质粒 (small DNA rings that are easy to work with).

(Supplement) Discussing why bacteria are used. A "discuss" answer explains each reason:

- **Rapid reproduction.** A bacterium can divide every 20 minutes or so in good conditions, so one modified cell quickly becomes billions, and a large amount of product is made in a short time.
- **Complex molecules.** Bacteria make proteins (such as enzymes and, once modified, insulin) using the same genetic code as humans, so they can read a human gene and make the human protein.
- **Few ethical concerns.** Bacteria have no nervous system and cannot feel pain, so most people do not object to growing them in tanks or changing their genes, unlike changing animals.
- **Plasmids.** A plasmid is a small separate ring of DNA. It is easy to cut open, insert a gene into and put back into a bacterium, and it is copied every time the bacterium divides.



Three doublings an hour turn one cell into about a billion in 10 hours.

Biotechnology in action

Yeast: biofuels and bread

Yeast 酵母 carries out **anaerobic respiration** 无氧呼吸 (without oxygen), making **ethanol** 乙醇 and carbon dioxide.

- the ethanol can be used as a **biofuel** 生物燃料.
- in bread-making, the carbon dioxide makes the dough rise.

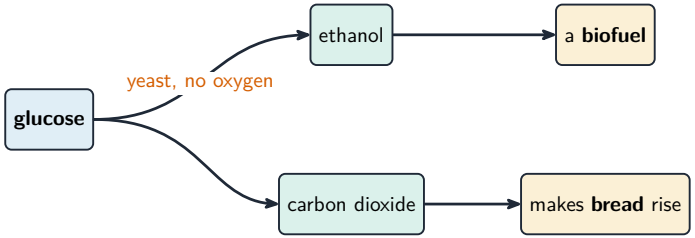


Fermentation tanks: microbes are grown at scale in biotechnology.

Biofuel. Crops rich in sugar or starch (such as sugar cane or maize) are broken down to glucose. Yeast ferments the glucose in large tanks with **no oxygen**, so it respires anaerobically and makes ethanol. The ethanol is separated (by distillation) and burned in car engines, alone or mixed with petrol. It is a **renewable** 可再生的 fuel, because the crops can be grown again each year.

Bread. Yeast, sugar and water are mixed into flour to make a dough, which is left in a **warm** place. The yeast's enzymes work best when warm, so it respires quickly. The air in the dough is soon used up and the yeast respires **anaerobically**. Its carbon dioxide forms bubbles trapped in the dough, so the dough **rises**. In the oven the heat kills the yeast, the bubbles expand and set to give a light texture, and the ethanol evaporates.

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Yeast makes ethanol (a biofuel) and carbon dioxide (which makes bread rise)

Enzymes in industry

- **pectinase** 果胶酶 breaks down pectin in plant cell walls to release more juice from fruit, giving more and clearer juice.
- biological **washing powders** 洗衣粉 contain enzymes (such as proteases and lipases) that digest stains, even at lower temperatures.
- **(Supplement) lactase** 乳糖酶 breaks down **lactose** 乳糖 to make lactose-free milk, for people who cannot digest lactose.

Pectinase in detail. Pectin 果胶 is a substance that holds plant cell walls together. Pectinase breaks it down, so the cell walls break apart more easily and the cells release more juice. Pectin also makes juice cloudy, so breaking it down gives **clearer** juice.

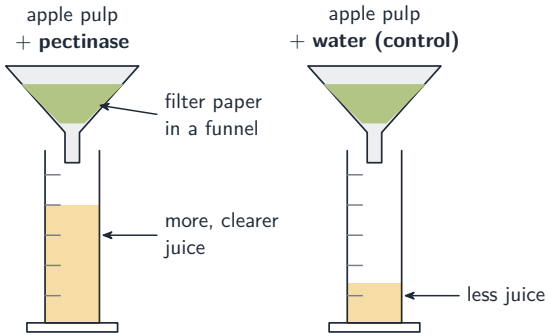
Investigating pectinase. Put equal masses of chopped apple pulp into two beakers. Add pectinase to one, and the same volume of water to the other (the control). Leave both in a water bath at the same temperature (about 40 °C) for the same time, then pour each through filter paper in a funnel into a measuring cylinder. Read the volume of juice collected after a fixed time, for example 10 minutes. You can repeat it at different temperatures, or with different volumes of enzyme, to find the best conditions.

Biological washing powders. Stains such as blood, egg and grass contain proteins, and greasy stains contain fats. **Proteases** 蛋白酶 digest the proteins into amino acids and **lipases** 脂肪酶 digest fats into fatty acids and glycerol. These small, soluble molecules wash away in the water. Because the enzymes work at about 30–40 °C, clothes can be washed at lower temperatures, which saves energy and protects delicate fabrics. At very high temperatures the enzymes are denatured and the powder works no better than a non-biological one.

Investigating washing powders. Stain identical squares of cloth with the same volume of egg or blood. Wash each in the same volume of water with biological powder, non-biological powder, or water alone (the control), at the same temperature and for the same time, then compare how much stain is left (or time how long each stain takes to disappear). Repeat at different temperatures to show that the biological powder works best at a moderate temperature.

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(Supplement) Lactose-free milk. Many adults stop making the enzyme lactase. Undigested lactose then passes to the large intestine, where bacteria ferment it and cause pain and wind. To make lactose-free milk, lactase (often from yeast) is added to the milk, or the milk is passed over lactase fixed onto beads. The lactase breaks lactose down into **glucose** and **galactose** 半乳糖, which are absorbed easily. The milk also tastes a little sweeter.



In the same time, pulp treated with pectinase gives more juice than the water control

pectinase	→	more fruit juice
protease + lipase	→	wash out stains
lactase	→	lactose-free milk

Enzymes used in industry

Fermenters (Supplement)

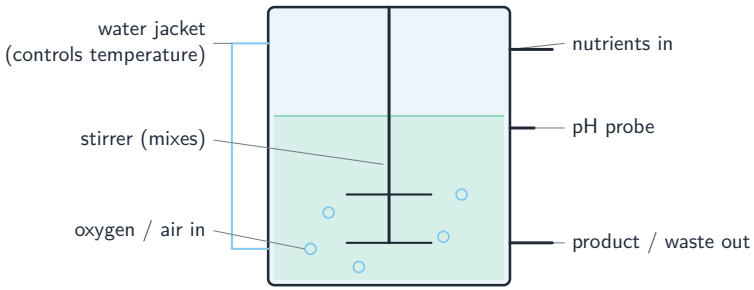
A **fermenter** 发酵罐 is a large tank used to grow bacteria or fungi to make useful products, such as **insulin** 胰岛素, **penicillin** 青霉素 and **mycoprotein** 真菌蛋白. The conditions inside must be carefully controlled: **temperature** 温度, pH, **oxygen** 氧气, the supply of nutrients, and the removal of waste products.

Condition	How it is controlled	Why it matters
temperature	a water jacket around the tank carries cold water; a probe checks it	the microorganisms' respiration releases heat; too hot and their enzymes are denatured, too cold and they grow slowly
pH	a pH probe; acid or alkali is added	each enzyme has an optimum pH; waste products such as carbon dioxide make the mixture acidic
oxygen	sterile air is bubbled in	for aerobic respiration, which releases more energy for growth (most fermenters)
nutrients	glucose (or another sugar) and a source of nitrogen, such as ammonium salts, are added	glucose for respiration; nitrogen to make proteins
mixing	a motor turns paddles (a stirrer)	spreads microorganisms, nutrients, oxygen and heat evenly
waste and **contamination** 污染	gases leave through an outlet; the tank and everything added is **sterilised** 消毒 first	unwanted microorganisms would compete for nutrients or spoil the product

The products come from different microorganisms:

- **insulin** – from genetically modified bacteria carrying the human insulin gene.
- **penicillin** – an antibiotic made by the fungus *Penicillium*. It makes most of its penicillin once it has stopped growing fast, when the nutrients start to run low.
- **mycoprotein** – the fungus *Fusarium* is grown on glucose; its threads (hyphae) are harvested, dried and sold as a high-protein, low-fat meat substitute.

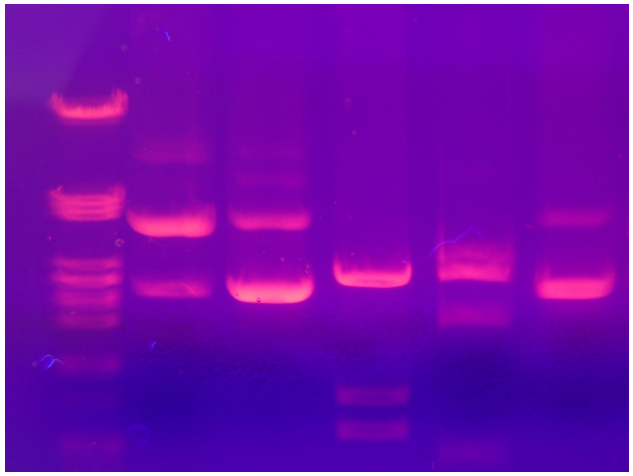
Worked example. Explain why the temperature inside a fermenter rises, and why it must be kept constant. The microorganisms respire, and respiration releases energy, some of it as heat, so the mixture warms up. Their enzymes work fastest at an optimum temperature; if it gets too hot, the enzymes are denatured and the microorganisms die, so less product is made. Cold water in the jacket removes the heat.



A fermenter grows microbes with the temperature, pH, oxygen and nutrients all controlled

Genetic modification

Genetic modification 基因改造 means changing an organism's **genetic material** 遗传物质 by removing, changing or inserting individual **genes** 基因.



DNA fragments separated by gel electrophoresis appear as glowing bands

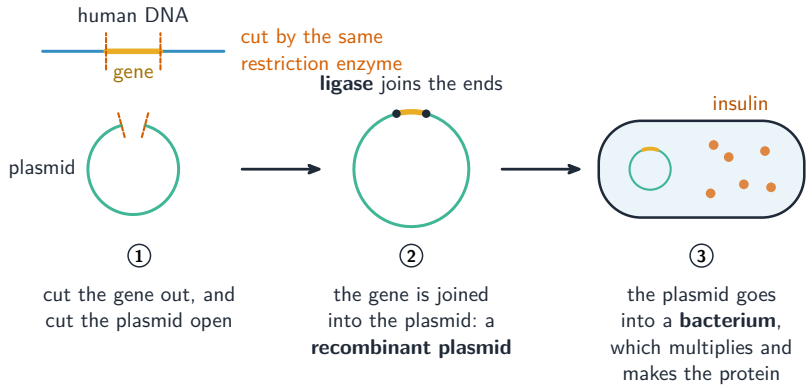
■ Making a human protein in bacteria (Supplement)

For example, to make a human **protein** 蛋白质 (such as insulin) in bacteria:

1. cut the human gene out of human DNA using **restriction enzymes** 限制酶, which leave **sticky ends** 黏性末端.
2. cut open a bacterial plasmid with the **same** restriction enzymes, giving matching sticky ends.

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3. join the human gene into the plasmid using DNA **ligase** 连接酶, making a **recombinant plasmid** 重组质粒.
4. put the recombinant plasmid into a bacterium.
5. the bacteria multiply and **express** 表达 the human gene, making the human protein.



A human gene is joined into a plasmid, then bacteria make the human protein

Worked example. Put the steps of making human insulin in bacteria in order. **Restriction enzymes** cut the human insulin gene out of human DNA, leaving sticky ends. The **same** restriction enzyme cuts open a bacterial plasmid, so its sticky ends match the gene's. **Ligase** joins the gene into the plasmid, making a recombinant plasmid. The plasmid is put into a bacterium, and the bacteria multiply in a fermenter, each one expressing the gene and making human insulin. Two marks hang on precision: the **same** enzyme must cut both the gene and the plasmid, which is what makes the sticky ends fit; and ligase **joins** - it does not cut.

■ Examples of genetic modification

Genetic modification is used to:

- put human genes into bacteria to make human proteins (such as insulin).
- put genes into **crop plants** 农作物 to give **resistance** 抗性 to **herbicides** 除草剂.
- put genes into crops to give resistance to insect pests.
- put genes into crops to improve their food value.

Examples you can name: **soya** that resists a herbicide, so farmers can spray the field to kill weeds without killing the crop; **maize** with a gene from a bacterium so that it makes a poison which kills insect pests feeding on it; and **"golden rice"**, which makes a substance the body turns into vitamin A, to prevent blindness in countries where rice is the main food.

(Supplement) Advantages and disadvantages of GM crops.

Advantages	Disadvantages
higher yields: less crop lost to weeds or pests	the inserted gene could spread to wild plants by pollen, making "superweeds" resistant to herbicide
less insecticide sprayed, so fewer harmless insects are killed	insects that are not pests may be harmed by the poison
better nutrition, e.g. golden rice with vitamin A	pests may evolve resistance to the crop's poison
crops can be grown in poorer conditions (e.g. drought)	GM seed can be costly, and farmers may have to buy new seed every year
less land needed to grow the same amount of food	some people worry about effects on health, or think it is wrong to change organisms

In a "discuss" question give points on **both** sides, each with a reason, and finish with a short conclusion if asked.

Common mistakes.

- Saying the alcohol makes bread rise. The **carbon dioxide** from yeast makes the dough rise; the small amount of ethanol evaporates when the bread is baked.
- Saying yeast makes ethanol by aerobic respiration. Ethanol comes from **anaerobic** respiration; with plenty of oxygen yeast makes carbon dioxide and water instead.
- Saying the enzymes in washing powder "kill" stains. Enzymes **digest** the large stain molecules (proteins, fats) into small soluble ones that wash away.
- Using two different restriction enzymes in genetic modification. The gene and the plasmid are cut with the **same** restriction enzyme, so their sticky ends match; DNA ligase then joins them.
- Saying the bacteria make insulin because they are "told to". The bacteria **express** the human gene: they read it like their own genes and make the human protein.
- Forgetting why a fermenter is cooled. The microorganisms' respiration releases heat; without cooling the temperature rises and their **enzymes** denature.

Exam tips

- Bacteria are used because they reproduce fast, make complex molecules, and contain plasmids.
- Yeast (anaerobic respiration) → ethanol (biofuel) and carbon dioxide (bread). Enzymes: pectinase (fruit juice), proteases and lipases (washing powders), lactase (lactose-free milk).

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- Fermenters make insulin, penicillin and mycoprotein; control temperature, pH, oxygen, nutrients and waste.
- Genetic modification: cut a gene with restriction enzymes (sticky ends) → join it into a plasmid with ligase (a recombinant plasmid) → put into bacteria → express the gene to make the protein.
- GM crops can resist herbicides or insect pests, or have better nutrition.
- For each fermenter condition, say **how** it is controlled and **why**: heat from respiration, enzymes denature, oxygen for aerobic respiration, nutrients for growth, sterility against contamination.
- In an enzyme investigation, the control is the same mixture with water instead of the enzyme (or with boiled enzyme).
- Lactase: lactose → glucose + galactose.

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