Course Companion

A-Level Biology

Every topic handout in one volume
全部专题讲义合集

exercises.lol

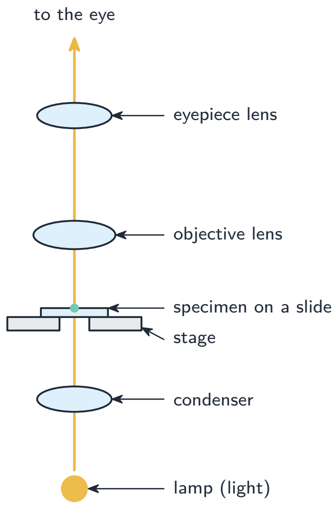
Contents 目录

Cell structure

A-Level Biology

How we study cells

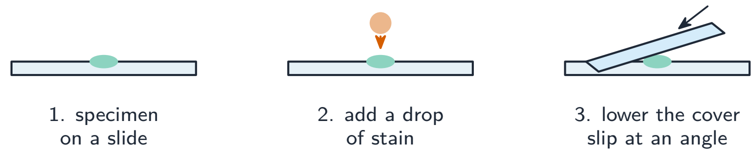
Cells 细胞 are very small, so you cannot see them with your eyes alone. You use a **microscope** 显微镜 to make a bigger picture of them. The first kind you meet is the **light microscope** 光学显微镜. It shines light through a thin **specimen** 标本 (the material you look at) and uses glass lenses to enlarge the view.



A light microscope: light passes up through the specimen, then two lenses (the objective and the eyepiece) magnify it

Making a slide and drawing what you see

To look at living material, you make a **temporary preparation** 临时装片. You put a small, thin piece of material on a glass **slide** 载玻片, add a drop of **stain** 染色剂 (a coloured liquid that makes parts easier to see), then lower a thin **cover slip** 盖玻片 on top to flatten it and keep out air.



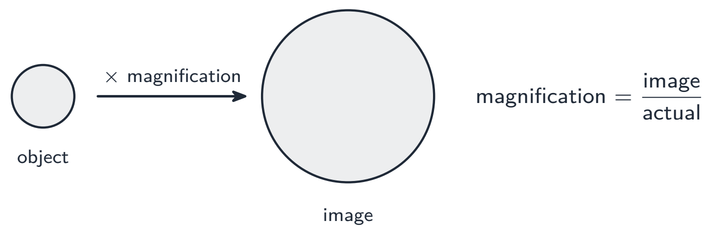
Making a temporary wet mount — lower the cover slip at an angle so no air bubbles are trapped

When you draw cells from a slide or a photograph, follow simple rules:

- use a sharp pencil and clear, single lines (no shading).
- draw only what you can really see, with the parts in the correct sizes.
- label the parts with straight lines that do not cross.

Magnification and actual size

Magnification 放大倍数 tells you how many times bigger the image is than the real object. It has no unit. You find it with one equation:



$$\textit{Magnification} = \textit{image size} \div \textit{actual size}$$

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

You can rearrange this to find any one value from the other two:

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

The top and the bottom of the fraction **must use the same unit**. Cells are tiny, so you work in small units:

- 1 mm = 1000 micrometre 微米 (µm)
- 1 µm = 1000 nanometre 纳米 (nm)
- so 1 mm = 1 000 000 nm.

Worked example. In a photomicrograph at magnification 5000, a **chloroplast** 叶绿体 measures 25 mm across. Its actual size is

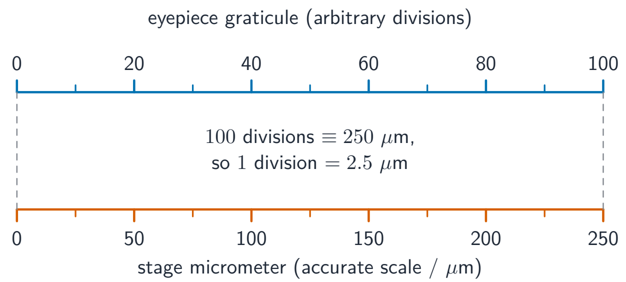
$$\frac{25\text{ mm}}{5000} = 0.005\text{ mm} = 5\text{ µm}.$$

The same equation works for drawings, photomicrographs 显微照片 (photos taken through a light microscope) and **electron micrographs** 电子显微照片 (the most detailed photos, explained below). Always convert to the same unit first, then divide.

Eyepiece graticule and stage micrometer

To measure a real cell under the microscope, you use an **eyepiece graticule** 目镜测微尺 — a tiny scale inside the eyepiece. Its divisions have no fixed size, so first you must **calibrate** 校准 them (work out what one division is worth).

You calibrate using a **stage micrometer** 载物台测微尺 — a special slide with an accurate scale on it (often 1 mm split into 100 parts, so each part is 10 µm). You line up the two scales, count how many graticule divisions fit a known length, and divide. Once calibrated, you can swap in your specimen and measure it with the graticule.



Calibrate the graticule by lining it up with the stage micrometer's known scale

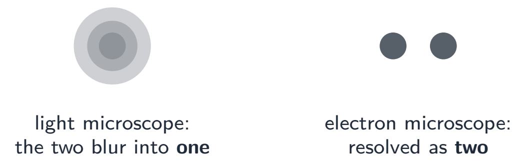
Resolution and magnification

These two words are easy to mix up. The examiner gives marks for the difference.

- **Magnification** is how many times bigger the image is than the object.
- **Resolution** 分辨率 is the smallest distance between two points that still lets you see them as **two** separate points.

Making an image bigger does not always show more detail. Past a certain point you just get a bigger, blurry image. Resolution sets the real limit on detail.

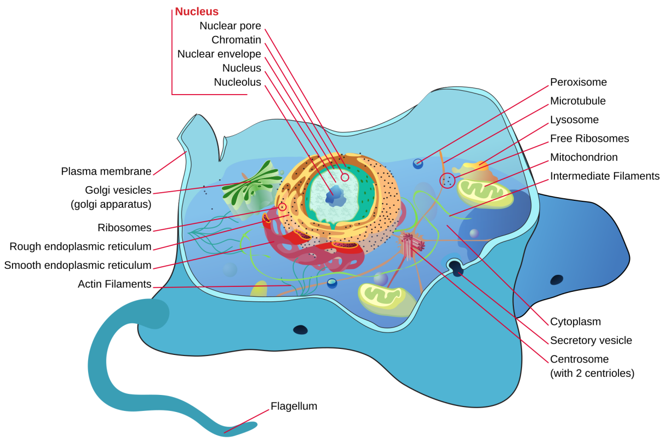
A light microscope has lower resolution because light has a fairly long **wavelength** 波长. An **electron microscope** 电子显微镜 uses beams of **electrons** 电子 instead of light. Electrons have a much shorter wavelength, so the resolution is far higher and you can see very small structures inside the cell. There are two kinds: **scanning** 扫描 (shows the surface in 3D) and **transmission** 透射 (passes electrons through a thin slice to show inside detail).



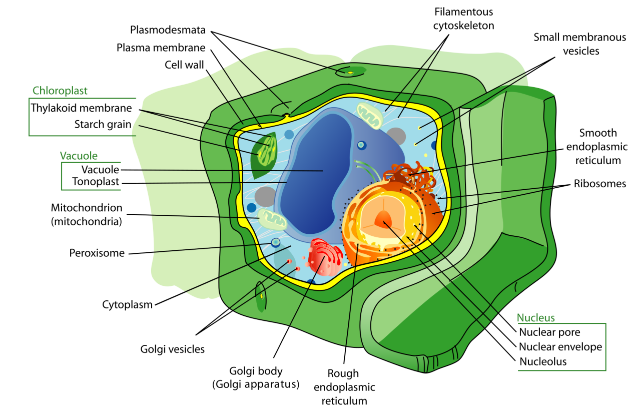
Resolution: a light microscope blurs two very close points into one; an electron microscope, with its shorter wavelength, resolves them as two

Eukaryotic cells and their organelles

Plant and animal cells are **eukaryotic cells** 真核细胞: their DNA is kept inside a **nucleus** 细胞核. Inside the cell are many small parts called **organelles** 细胞器, each with its own job. The jelly-like fluid around them is the **cytoplasm** 细胞质.



A generalised animal cell and its organelles



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

In a photomicrograph or electron micrograph you identify organelles by their shape, size and position; in a drawing you show their outlines and label them.

Organelle	Structure	Function
cell surface membrane 细胞膜	thin layer around the cell	controls what enters and leaves the cell
nucleus	large, surrounded by a **nuclear envelope** 核膜 (a double membrane with holes); contains a **nucleolus** 核仁	holds the DNA; controls the cell; the nucleolus makes ribosomes
rough endoplasmic reticulum 粗面内质网 (rough ER)	sheets of membrane with ribosomes on the surface	makes and transports **proteins** 蛋白质 (for example **antibodies** 抗体)
smooth endoplasmic reticulum 滑面内质网 (smooth ER)	sheets of membrane, no ribosomes	makes **lipids** 脂质
Golgi body 高尔基体	stack of flat membrane sacs	changes and packs proteins and lipids into **vesicles** 囊泡 for **secretion** 分泌
mitochondria 线粒体	oval, with a folded inner membrane; has small circular DNA	site of **respiration** 呼吸作用 — releases energy 能量 as ATP
ribosomes 核糖体	very small; 80S in the cytoplasm, 70S in chloroplasts and mitochondria	join **amino acids** 氨基酸 to **synthesise** 合成 proteins
lysosomes 溶酶体	small sacs of **enzymes** 酶	break down old organelles and waste
centrioles 中心粒 and **microtubules** 微管	small tubes made of protein	help move chromosomes and form the cell's "skeleton"
cilia 纤毛	tiny hairs on the cell surface that beat	move fluid or move the cell
microvilli 微绒毛	tiny folds of the cell surface membrane	increase surface area for **absorption** 吸收
chloroplasts (plants)	green, with stacked membranes; has small circular DNA	site of **photosynthesis** 光合作用
cell wall 细胞壁 (plants)	strong outer layer of **cellulose** 纤维素	supports and protects the cell; stops it bursting
plasmodesmata 胞间连丝 (plants)	tiny channels through the cell walls	link the cytoplasm of neighbouring cells
large permanent **vacuole** 液泡 (plants)	big sac of watery fluid, with a membrane called the **tonoplast** 液泡膜	stores water and keeps the cell firm

Cells use **ATP** made in respiration as their energy supply for every job that needs energy, such as making proteins, moving things and dividing.

Comparing plant and animal cells

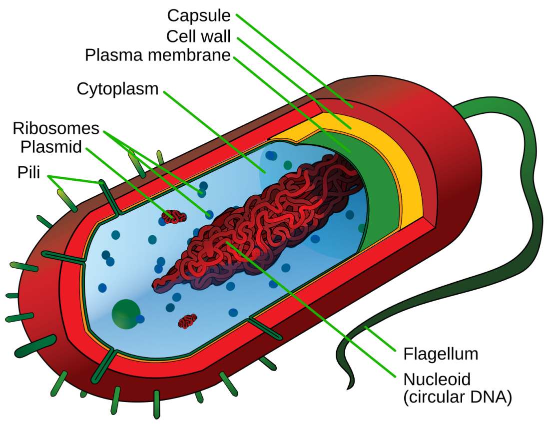
Feature	Plant cell	Animal cell
cell wall	present (cellulose)	absent
chloroplasts	present	absent
large permanent vacuole	present	absent (only small, temporary ones)
centrioles	absent in most	present
shape	fixed and regular	rounder and more flexible

Both have a cell surface membrane, cytoplasm, a nucleus, mitochondria, ribosomes, ER and a Golgi body.

Prokaryotic cells (bacteria)

A **prokaryotic cell** 原核细胞, such as a **bacterium** 细菌, is much smaller and simpler than a eukaryotic cell. Its key features are:

- **unicellular** 单细胞 — it is a single cell.
- generally 1–5 μm across.
- a cell wall made of **peptidoglycan** 肽聚糖 (not cellulose).
- circular DNA lying free in the cytoplasm — there is **no nucleus**.
- 70S ribosomes (smaller than the 80S ones in the cytoplasm of eukaryotes).
- **no organelles surrounded by a double membrane** — so no nucleus, no mitochondria and no chloroplasts.



A prokaryotic cell: the circular DNA (nucleoid) lies free, with no nucleus and no double-membrane organelles

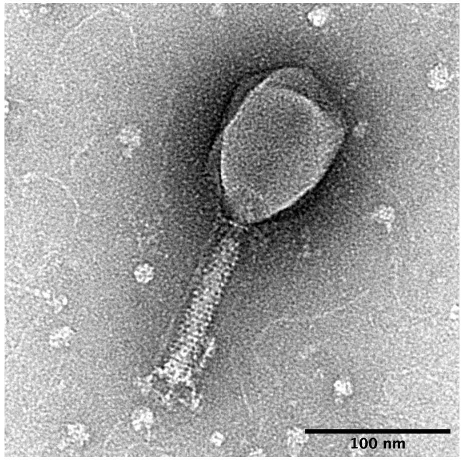
Comparing prokaryotic and eukaryotic cells

Feature	Prokaryotic cell	Eukaryotic cell
size	about 1–5 μm	about 10–100 μm
DNA	circular, free in cytoplasm	linear, inside a nucleus
nucleus	none	present
double-membrane organelles	none	mitochondria (and chloroplasts in plants)
ribosomes	70S	80S (with 70S inside mitochondria and chloroplasts)
cell wall	peptidoglycan	cellulose (plants) or none (animals)

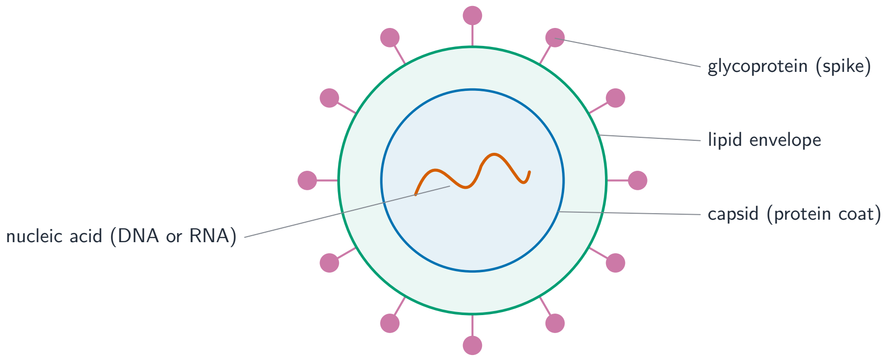
Viruses

All **viruses** 病毒 are **non-cellular** 非细胞 — they are not made of cells at all. Each virus is built from just two or three parts:

- a core of **nucleic acid** 核酸, which is **either DNA or RNA** (never both).
- a protein coat around the core called a **capsid** 衣壳.
- in some viruses, an outer **envelope** 包膜 made of **phospholipids** 磷脂.



A real virus, magnified hugely. The rounded head is the protein capsid wrapped around the nucleic acid core; the tail injects that nucleic acid into a bacterium. Note the scale bar — the whole virus is about 100 nm, far smaller than any cell



A generalised virus: nucleic acid inside a protein capsid, with a lipid envelope in some viruses

A virus has no cytoplasm, no organelles and no ribosomes. It cannot respire or make its own proteins. It can only copy itself inside a living **host** 宿主 cell, so it sits at the edge of what we call “living”.

Exam tips

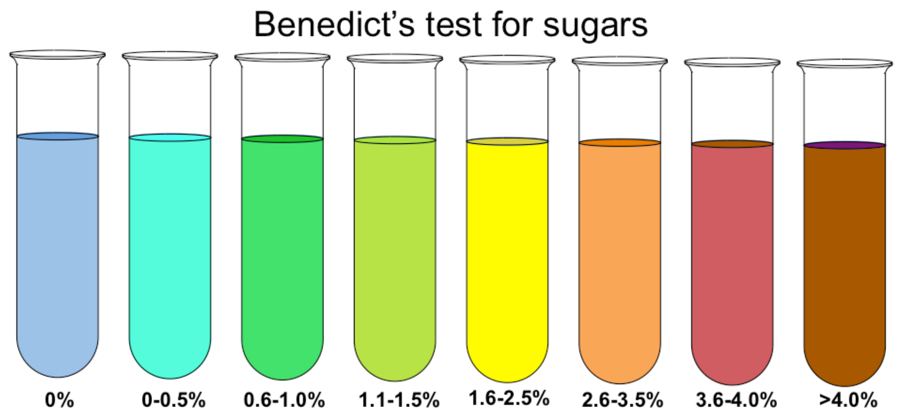
- Magnification = image size ÷ actual size — **convert units first** (mm ↔ μm ↔ nm), then rearrange for whichever is unknown.
- Distinguish **magnification** (how many times larger) from **resolution** (smallest distance still seen as two points); electron microscopes resolve more because electrons have a shorter wavelength.
- Give each organelle a **structure + function** pair (e.g. mitochondrion: folded inner membrane → aerobic respiration).
- State the **prokaryote vs eukaryote** differences exactly: no nucleus, smaller (70S) ribosomes, no membrane-bound organelles, circular DNA.
- Viruses are **non-living** — describe them only by capsid, genetic material and (sometimes) an envelope.

Biological molecules

A-Level Biology

Testing for biological molecules

Living things are built from four main kinds of large **molecule** 分子: **carbohydrates** 碳水化合物, **lipids** 脂质, **proteins** 蛋白质 and **nucleic acids** 核酸. You can use simple chemical tests to find out which kinds are present in a sample.



Benedict’s test: blue turns green, then orange, then brick-red as more reducing sugar is present

Test	What it finds	Method	Positive result
Benedict’s test	**reducing sugar** 还原糖	add Benedict’s solution and heat in a water bath	blue changes to green, yellow, orange, then brick-red **precipitate** 沉淀
iodine test	**starch** 淀粉	add orange-brown **iodine** 碘 solution	colour changes to blue-black
emulsion test	**lipid**	mix sample with ethanol, then pour into water	a white, cloudy **emulsion** 乳浊液 forms
biuret 双缩脲 test	**protein**	add biuret solution at room temperature	blue changes to purple

Semi-quantitative Benedict’s test

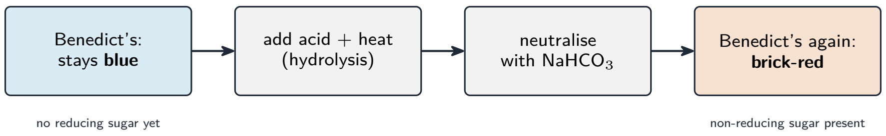
The normal Benedict’s test only tells you “yes or no”. A **semi-quantitative** 半定量 test gives a rough amount. First you **standardise** 标准化 the test: you run it on solutions of known **concentration** 浓度 and record the result for each. Then you can estimate an unknown by either:

- the **time to the first colour change** (more sugar changes colour faster), or
- comparing the final colour to your set of colour standards.

Testing for non-reducing sugars

Some sugars, such as sucrose, are **non-reducing sugar** 非还原糖: they give a negative Benedict's test. To detect them:

1. Do a normal Benedict's test first. It stays blue (no reducing sugar).
2. Take a fresh sample and add dilute **hydrochloric acid** 盐酸, then heat. This **acid hydrolysis** breaks the sugar into smaller reducing sugars.
3. Cool, then **neutralise** 中和 the acid with sodium hydrogencarbonate.
4. Now do the Benedict's test again. A brick-red colour shows a non-reducing sugar was present.



Testing for a non-reducing sugar: hydrolyse it with acid first, then the second Benedict's test turns red

Worked example. A solution gives a **negative** Benedict's test. It is then boiled with dilute hydrochloric acid, neutralised with sodium hydrogencarbonate, and re-tested with Benedict's - now it turns brick-red. What was present, and why is each step needed? The first negative result rules out a **reducing sugar**. Boiling with acid **hydrolyses** the glycosidic bond, splitting a non-reducing sugar such as **sucrose** into its reducing monosaccharides. The neutralising step is essential because Benedict's **only works in alkaline conditions** - skip it and the test fails even when sugar is present. The positive re-test therefore shows a **non-reducing sugar** was there all along. Quote the **first, negative** test as part of the answer: without it, the final red colour cannot tell a non-reducing sugar from a reducing one.

Carbohydrates

Monomers, polymers and macromolecules

- a **monomer** 单体 is a small molecule that is a single unit.
- a **polymer** 聚合物 is a long molecule made of many monomers joined together.
- a **macromolecule** 大分子 is any very large molecule.

Sugars come in three sizes:

- a **monosaccharide** 单糖 is a single sugar unit, such as **glucose** 葡萄糖 and fructose.
- a **disaccharide** 二糖 is two units joined, such as maltose and sucrose.
- a **polysaccharide** 多糖 is many units joined into a polymer.

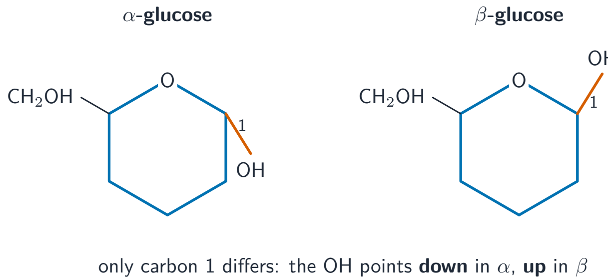
Glucose, **fructose** 果糖 and **maltose** 麦芽糖 are reducing sugars. **Sucrose** 蔗糖 is a non-reducing sugar.

Two ring forms of glucose

Glucose has six carbon atoms and forms a ring. There are two ring forms. They differ only at carbon 1:

- in α**-glucose**, the –OH group on carbon 1 points **down**, below the ring.
- in β**-glucose**, the –OH group on carbon 1 points **up**, above the ring.

This small difference decides which polysaccharide the glucose can build.

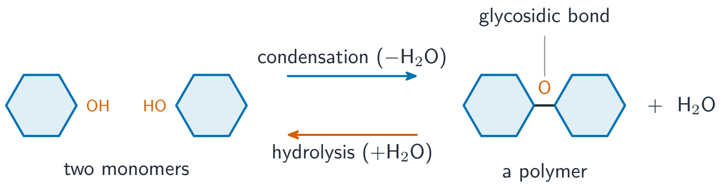


The two ring forms differ only at carbon 1: the –OH points down in α, up in β

Joining and breaking sugars

Monomers are joined by strong **covalent bonds** 共价键. When two sugars join, a **glycosidic bond** 糖苷键 forms between them. This happens by **condensation** 缩合: a molecule of water is removed each time a bond forms.

The reverse is **hydrolysis** 水解: a water molecule is added to break a glycosidic bond. This is why the non-reducing sugar test needs acid and heat — they hydrolyse sucrose into glucose and fructose.



Condensation removes water to join monomers; hydrolysis adds water to split them

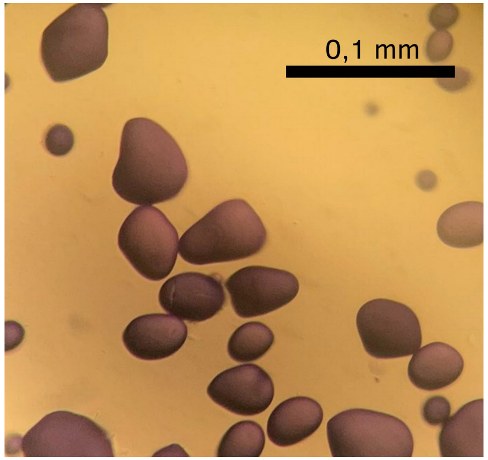
Storage polysaccharides: starch and glycogen

Starch is the energy 能量 store in plants. It is made of two polymers of α-glucose:

- **amylose** 直链淀粉 — a long, unbranched chain that coils into a spiral.
- **amylopectin** 支链淀粉 — a chain with many side branches.

Glycogen 糖原 is the energy store in animals. It is like amylopectin but has even more branches, so it can be broken down quickly when energy is needed.

These stores suit their job well: they are compact, they are **insoluble** 不溶 (so they do not leave the cell), and they do not change the **water potential** 水势 of the cell (so they do not pull water in by **osmosis** 渗透). The many branches give many ends, so glucose can be added or removed fast.



Real starch grains inside a potato, stained by iodine. Each grain is a dense, insoluble package of amylose and amylopectin — note the scale: the largest are only about 0.1 mm across

Cellulose

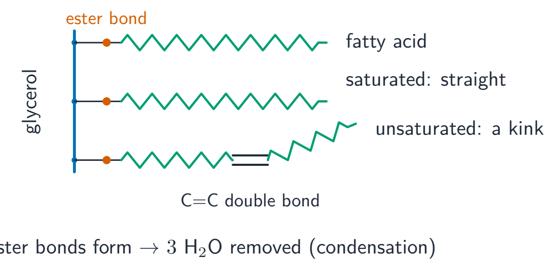
Cellulose 纤维素 is made of β-glucose. Because of the β form, every other glucose is flipped over, so the chains are long and straight. Many straight chains lie side by side and are held together by **hydrogen bonds** 氢键 into strong bundles called **microfibrils** 微纤丝. These give the plant **cell wall** 细胞壁 its strength and stop the cell bursting.

The shape fits the job: amylose coils and amylopectin/glycogen branch (for compact stores), while straight cellulose chains pack into strong fibres

Lipids

Triglycerides

A **triglyceride** 甘油三酯 is the main fat or oil. It is **non-polar** 非极性 and **hydrophobic** 疏水 (it does not mix with water). It is made from one **glycerol** 甘油 molecule joined to three **fatty acids** 脂肪酸 by **ester bonds** 酯键. Each ester bond forms by condensation, so three water molecules are removed.



One glycerol plus three fatty acid tails; a straight tail is saturated, a kinked one unsaturated

Fatty acids are of two kinds:

- **saturated** 饱和 — no carbon–carbon **double bonds** 双键; these fats are usually solid.
- **unsaturated** 不饱和 — one or more double bonds; these oils are usually liquid.

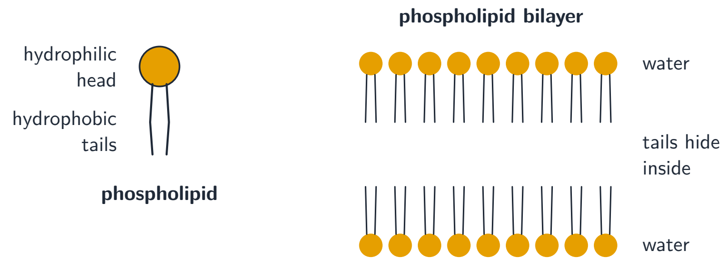
Triglycerides make a good long-term energy store: they release about twice as much energy per gram as carbohydrates, they are insoluble, and they store little extra mass because they hold no water. Under the skin they also give **insulation** 隔热 and protect the organs.

Phospholipids

A **phospholipid** 磷脂 is like a triglyceride, but one fatty acid is replaced by a **phosphate** 磷酸 group. This gives the molecule two ends with different behaviour:

- a **hydrophilic** 亲水 ("water-loving") **polar** 极性 phosphate head.
- two hydrophobic ("water-fearing") fatty acid tails.

This split personality is why phospholipids form the membranes around cells.



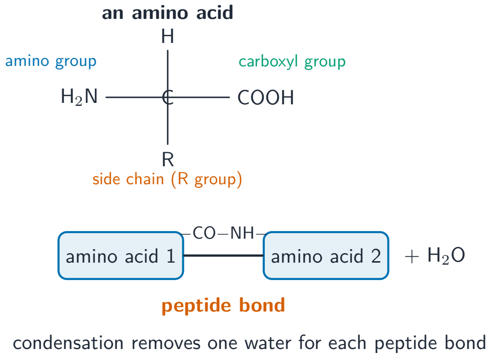
The hydrophilic heads face the water; the hydrophobic tails hide inside, forming a bilayer

Proteins

Amino acids and the peptide bond

Proteins are polymers of **amino acids** 氨基酸. Every amino acid has the same general structure around a central carbon atom: an **amino group** 氨基 ($-NH_2$), a **carboxyl group** 羧基 ($-COOH$), a hydrogen atom, and a variable **side chain** 侧链 (the R group). The R group is different in each amino acid.

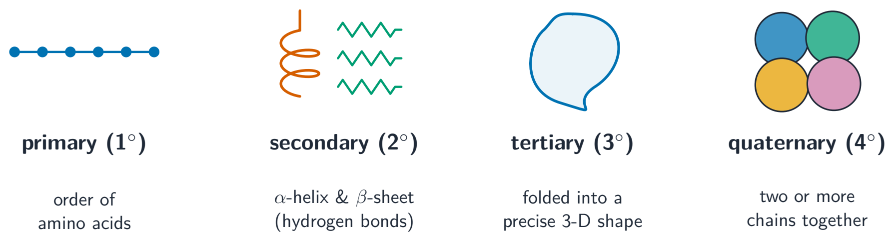
Two amino acids join by condensation. The bond formed between the amino group of one and the carboxyl group of the next is a **peptide bond** 肽键, and a water molecule is removed. Many amino acids joined this way make a **polypeptide** 多肽. Adding water (hydrolysis) breaks a peptide bond.



Every amino acid has an amino group, a carboxyl group and an R group; two join by a peptide bond

Four levels of protein structure

Level	What it means
primary structure 一级结构	the order of amino acids in the chain
secondary structure 二级结构	local shapes — the α-**helix** 螺旋 and the β-**pleated sheet** 折叠片 — held by hydrogen bonds
tertiary structure 三级结构	the whole chain folded into a precise 3-D shape
quaternary structure 四级结构	two or more polypeptide chains joined into one protein



The four levels: primary → secondary → tertiary → quaternary structure

The folded shape is held together by four kinds of interaction between R groups:

- **hydrophobic interactions** 疏水作用 (non-polar R groups cluster away from water).
- hydrogen bonding.

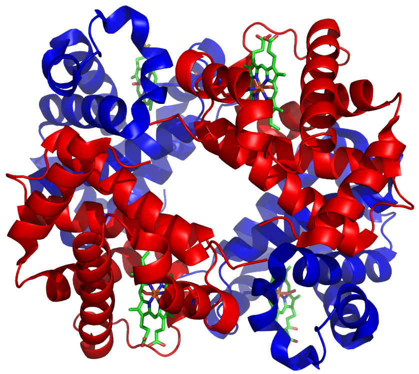
- **ionic bonds** 离子键 (between charged R groups).
- covalent bonding, including strong **disulfide bonds** 二硫键.

Globular and fibrous proteins

- **globular proteins** 球状蛋白质 fold into a rounded shape, are usually **soluble** 可溶, and do jobs in the body (for example enzymes and haemoglobin).
- **fibrous proteins** 纤维状蛋白质 form long strands, are usually insoluble, and give structure and support (for example collagen).

Haemoglobin — a globular protein

Haemoglobin 血红蛋白 carries **oxygen** 氧气 in red blood cells. It has a quaternary structure made of four polypeptide chains: two alpha (α-globin) chains and two beta (β-globin) chains. Each chain holds a **haem group** 血红素. At the centre of each haem group is an **iron** 铁 atom, and this is where one oxygen molecule binds. Four chains mean one haemoglobin molecule can carry four oxygen molecules.



A real haemoglobin molecule, worked out from X-ray data. Count them: two alpha chains (red), two beta chains (blue), and one green haem group held in each — so four oxygen molecules in total

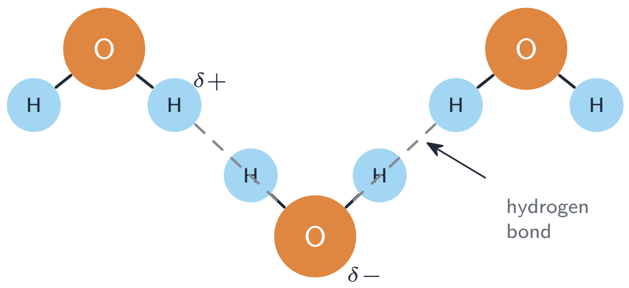
Collagen — a fibrous protein

Collagen 胶原蛋白 gives strength to skin, **tendons** 肌腱, bone and blood vessel walls. One collagen molecule is three polypeptide chains wound tightly around each other in a triple strand, held by hydrogen bonds. Many of these molecules lie side by side, slightly staggered, and are cross-linked into thick **fibres** 纤维. The staggered, cross-linked arrangement makes collagen very strong when pulled.

Water

Water is a small molecule, but its two O–H bonds are **polar**: the oxygen end is slightly negative and the hydrogen ends are slightly positive. So one water molecule attracts its neighbours, forming weak hydrogen bonds between them. These hydrogen bonds explain water's useful properties:

- **solvent action** — water is a good **solvent** 溶剂, so many substances dissolve in it. This lets reactions happen and lets substances be carried around the body.
- **high specific heat capacity** 比热容 — water needs a lot of energy to warm up, so its temperature stays steady. This protects living things from quick temperature changes.
- **latent heat of vaporisation** 汽化潜热 — water needs a lot of energy to **evaporate** 蒸发. So when water evaporates (for example as sweat dries), it carries away a lot of heat and cools the body.



Water is polar ($\delta-$ oxygen, $\delta+$ hydrogens), so its molecules attract each other by hydrogen bonds — the reason for all the properties above

Exam tips

- Learn each **food test** as reagent + positive result + colour change (Benedict's → brick-red; iodine → blue-black; biuret → purple; emulsion → white).
- Benedict's detects **reducing** sugars; for a non-reducing sugar you must **hydrolyse with acid first**, then re-test.
- Name the bond precisely: **glycosidic** (carbohydrates), **ester** (lipids), **peptide** (proteins) — all made by **condensation** (water removed).
- Link structure to function: cellulose (straight chains, H-bonds → strong), glycogen/starch (branched/coiled → compact store).
- For proteins, name the bond at each level: primary (peptide), secondary (hydrogen), tertiary (R-group interactions), quaternary.

Enzymes

A-Level Biology

What enzymes are

Enzymes 酶 are **globular proteins** 球状蛋白质 — a type of **protein** 蛋白质 with a rounded, soluble shape. They are biological catalysts: they **catalyse** 催化 (speed up) the chemical reactions in living things, and they are not used up, so each enzyme works again and again.

Enzymes work in two places:

- **intracellular** 细胞内 enzymes work inside the **cell** 细胞 that made them. An example is **catalase** 过氧化氢酶, which breaks down harmful hydrogen peroxide.
- **extracellular** 细胞外 enzymes are **secreted** 分泌 (sent out) to work outside the cell. An example is **amylase** 淀粉酶, which is released into the gut to **digest** 消化 **starch** 淀粉.

Yeast enzymes ferment sugar, giving off bubbles of carbon dioxide

How enzymes work

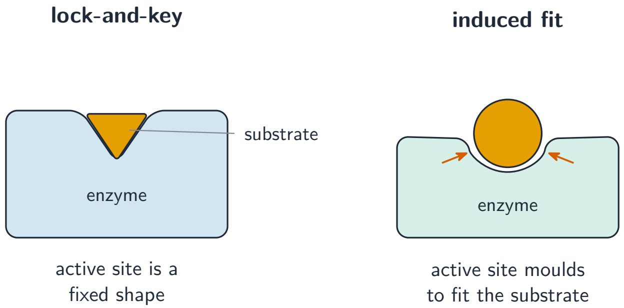
Each enzyme has a special pocket called the **active site** 活性位点. The molecule it acts on is its **substrate** 底物. The substrate fits into the active site to form an **enzyme–substrate complex** 酶底物复合物. The reaction then happens, and the products **products** 产物 leave, freeing the active site for the next substrate.

Specificity

An enzyme is **specific**: it usually works on only one substrate. This is because the shape of the active site is **complementary** 互补 to (fits) the shape of that substrate and no other. We call this **specificity** 专一性.

Two ideas explain how the substrate fits:

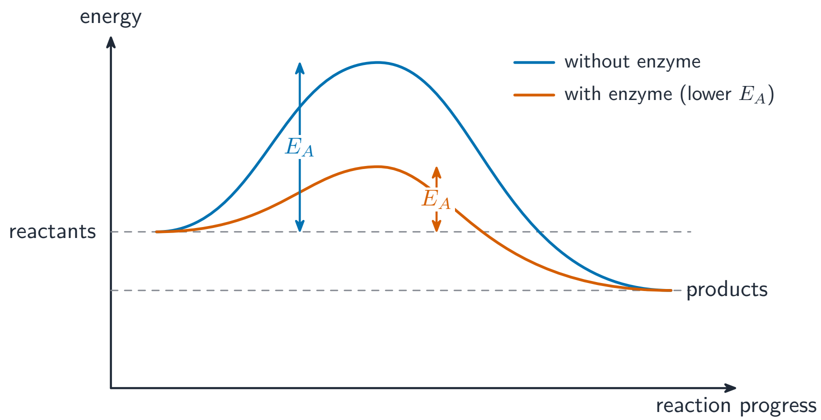
- the **lock-and-key hypothesis** 锁钥学说 — the active site is a fixed shape, and only a substrate with the matching shape fits, like a key in a lock.
- the **induced-fit hypothesis** 诱导契合学说 — the active site is not quite the right shape at first. When the substrate binds, the active site changes shape a little to wrap around it tightly. This idea fits the evidence better.



Lock-and-key: a fixed active site. Induced fit: the active site changes shape to grip the substrate

Lowering activation energy

Every reaction needs a small "push" of energy to start, called the **activation energy** 活化能. An enzyme lowers the activation energy. This lets the reaction go quickly at the cell's normal **temperature** 温度, instead of needing high heat.



The enzyme route has a lower activation energy (E_A), so more molecules can react

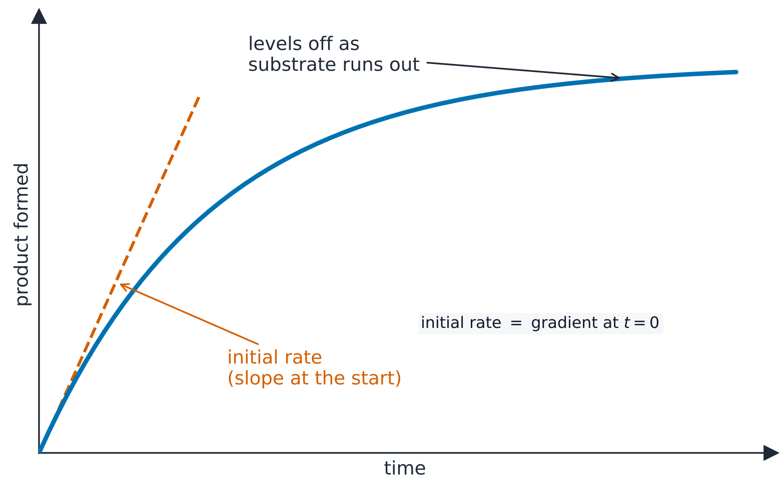
Measuring the rate of a reaction

You can follow an enzyme reaction in two ways:

- measure how fast **product** is made. With catalase, oxygen gas is a product, so you collect the gas and measure its volume over time.
- measure how fast substrate disappears. With amylase, you remove samples and use the iodine test; the blue-black colour fades as the starch is used up.

A **colorimeter** 比色计 makes this exact. It shines light through the tube and measures how much light is absorbed, so a colour change becomes a number you can plot.

The **rate of reaction** 反应速率 is steepest at the start (most substrate present), so the **initial rate** (the slope at time zero) is the fairest value to compare.



Product builds fastest at the start; the initial rate is the slope of the tangent at time zero — the fairest value to compare

Worked example. In the first 20 seconds of a catalase reaction, 16 cm^3 of oxygen is collected. Estimate the rate of reaction.

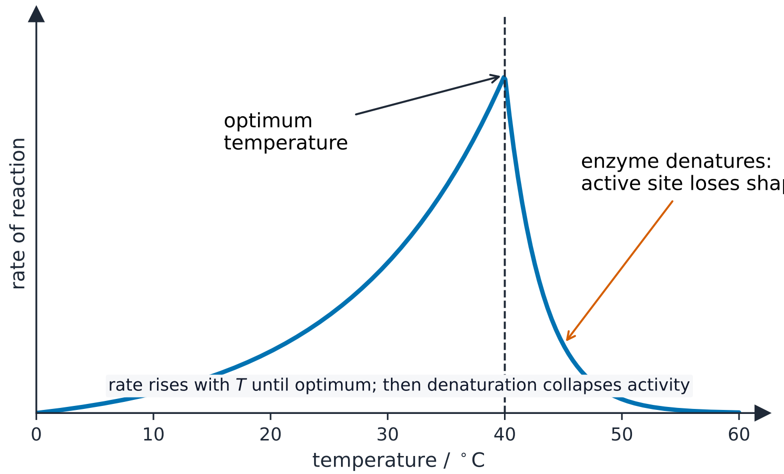
$$\text{rate} = \frac{\text{volume of product}}{\text{time}} = \frac{16}{20} = 0.8\ \text{cm}^3\,\text{s}^{-1}.$$

Because the reaction is fastest at the start, measuring over this short early interval gives a value close to the initial rate; averaging over a longer time would include the slower later stages and underestimate it.

Factors that affect enzyme activity

Temperature

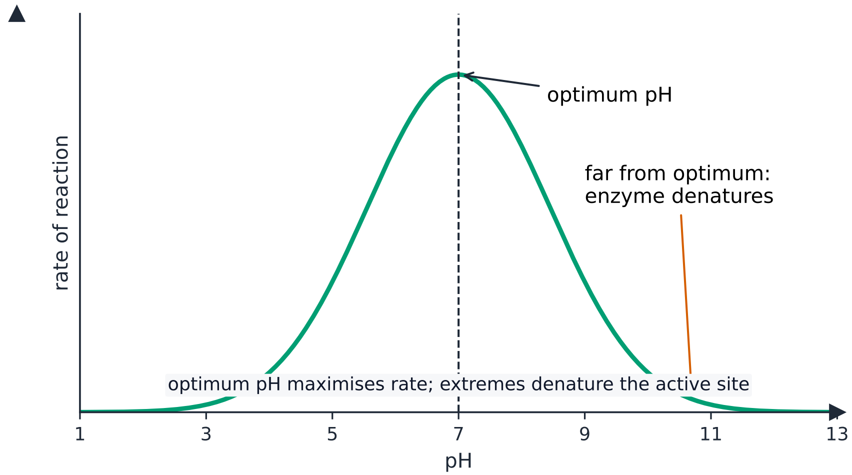
As temperature rises, molecules gain more **kinetic energy** 动能 and **collide** 碰撞 more often, so the rate rises. But above the **optimum temperature** 最适温度 the enzyme begins to **denature** 变性: the heat breaks the bonds holding its shape, so the active site changes and no longer fits the substrate. The rate then falls quickly.



Rate rises to the optimum, then falls fast as the enzyme denatures

pH

Each enzyme has an optimum pH. If the pH moves too far from it, the enzyme denatures and the rate drops. To study pH fairly, you keep it steady with a **buffer solution** 缓冲液.



The rate peaks at the optimum pH and falls away on either side

Enzyme concentration

With plenty of substrate, more enzyme means more active sites, so the rate goes up in proportion to enzyme concentration.

Substrate concentration

At first, adding more substrate speeds the reaction. But once every active site is busy, adding more makes no difference — the rate levels off at a maximum.

Inhibitor concentration

An **inhibitor** 抑制剂 is a molecule that slows an enzyme. The more inhibitor present, the lower the rate.

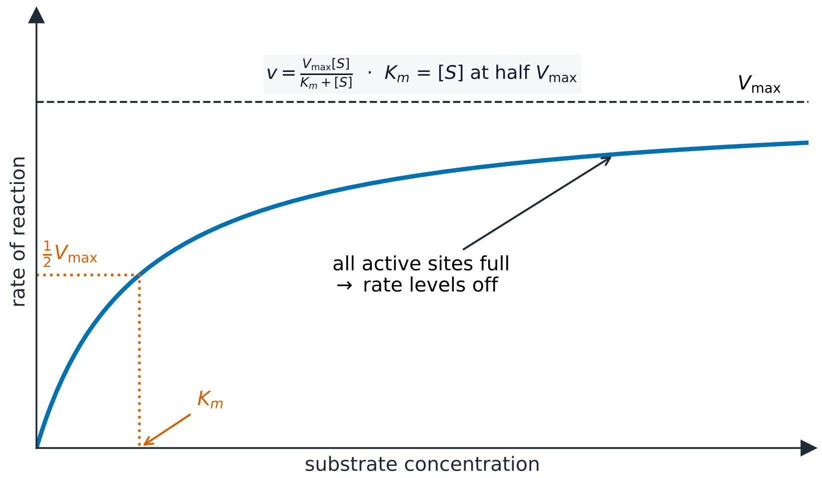
V_max and the Michaelis–Menten constant

The levelling-off rate, when all active sites are full, is the maximum rate, written $V_{\max}$.

The **Michaelis–Menten constant** 米氏常数 (K_m) is the substrate concentration that gives **half** of $V_{\max}$. It tells you about the enzyme's **affinity** 亲和力 (pulling power) for its substrate:

- a **low** K_m means the enzyme reaches half-speed at a low substrate concentration, so it has a **high** affinity.
- a **high** K_m means a **low** affinity.

So K_m lets you compare how strongly different enzymes hold their substrates.

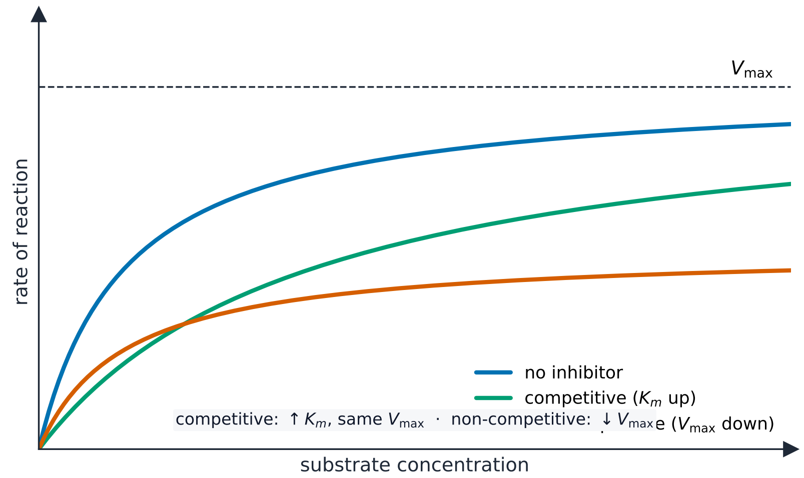


Rate climbs to V_{max} when all active sites are full; K_m is the substrate concentration giving half V_{max}

Reversible inhibitors

Some inhibitors are **reversible** 可逆: they can leave the enzyme again. There are two types.

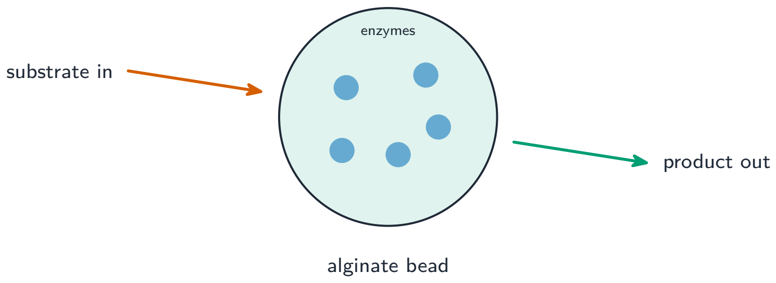
Type	Where it binds	Effect of adding more substrate	Effect on $V_{\max}$ and K_m
competitive inhibitor 竞争性抑制剂	in the active site (it has a similar shape to the substrate)	more substrate out-competes it, so its effect is reduced	$V_{\max}$ unchanged; K_m rises
non-competitive inhibitor 非竞争性抑制剂	at another site, changing the active site's shape	adding more substrate does not help	$V_{\max}$ falls; K_m unchanged



A competitive inhibitor raises K_m (more substrate overcomes it); a non-competitive one lowers V_{max}

Immobilised enzymes

An **immobilised enzyme** 固定化酶 is fixed in place — for example, trapped inside small beads of **alginate** 海藻酸盐 — instead of floating free in solution. The substrate solution flows past the beads.



The enzymes stay trapped in the bead while substrate flows in and product flows out — so the enzyme is never washed away

A free enzyme usually works a little faster, because the substrate can reach it easily. But immobilised enzymes have big practical advantages:

- the enzyme is not washed away, so it can be used again and again.
- the product is pure — it is not mixed with enzyme.
- the enzyme is more stable, so it survives changes in temperature and pH better.
- the process can run continuously, with substrate flowing in and product flowing out.

Biological washing powders contain enzymes that digest food and blood stains at low temperatures

Exam tips

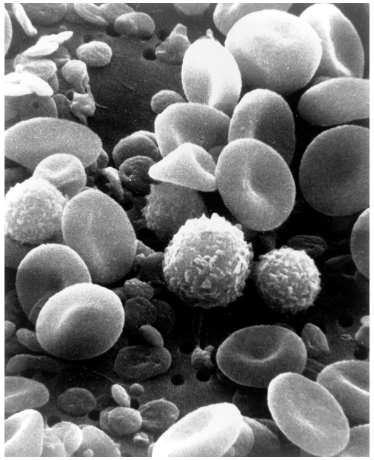
- Explain enzyme action with the **induced-fit** model (the active site moulds around the substrate) — now preferred to lock-and-key.
- Above the optimum the enzyme **denatures** (hydrogen bonds and tertiary structure break) — write “denatures”, never “dies” or “is killed”.
- Distinguish inhibitors: **competitive** binds the active site (overcome by more substrate, same V_{max}); **non-competitive** binds elsewhere (lower V_{max}).
- Compare rates using the **initial rate** (tangent at time zero) — the fairest measure, before substrate becomes limiting.

Cell membranes and transport

A-Level Biology

The cell surface membrane

Every cell is wrapped in a **cell surface membrane** 细胞膜. We describe its structure with the **fluid mosaic model** 流动镶嵌模型.



Red blood cells under a scanning electron microscope — each is wrapped in a cell surface membrane

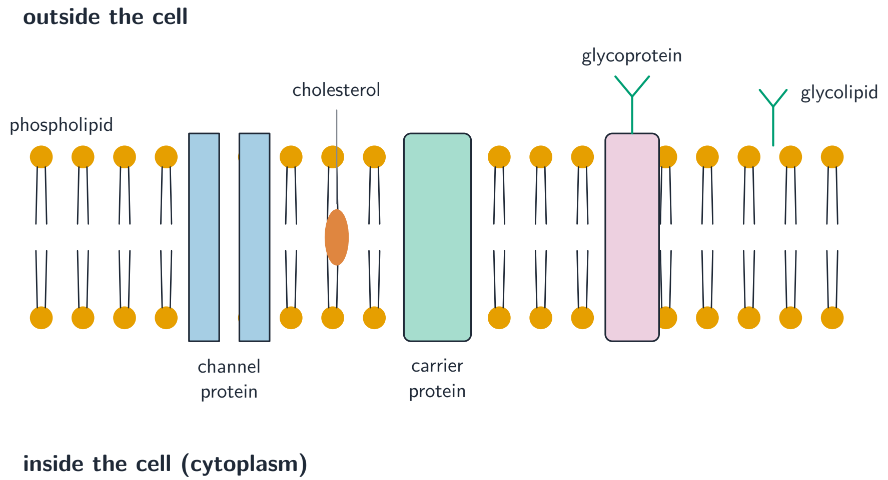
The phospholipid bilayer

The membrane is built mainly from **phospholipids** 磷脂. Each phospholipid has a **hydrophilic** 亲水 ("water-loving") head and two **hydrophobic** 疏水 ("water-fearing") tails. There is water on both sides of the membrane, so the phospholipids line up in two layers — a **bilayer** 双层 — with the heads facing the water outside and inside, and the tails hidden in the middle, away from water. This arrangement forms by itself because of those hydrophilic and hydrophobic interactions.

The model is called "fluid" because the phospholipids are not fixed: they slide past each other, so the membrane can move and bend. It is called a "mosaic" because many **proteins** 蛋白质 are dotted through it, like tiles in a picture.

What floats in the membrane

Part	Where it sits	Main roles
phospholipids	the two layers	form the basic barrier
proteins	through the membrane or on its surface	transport, support and signalling
carrier proteins 载体蛋白	span the membrane	carry specific molecules across
channel proteins 通道蛋白	span the membrane	form water-filled pores for ions to pass
cholesterol 胆固醇	between the phospholipid tails	controls **fluidity** 流动性 and adds strength
glycolipids 糖脂 and **glycoproteins** 糖蛋白	carbohydrate chains on the outer surface	cell recognition; some act as **antigens** 抗原



The fluid mosaic model: proteins, cholesterol and carbohydrate chains sit in a fluid phospholipid bilayer

So the membrane molecules together give the membrane its **stability** 稳定性, its fluidity, its **permeability** 通透性 (control over what gets through), its transport jobs, its signalling jobs, and its cell recognition.

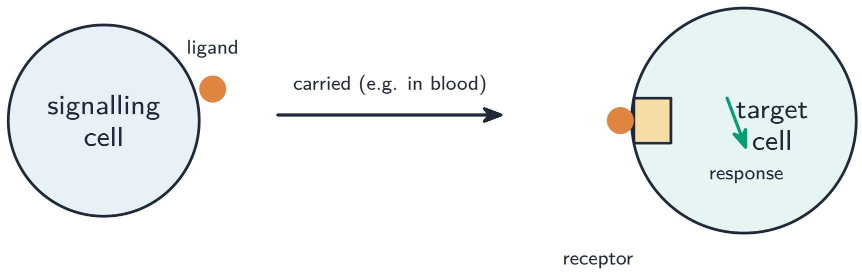
The membrane is **partially permeable** 半透膜: it lets some substances through easily but blocks others.

Cell signalling

Cells talk to each other by **cell signalling** 细胞信号传递. The main stages are:

1. a cell **secretes** a signal chemical called a **ligand** 配体 (for example a **hormone** 激素).
2. the ligand is carried (often in the blood) to a **target cell** 靶细胞.

3. the ligand binds to a specific **receptor** 受体 on the target cell's surface membrane. The shape of the receptor matches that ligand only. Binding then triggers a particular response inside the target cell.



The ligand fits one receptor shape only, so only cells with that receptor respond to the signal

Moving substances across the membrane

There are six processes. Some are **passive** 被动 (they need no energy 能量), and some are **active** (they use energy from ATP).

Simple diffusion

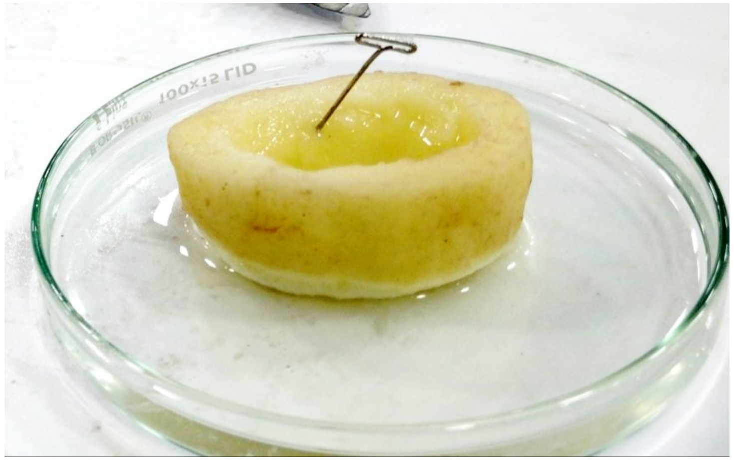
Diffusion 扩散 is the net movement of particles from where they are at a high **concentration** 浓度 to where they are at a low concentration, until they are spread evenly. **Simple diffusion** 简单扩散 is when particles pass straight through the bilayer, down the **concentration gradient** 浓度梯度. Only small or non-polar molecules can do this — such as **oxygen** 氧气 and **carbon dioxide** 二氧化碳. It is passive.

Facilitated diffusion

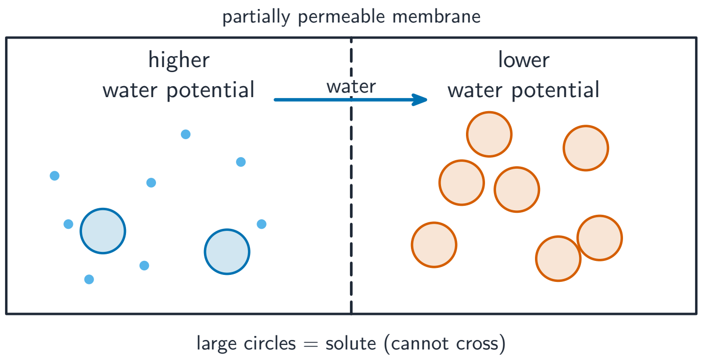
Charged **ions** 离子 and large polar molecules (such as **glucose** 葡萄糖) cannot cross the oily bilayer by themselves. In **facilitated diffusion** 易化扩散 they cross through channel proteins or carrier proteins, still moving down the concentration gradient. It is also passive.

Osmosis

Osmosis 渗透 is the diffusion of water across a partially permeable membrane, from a higher **water potential** 水势 to a lower water potential. It is passive.



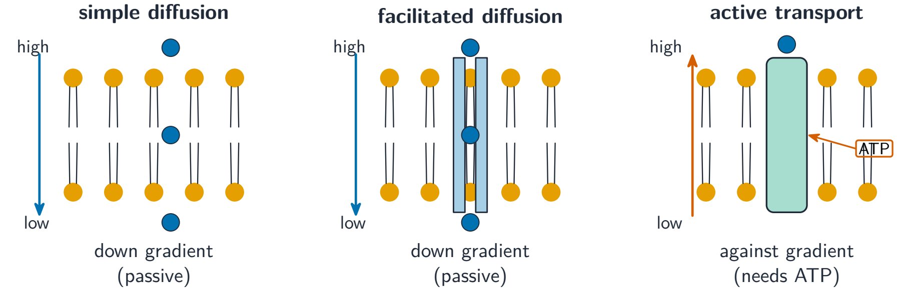
A potato osmometer: the sugar solution rises up the tube as water enters the potato by osmosis



Water crosses to the lower water potential; the solute is too big to cross the partially permeable membrane

Active transport

Active transport 主动运输 moves a substance **against** its concentration gradient — from low to high concentration. This needs carrier proteins and energy from ATP.

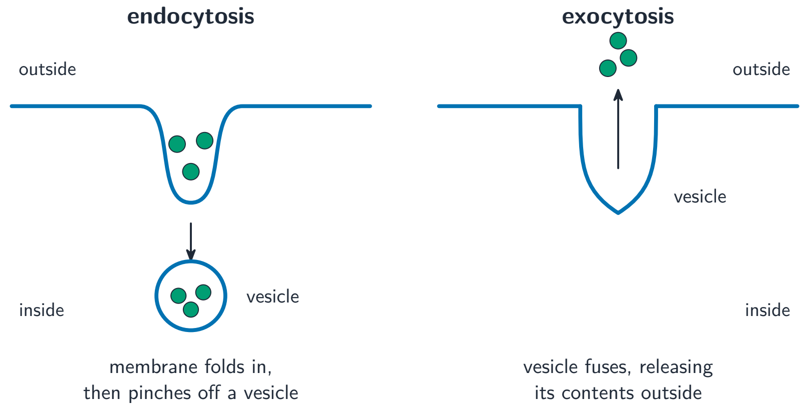


Diffusion and facilitated diffusion are passive (down the gradient); active transport goes against it and needs ATP

Endocytosis and exocytosis

These move large amounts of material in bulk, using ATP.

- in **endocytosis** 胞吞作用, the membrane folds inwards around material and pinches off a **vesicle** 囊泡 to bring it into the cell.
- in **exocytosis** 胞吐作用, a vesicle fuses with the membrane and releases its contents outside the cell.



Endocytosis brings material in by forming a vesicle; exocytosis fuses a vesicle to release its contents

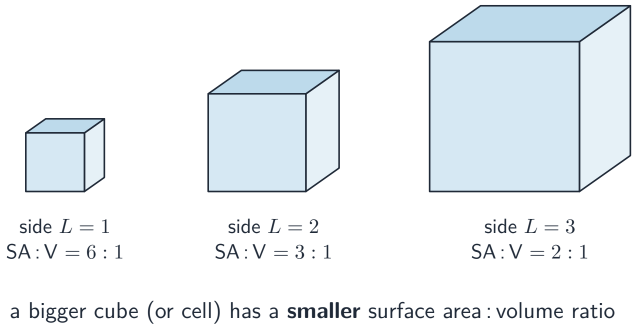
Surface area to volume ratio

A cell takes in and removes substances across its surface. As an object gets bigger, its **volume** 体积 grows faster than its **surface area** 表面积. So the surface area to volume ratio gets **smaller** as size increases.

For a cube of side L:

$$\text{surface area} = 6L^2, \qquad \text{volume} = L^3, \qquad \text{ratio} = \frac{6}{L}.$$

A large L gives a small ratio. This is why small cells (and thin, flat shapes) exchange materials quickly, while large cells cannot rely on diffusion alone.



As a cube (or cell) grows, its surface area : volume ratio gets smaller

Worked example. Compare the surface area : volume ratio of a cube-shaped cell of side 4 with one of side 10.

For side 4: surface area $= 6 \times 4^2 = 96$ and volume $= 4^3 = 64$, so the ratio is $96 : 64 = 1.5 : 1$. For side 10: surface area $= 6 \times 10^2 = 600$ and volume $= 10^3 = 1000$, so the ratio is $600 : 1000 = 0.6 : 1$. The larger cell has the smaller ratio, so it exchanges materials across its surface more slowly for its size — which is why large organisms need specialised exchange surfaces such as lungs and gills.

You can show this with **agar** 琼脂 blocks of different sizes soaked in dye or acid: the smallest block, with the largest surface area to volume ratio, changes colour all the way through fastest. Diffusion across non-living materials can also be studied with **dialysis tubing** 透析袋 (Visking tubing).

Water potential and living cells

Water potential measures how likely water is to leave a solution. Pure water has the highest water potential. Adding a **solute** 溶质 (a dissolved substance) lowers it. Water always moves by osmosis from a higher to a lower water potential.

To estimate the water potential of plant tissue, you place pieces in sucrose solutions of different water potentials. The solution that causes **no change** in mass or length has about the same water potential as the tissue.

Effect on plant cells

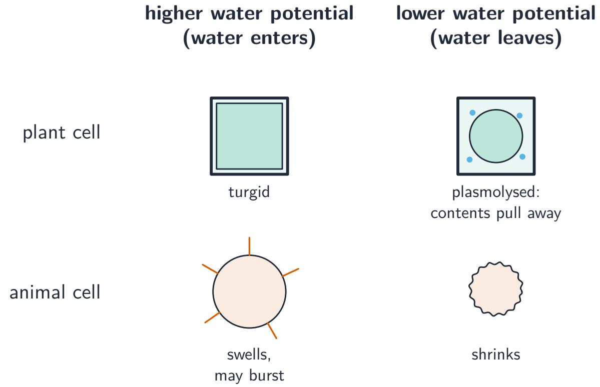
- in a solution of **higher** water potential (for example **distilled water** 蒸馏水), water enters the cell. The cell swells and becomes **turgid** 膨胀, but the strong cell wall stops it bursting.

- in a solution of **lower** water potential, water leaves. The cell contents shrink and the membrane pulls away from the cell wall — this is **plasmolysis** 质壁分离.

Effect on animal cells

Animal cells have no cell wall to protect them.

- in a solution of higher water potential, water enters and the cell may burst. In a red blood cell this bursting is called **haemolysis** 溶血.
- in a solution of lower water potential, water leaves and the cell shrinks.



A plant cell becomes turgid or plasmolysed; an animal cell may burst (haemolysis) or shrink

Exam tips

- Describe the membrane as a **fluid mosaic**: a phospholipid bilayer with proteins, cholesterol and glycoproteins.
- Sort each process: diffusion, facilitated diffusion and osmosis are **passive** (down a gradient); active transport and endo/exocytosis need **ATP** and can go against it.
- For osmosis always use **water potential** (Ψ): water moves from **high (less negative) to low (more negative)** Ψ; pure water is 0, the highest.
- State the outcome by cell type: plant cell turgid/plasmolysed; animal cell lyses/crenates — link it to the water-potential gradient.

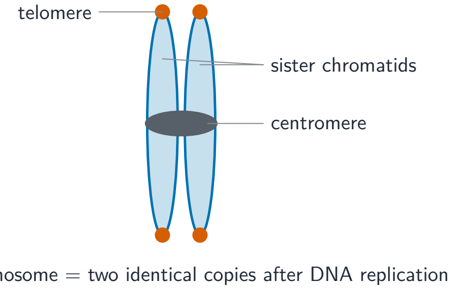
The mitotic cell cycle

A-Level Biology

The structure of a chromosome

A **chromosome** 染色体 is one very long molecule of DNA wound tightly around special **proteins** 蛋白质 called **histones** 组蛋白. Winding the DNA like this lets a huge length fit inside the nucleus and keeps it tidy.

Before a cell divides, its DNA is copied (this copying is called **replication** 复制). After copying, each chromosome is made of two identical copies joined together. These two copies are the **sister chromatids** 姐妹染色单体, and they are held together at a point called the **centromere** 着丝粒. The tips of each chromosome are capped by **telomeres** 端粒, which protect the ends.



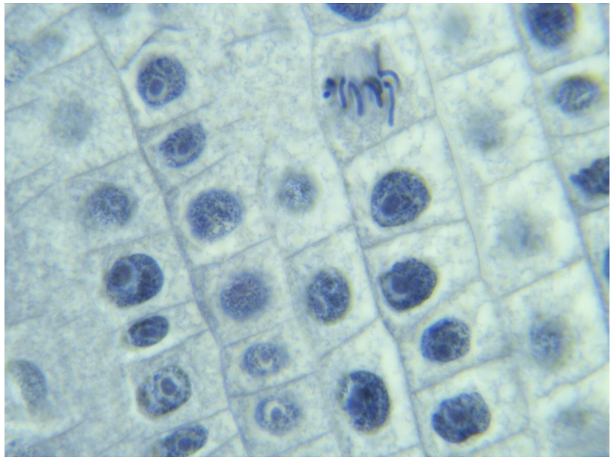
After replication a chromosome is two sister chromatids joined at the centromere, with telomeres at the tips

Why mitosis matters

Mitosis 有丝分裂 is a type of nuclear division that makes two **daughter cells** 子细胞 that are **genetically identical** — they carry exactly the same **genes** 基因 as the parent cell and as each other.

This matters for:

- **growth** of **multicellular** 多细胞 **organisms** 生物体 (making more cells).
- **replacement** of damaged or dead cells.
- **repair** of **tissues** 组织 by making new cells.
- **asexual reproduction** 无性生殖 (one parent makes identical offspring).

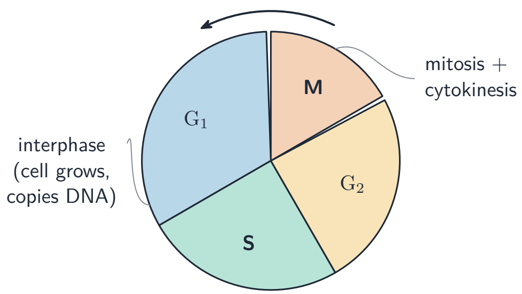


Onion root tip at metaphase: mitosis produces identical body cells for growth and repair

The mitotic cell cycle

The **cell cycle** 细胞周期 is the full life of a cell from one division to the next. It has three parts:

1. **interphase** 间期 — the longest part. The cell grows in the $\mathbf{G_1}$ phase, copies its DNA in the **S** phase (replication), and grows again and prepares to divide in the $\mathbf{G_2}$ phase.
2. **mitosis** — the nucleus divides into two identical nuclei.
3. **cytokinesis** 胞质分裂 — the rest of the cell splits, giving two separate daughter cells.



Most of the cycle is interphase (G_1, S, G_2); mitosis (M) and cytokinesis are a short part

The mitotic index

The mitotic index is the fraction of cells in a sample that are in mitosis. You find it by counting cells under a microscope:

$$\text{mitotic index} = \frac{\text{number of cells in mitosis}}{\text{total number of cells}}.$$

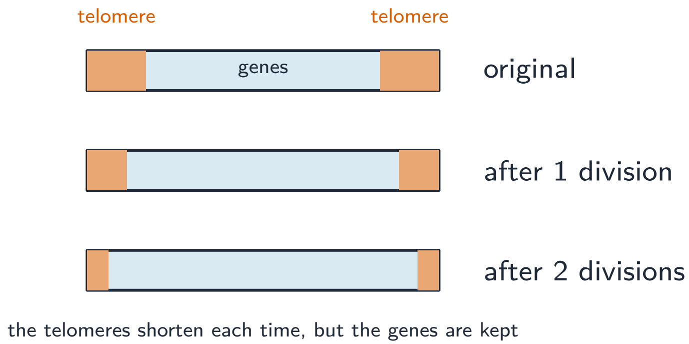
Worked example. In a root-tip sample, 8 of the 50 cells seen are in mitosis. Find the mitotic index.

$$\text{mitotic index} = \frac{8}{50} = 0.16.$$

A high mitotic index means many cells are dividing quickly — normal in a growing root tip, but in adult animal tissue it can be a warning sign of uncontrolled growth.

Telomeres and the ends of chromosomes

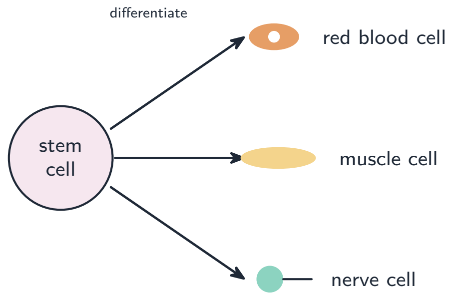
When DNA is replicated, the copying cannot reach the very end of the molecule, so a little is lost each time. Telomeres are short, repeated lengths of DNA at the ends that carry **no genes**. Because the telomeres are shortened instead, no important genes are lost during replication.



The telomeres (which carry no genes) shorten a little at each division, so the genes in the middle are never lost

Stem cells

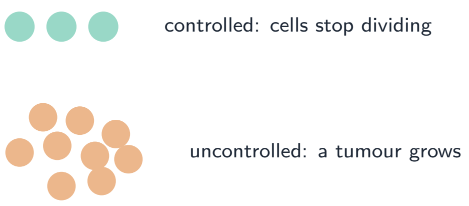
A **stem cell** 干细胞 is an unspecialised cell that can keep dividing by mitosis and can **differentiate** 分化 (change) into different specialised cell types. Stem cells are the source of new cells for replacing lost cells and repairing tissues.



One unspecialised stem cell can differentiate into many specialised cell types

Uncontrolled division and tumours

The cell cycle is normally tightly controlled, so cells divide only when needed. If this control is lost, a cell may divide again and again without stopping. This uncontrolled division produces a lump of cells called a **tumour** 肿瘤.

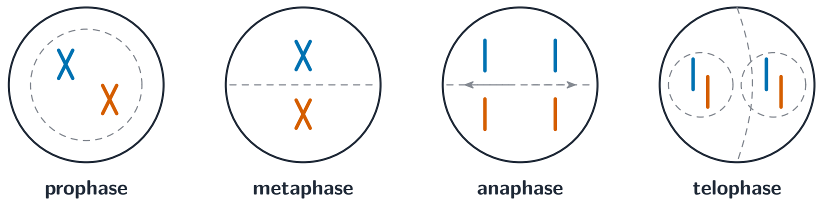


Normally cells stop dividing when they should; if that control is lost, they keep dividing into a tumour

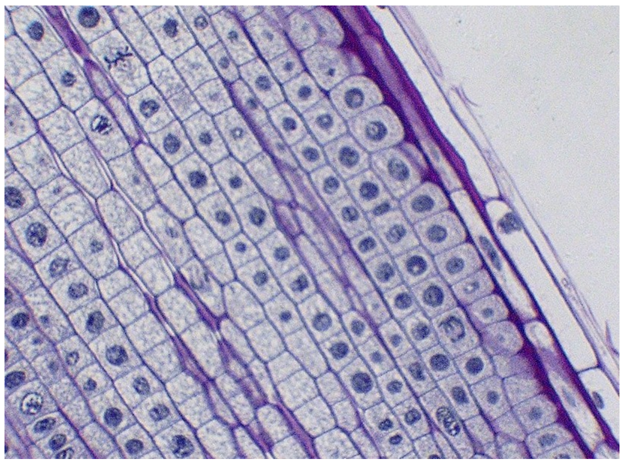
The stages of mitosis

Mitosis runs through four stages. You should be able to recognise them in photomicrographs and slides.

Stage	What happens
prophase 前期	chromosomes coil up and become visible as two sister chromatids; the **nuclear envelope** 核膜 breaks down; a **spindle** 纺锤体 of fibres forms across the cell
metaphase 中期	chromosomes line up along the middle (the **equator** 赤道); spindle fibres attach to each centromere
anaphase 后期	the centromeres split; the sister chromatids are pulled to opposite ends (poles) of the cell
telophase 末期	a set of chromosomes reaches each pole; a new nuclear envelope forms around each set, making two nuclei



The four stages: prophase, metaphase, anaphase, telophase



A real onion root tip: in a growing tip many cells are caught dividing

Cytokinesis then follows. In an animal cell the cell surface membrane pinches inwards to split the cell; in a plant cell a new wall forms across the middle. The result is two genetically identical daughter cells.

Exam tips

- Learn the stages **in order** (prophase, metaphase, anaphase, telophase) with one key event each; interphase (G1, S, G2) is **not** part of mitosis.
- Mitosis gives **two genetically identical diploid** cells — for growth, repair and asexual reproduction.
- **Mitotic index** = cells in mitosis ÷ total cells; a high value means rapid division.
- Link **uncontrolled mitosis** to tumours and telomere shortening to the limit on the number of divisions.

Nucleic acids and protein synthesis

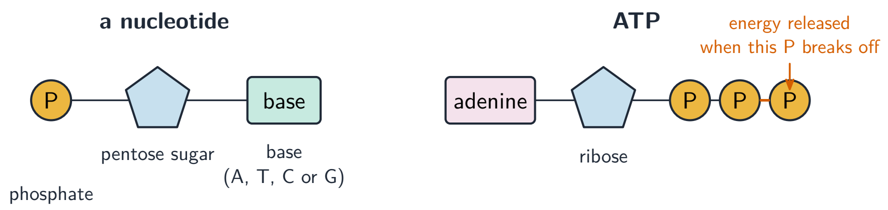
A-Level Biology

Nucleotides — the building blocks

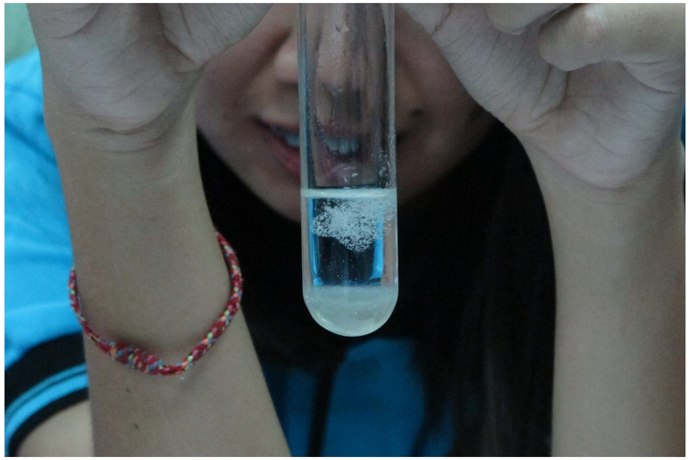
Nucleic acids 核酸 (DNA and RNA) are polymers of small units called **nucleotides** 核苷酸. Each nucleotide is made of three parts joined together:

- a **phosphate** 磷酸 group,
- a sugar (a 5-carbon sugar),
- a nitrogen-containing **base** 碱基.

ATP is a special nucleotide. It has the base **adenine** 腺嘌呤, the sugar **ribose** 核糖, and **three** phosphate groups. Breaking off the last phosphate releases **energy** 能量 for the cell.



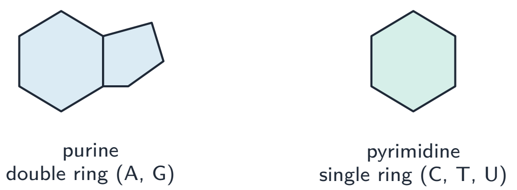
A nucleotide is a phosphate, a sugar and a base; ATP is a nucleotide with three phosphates



DNA extracted from cells appears as pale, stringy strands of these nucleotide polymers

There are five bases, in two groups:

- **purines** 嘌呤 have a **double ring** (two rings): adenine and **guanine** 鸟嘌呤.
- **pyrimidines** 嘧啶 have a **single ring** (one ring): **cytosine** 胞嘧啶, **thymine** 胸腺嘧啶 and **uracil** 尿嘧啶.



The two groups differ in shape: a purine is a double ring, a pyrimidine a single ring — which is why a purine always pairs with a pyrimidine

The structure of DNA

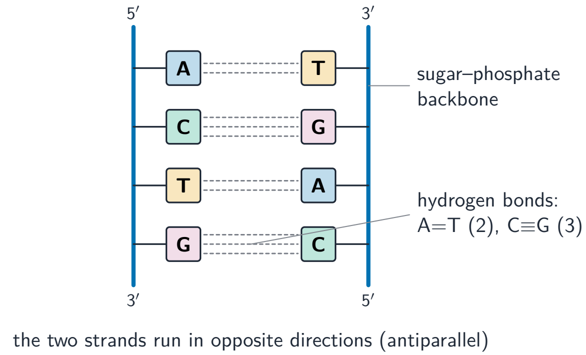
A DNA molecule is two strands twisted together into a **double helix** 双螺旋.

Each **strand** 链 has a backbone of alternating sugar (here the sugar is **deoxyribose** 脱氧核糖) and phosphate. The sugar of one nucleotide is joined to the phosphate of the next by a **phosphodiester bond** 磷酸二酯键.

The two strands are held together by their bases, which meet in the middle. The pairing is exact — this is **complementary base pairing** 碱基互补配对:

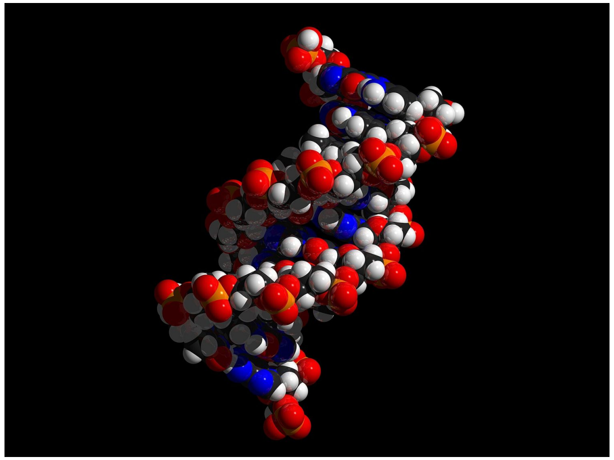
- A always pairs with T, held by **two hydrogen bonds** 氢键.
- C always pairs with G, held by **three** hydrogen bonds (so a C–G **base pair** 碱基对 is harder to separate).

The two strands run in opposite directions: one goes 5′ to 3′ while the other goes 3′ to 5′. We say they are **antiparallel** 反平行.



Complementary base pairing: A pairs with T (2 hydrogen bonds), C with G (3); the strands are antiparallel

The flat ladder above is twisted into a spiral. This space-filling model, where every atom is a ball, shows the real shape of the **double helix**:



*A space-filling model of DNA: the two strands twist around each other into the **double helix** — the ladder of the diagram, coiled up*

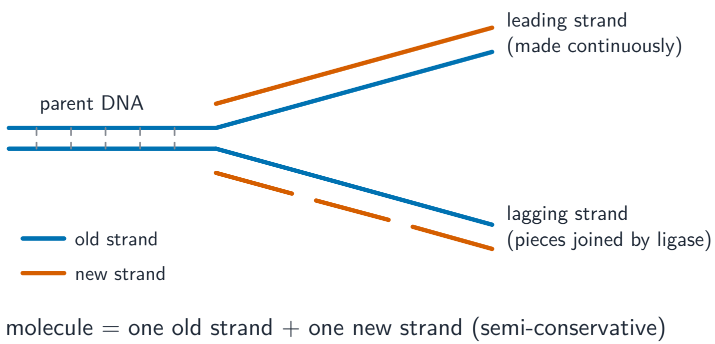
DNA replication

DNA **replication** 复制 (copying) happens during the S phase of the cell cycle. It is **semi-conservative** 半保留复制: each new molecule keeps one old strand and one new strand. The steps are:

1. the double helix unwinds and the hydrogen bonds break, so the two strands separate.
2. each old strand acts as a template. Free nucleotides pair with the exposed bases by complementary base pairing.
3. the **enzyme** 酶 **DNA polymerase** 聚合酶 joins the new nucleotides into a strand. It can only add nucleotides in the 5′ to 3′ direction.

Because of that 5′ to 3′ rule, the two new strands are made differently:

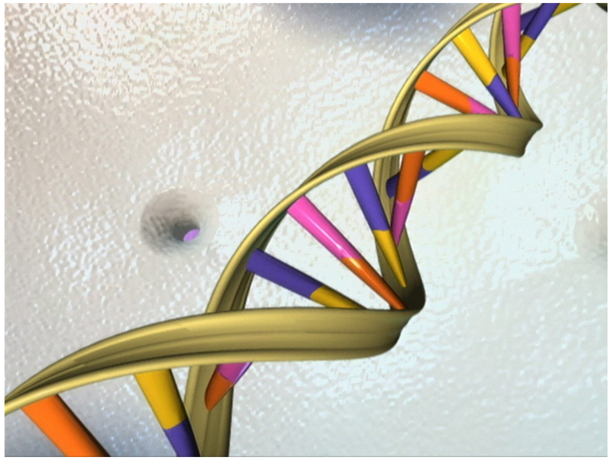
- the **leading strand** 前导链 is built continuously, following the unwinding.
- the **lagging strand** 后随链 is built in short pieces, working away from the unwinding point. The enzyme **DNA ligase** 连接酶 then joins these pieces together.



Replication is semi-conservative: each new molecule keeps one old strand (blue) and one new strand (orange)

RNA

RNA is also made of nucleotides, but it is a single strand, its sugar is ribose, and it uses uracil in place of thymine. The most important type here is **messenger RNA (mRNA)**, which carries a copy of a gene's instructions out of the nucleus to be used.



DNA double helix: RNA is a related nucleic acid that carries genetic information into protein synthesis

The genetic code

A **gene** 基因 is a sequence of DNA nucleotides that codes for one **polypeptide** 多肽.

The code is read in **triplets** 三联体 — groups of three bases. Each triplet either codes for one specific **amino acid** 氨基酸, or acts as a start or stop signal. The code is **universal**: nearly all living things use the same triplets for the same amino acids.

There are 64 possible triplets but only 20 common amino acids, so most amino acids are coded by more than one triplet.

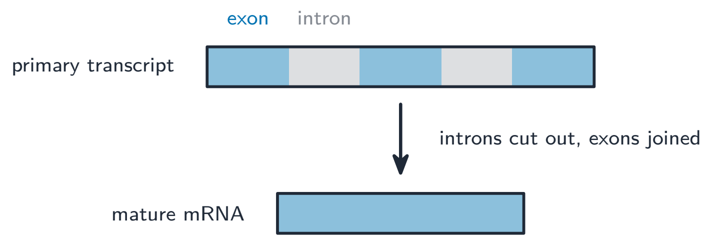
Protein synthesis: transcription and translation

Transcription (in the nucleus)

The DNA gene is copied into mRNA. This is **transcription** 转录.

- the strand of DNA that is copied is the **template strand** 模板链; the partner strand is the **non-transcribed strand** 非转录链.

- the enzyme **RNA polymerase** joins RNA nucleotides that pair with the template bases (with uracil pairing to adenine).
- in eukaryotes the first RNA made (the **primary transcript** 初级转录本) contains coding parts called **exons** 外显子 and non-coding parts called **introns** 内含子. The introns are cut out and the exons joined together to form the finished mRNA.

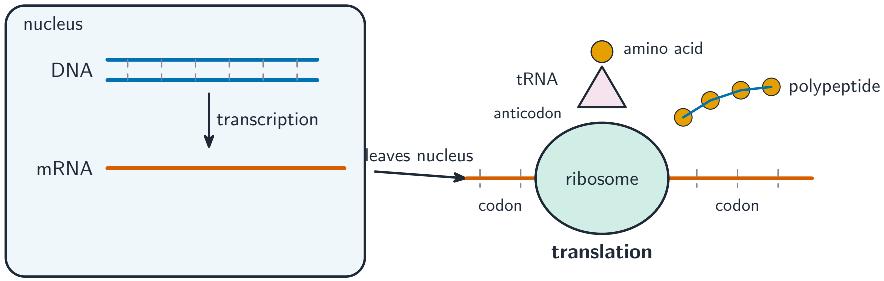


Splicing: the non-coding introns are cut out and the coding exons joined to make the finished mRNA

Translation (at the ribosome)

The mRNA leaves the nucleus and attaches to a **ribosome** 核糖体. Building the polypeptide from the mRNA code is **translation** 翻译.

- the mRNA is read in **codons** 密码子 (each codon is one triplet of mRNA bases).
- molecules of **transfer RNA (tRNA)** bring amino acids to the ribosome. Each tRNA has an **anticodon** 反密码子 that pairs with a matching codon.
- as the codons are read in order, the ribosome joins the amino acids with **peptide bonds** 肽键, building the polypeptide.



Transcription copies DNA into mRNA in the nucleus; translation at the ribosome builds the polypeptide

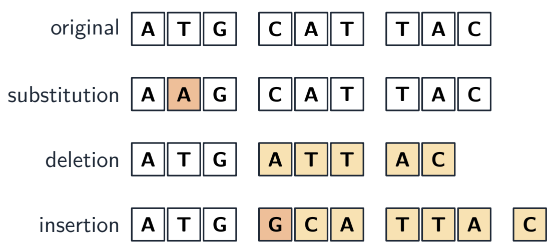
Worked example. A DNA template strand reads `TAC GGA CTT`. Give the mRNA codons, and say how long the polypeptide is. Transcribe by **complementary base pairing**, remembering that RNA uses **uracil** in place of thymine: `TAC` gives `AUG`, `GGA` gives `CCU`, `CTT` gives `GAA`. So the mRNA reads `AUG CCU GAA`. `AUG` is the **start** codon (methionine), so the polypeptide is **three** amino acids long - two once the start methionine is removed. Two errors cost most of the marks here: pairing A with **T** instead of **U** when writing mRNA, and transcribing the **coding** strand instead of the **template** strand. The mRNA is complementary to the template, and identical to the coding strand apart from U replacing T.

Gene mutations

A gene **mutation** 突变 is a change in the base sequence of a DNA molecule. It may change the polypeptide made. There are three types:

- **substitution** 替换 — one base is swapped for a different base. This changes at most one amino acid, and sometimes none (because most amino acids have more than one triplet).
- **deletion** 缺失 — a base is removed.
- **insertion** 插入 — an extra base is added.

A deletion or insertion shifts how every later triplet is read, so it usually changes many amino acids after that point and has a large effect on the polypeptide.



red = changed base; shaded = shifted by a frameshift (deletion or insertion)

A substitution changes one triplet; a deletion or insertion shifts every later triplet (a frameshift)

Exam tips

- DNA is **antiparallel**, held by hydrogen bonds (A=T two, C≡G three); replication is **semi-conservative** (each product keeps one old strand).
- State **where** and **what**: transcription (nucleus → mRNA), translation (ribosome, mRNA + tRNA → polypeptide).
- Describe the code with all four terms: **triplet, non-overlapping, degenerate, universal**.
- For a **gene mutation** (substitution, insertion, deletion) explain the effect on the protein — and why a substitution can be silent (degeneracy).

Transport in plants

A-Level Biology

The two transport tissues

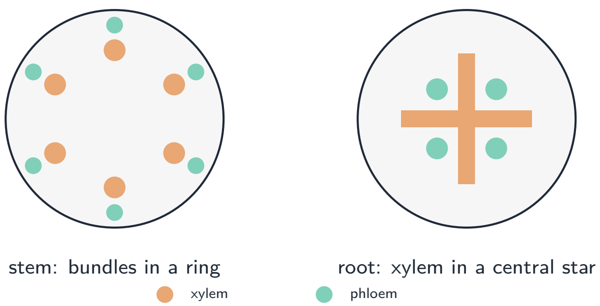
Plants move substances through two transport **tissues** 组织:

- **xylem** 木质部 carries water and dissolved **mineral ions** 矿物离子 up from the roots.
- **phloem** 韧皮部 carries dissolved foods (called **assimilates** 同化物, mainly sugars) to wherever they are needed.

In a **transverse section** 横切面 (a cut straight across) of a **dicotyledonous plant** 双子叶植物:

- in the **stem**, xylem and phloem sit together in bundles near the outside, with xylem on the inside of each bundle.
- in the **root**, the xylem is in the centre, often in a star shape, with phloem between the arms.
- in the **leaf**, both are found in the veins.

When you draw a plan diagram, you draw only the outlines of the tissues, not the single cells.



Where the tissues sit: stem bundles form a ring near the edge (xylem inside); in the root the xylem makes a central star

The wood of a tree trunk is xylem; each ring is one year of growth

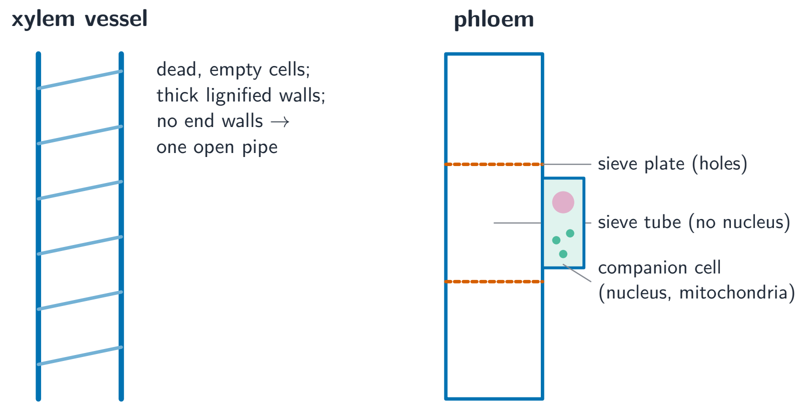
Xylem vessels

Xylem water-carrying tubes are called **vessels** 导管. They are made of dead, empty cells joined end to end, with the end walls gone, so they form one long open pipe. Their walls are thickened and waterproofed with **lignin** 木质素. So the structure suits the job: the hollow, open tube with no contents lets water flow fast, and the lignin gives strength and support.

Phloem sieve tubes and companion cells

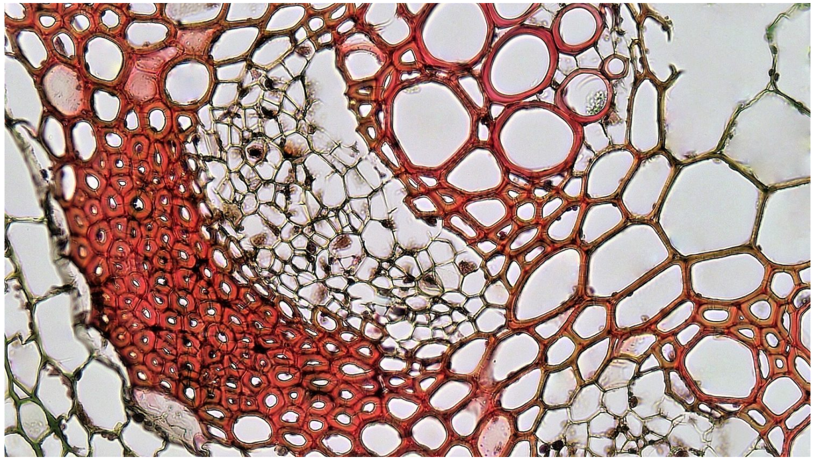
Phloem food-carrying tubes are called **sieve tubes** 筛管. They are living cells joined end to end, but their end walls are not gone — they become **sieve plates** 筛板 with many holes that sap flows through. To leave room for flow, a sieve tube cell loses most of its contents and has no nucleus.

Beside each sieve tube is a **companion cell** 伴胞. It keeps its **nucleus** 细胞核 and has many **mitochondria** 线粒体. It does the living work for the sieve tube and loads sugars into it.



Xylem is a dead, open pipe; phloem is living sieve tubes with sieve plates and companion cells

This is what a real **vascular bundle** 维管束 looks like under the microscope, in a stained section of a young sunflower stem:



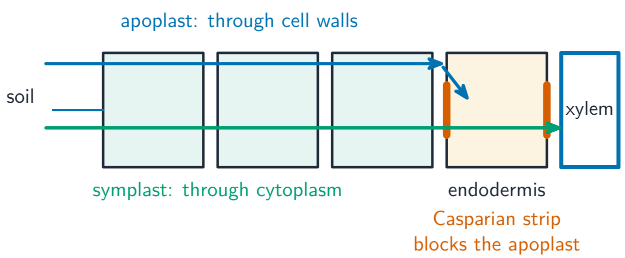
*A real **vascular bundle** in section: the big red cells are xylem vessels (thick lignified walls); the smaller cells above are phloem*

Water from the soil to the xylem

Water enters a **root hair cell** 根毛细胞 by **osmosis** 渗透, because the root hair has a lower water potential than the soil water. Water then crosses the root to the xylem by two pathways:

- the **apoplast pathway** 质外体途径 — water moves through the **cell walls** 细胞壁 (made of **cellulose** 纤维素) and the spaces between cells, without entering the cytoplasm. This is fast.
- the **symplast pathway** 共质体途径 — water moves through the cytoplasm of cells, passing from cell to cell through the **plasmodesmata** 胞间连丝.

At a ring of cells called the **endodermis** 内皮层, the apoplast pathway is blocked by the **Casparian strip** 凯氏带, a waterproof band of **suberin** 木栓质. This forces all the water through the cell membranes, which lets the plant control what enters the xylem.



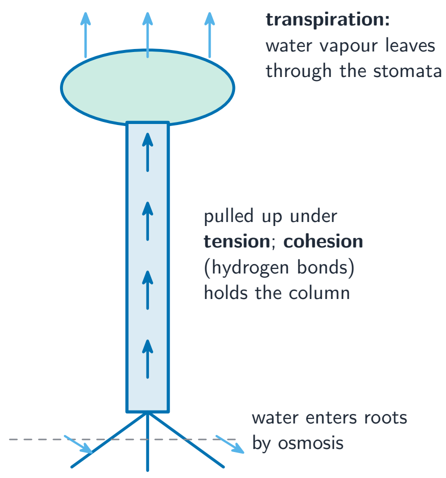
The apoplast goes through the walls, the symplast through the cytoplasm; the Casparian strip blocks the apoplast at the endodermis

Transpiration and the movement of water up the xylem

Transpiration 蒸腾作用 is the loss of water vapour from a plant. Water **evaporates** (turns to vapour) from the wet cell surfaces inside the leaf — this is **evaporation** 蒸发. The **water vapour** 水蒸气 then **diffuses** 扩散 out through the **stomata** 气孔 into the **atmosphere** 大气.

This loss at the top pulls water up the xylem in a continuous column. It works because of hydrogen bonding between water molecules:

- water molecules attract each other through **hydrogen bonds** 氢键, so they stick together. This sticking is **cohesion** 内聚力, and it lets the whole column be pulled up under **tension** 张力 (the cohesion–tension idea).
- water molecules also stick to the cellulose of the cell walls. This is **adhesion** 附着力, which helps hold the column in place.

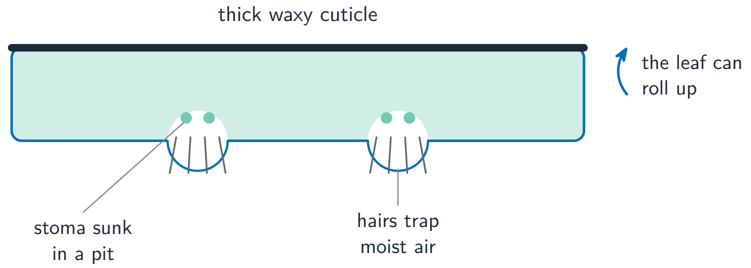


Transpiration at the leaf pulls the whole water column up the xylem; cohesion (hydrogen bonds) keeps it together

Worked example. A plant cell with a water potential of −800 kPa is placed in a solution of water potential −400 kPa. Which way does water move, and what happens to the cell? Water always moves **down** a water potential gradient - from the **less negative** (higher) value to the **more negative** (lower) one. The solution at −400 is **higher** than the cell at −800, so water moves **into** the cell. The cell swells, the protoplast presses on the cell wall, the **pressure potential** rises, and the cell becomes **turgid**. Two traps: −400 is **greater** than −800, which is the sign error that reverses half of all answers; and pure water is the maximum at **0**, so every solution is negative and a water potential can never rise above zero.

Xerophytes

A **xerophyte** 旱生植物 is a plant **adapted** 适应 to live where water is scarce. Its leaves reduce water loss by transpiration in several ways: a thick waxy **cuticle** 角质层, **stomata** sunk in pits, hairs that trap moist air, and leaves that can roll up. You should be able to draw a labelled leaf section showing these features.



Xerophyte leaves cut water loss: a thick cuticle, sunken stomata, trapped moist air and rolling up

Translocation: moving assimilates in the phloem

Assimilates such as **sucrose** 蔗糖 and **amino acids** 氨基酸 are carried in the phloem from a **source** 源 to a **sink** 库.

- a **source** is where the assimilate is made or released (for example a photosynthesising leaf).
- a **sink** is where it is used or stored (for example a growing root).

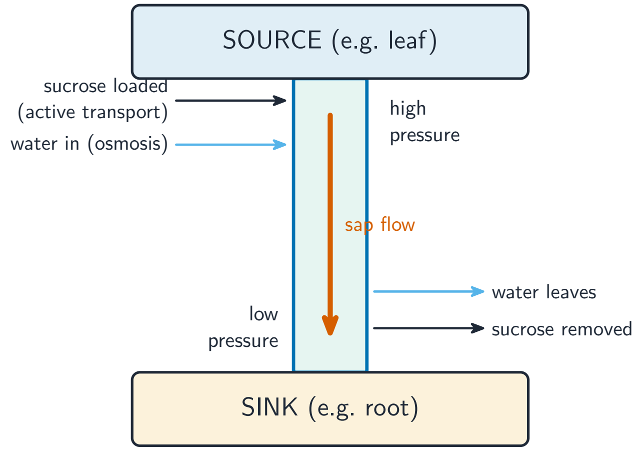
Loading at the source

Companion cells load sucrose into the sieve tubes against its concentration gradient. They use **proton pumps** 质子泵 to pump hydrogen ions out, then **cotransporter proteins** 协同运输蛋白 bring sucrose back in together with those ions. This is a form of **active transport** 主动运输.

Loading sucrose lowers the **water potential** 水势 inside the sieve tube, so water follows by osmosis. This raises the **hydrostatic pressure** 静水压 there.

Mass flow

At the sink, sucrose is removed, so the water potential rises, water leaves, and the pressure falls. The result is a pressure difference between source (high) and sink (low). Sap flows from high to low pressure down this gradient. This pressure-driven flow is called **mass flow** 集流.



Loading sucrose at the source raises the pressure; sap then flows by mass flow to the sink

Exam tips

- State the tissue for each direction: **xylem** carries water up (dead, lignified), **phloem** carries assimilates both ways (living sieve tubes + companion cells).
- Explain water movement by **cohesion-tension**: transpiration pulls a continuous water column held by cohesion (H-bonds) and adhesion.
- List the factors affecting **transpiration rate** (light, temperature, humidity, air movement) and how a potometer measures uptake.
- For **xerophytes**, link each adaptation (thick cuticle, sunken stomata, rolled leaves, hairs) to reduced water loss.

Transport in mammals

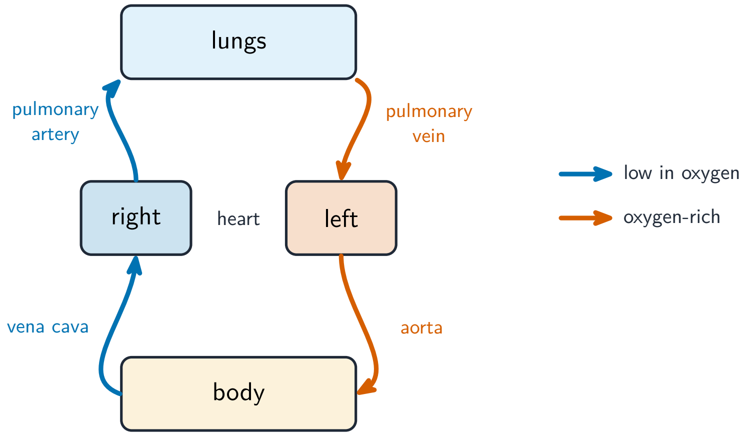
A-Level Biology

The circulatory system

Mammals have a **closed double circulation**. "Closed" means the blood stays inside **blood vessels** 血管 the whole time. "Double" means the blood passes through the **heart** 心脏 twice for each full trip around the body. This gives two linked loops, so we call it a **double circulation** 双循环 and the whole thing a **circulatory system** 循环系统:

- the **pulmonary circulation** 肺循环 carries blood from the heart to the lungs and back.
- the **systemic circulation** 体循环 carries blood from the heart to the rest of the body and back.

Blood travels in this order: **arteries** 动脉 → **arterioles** 小动脉 → **capillaries** 毛细血管 → **venules** 小静脉 → **veins** 静脉.



Double circulation: the pulmonary loop goes to the lungs, the systemic loop to the body; blood passes through the heart twice

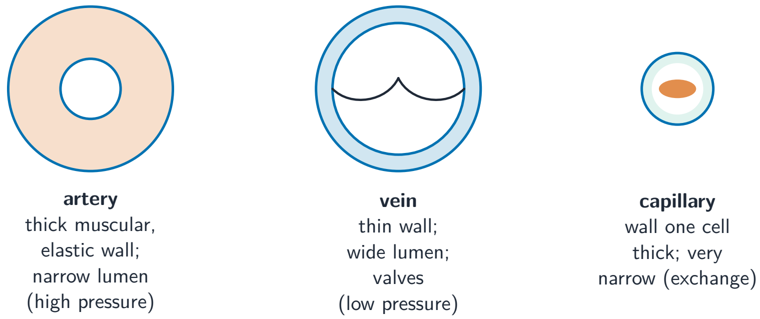
The main vessels are:

- the **pulmonary artery** 肺动脉 — carries blood low in **oxygen** 氧气 from the heart to the lungs.

- the **pulmonary vein** 肺静脉 — carries oxygen-rich blood from the lungs back to the heart.
- the **aorta** 主动脉 — the big artery that carries oxygen-rich blood from the heart to the body.
- the **vena cava** 腔静脉 — the big vein that returns oxygen-poor blood from the body to the heart.

How the vessels suit their jobs

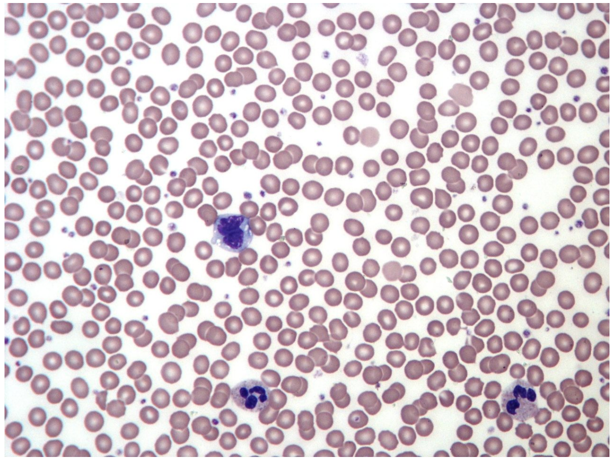
Vessel	Structure	Function
artery	thick wall of **muscle** 肌肉 and **elastic** 弹性 fibres; narrow **lumen** 管腔 (the space inside)	carries blood at high pressure away from the heart; elastic walls stretch and recoil to smooth the flow; muscle controls the flow
capillary	wall just one cell thick; very narrow	short distance for exchange of substances between blood and cells
vein	thin wall; wide lumen; has **valves** 瓣膜	returns blood at low pressure to the heart; valves stop blood flowing backwards



An artery has a thick wall and narrow lumen; a vein a thin wall, wide lumen and valves; a capillary is one cell thick

Blood cells

You should recognise: **red blood cells** 红细胞 (which carry oxygen), and three white blood cells — **monocytes** 单核细胞, **neutrophils** 中性粒细胞 and **lymphocytes** 淋巴细胞.

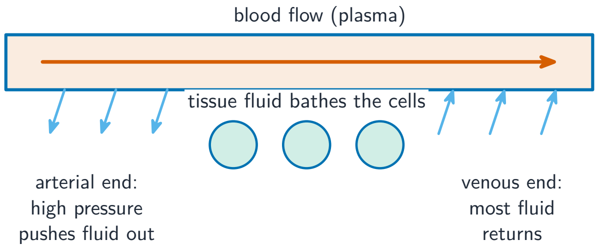


*A stained **blood smear**: many small red cells, plus a lymphocyte (centre) and neutrophils (lobed nucleus) — the white cells are larger and have a nucleus*

Water, plasma and tissue fluid

Water is the main part of blood. It is a good **solvent** 溶剂, so it carries dissolved substances, and it has a high **specific heat capacity** 比热容, so the blood's temperature stays steady.

At the start of a capillary, the high blood pressure pushes liquid (but not the cells or large proteins) out of the **plasma** 血浆 and through the capillary wall. This liquid around the cells is **tissue fluid** 组织液. It supplies the cells with oxygen and glucose and carries waste away. Most of it returns to the capillary at the far end, where the pressure is lower.



High pressure at the arterial end pushes fluid out to form tissue fluid; most returns at the venous end

Transport of oxygen and carbon dioxide

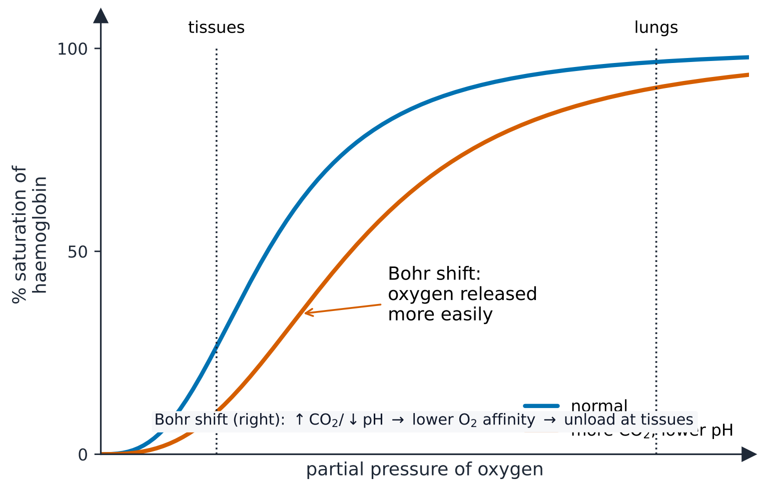
Carrying oxygen

Oxygen is carried by **haemoglobin** 血红蛋白 in the red blood cells. We show how well haemoglobin holds oxygen with the **oxygen dissociation curve** 氧解离曲线. This S-shaped graph plots the **saturation** 饱和度 (how full of oxygen the haemoglobin is) against the **partial pressure** 分压 of oxygen:

- where the partial pressure of oxygen is **high** (in the lungs), haemoglobin loads up and becomes almost fully saturated.
- where it is **low** (in respiring tissues), haemoglobin unloads its oxygen for the cells to use.

The Bohr shift

When tissues are very active, they release more **carbon dioxide** 二氧化碳, which lowers the pH. This makes haemoglobin release oxygen more easily, so the curve moves to the right. This helpful change is the **Bohr shift** 波尔位移: oxygen is given up exactly where it is most needed.



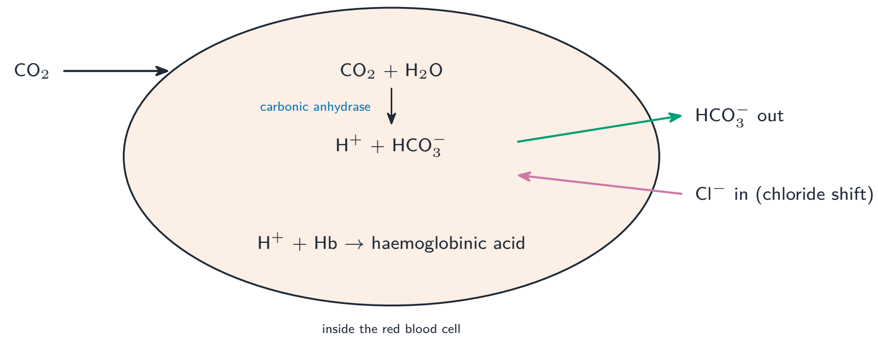
Haemoglobin loads oxygen in the lungs and unloads it in the tissues; the Bohr shift moves the curve right so more is released

Carrying carbon dioxide

A little carbon dioxide dissolves straight into the plasma, but most is carried after a reaction inside the red blood cells:

1. the **enzyme** 酶 **carbonic anhydrase** 碳酸酐酶 speeds up the reaction of carbon dioxide with water to make carbonic acid.
2. the carbonic acid splits into hydrogen ions and **hydrogencarbonate ions** 碳酸氢根离子.
3. the hydrogencarbonate ions move out into the plasma. This is the main way carbon dioxide is carried.
4. to keep the charge balanced, **chloride ions** 氯离子 move into the red blood cells. This movement is the **chloride shift** 氯转移.
5. the hydrogen ions join haemoglobin to form **haemoglobinic acid** 血红蛋白酸; this mops up the hydrogen ions and keeps the pH steady.

Some carbon dioxide also joins haemoglobin directly to form **carbamino-haemoglobin** 氨甲酰血红蛋白.



Most CO_2 travels as hydrogencarbonate ions; the chloride shift keeps the charge balanced and haemoglobin mops up the H^+

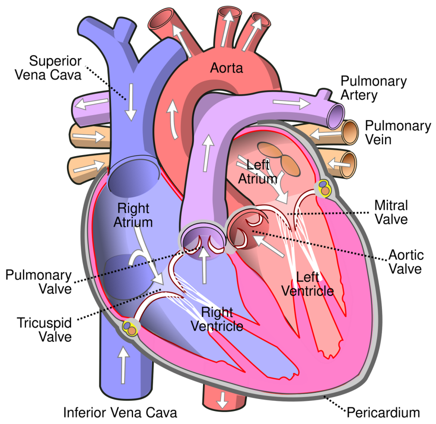
Worked example. At the lungs the partial pressure of oxygen is about 12 kPa and haemoglobin is about 98% saturated; in an exercising muscle it is about 3 kPa and saturation falls to about 40%. How much oxygen is unloaded, and why is the curve S-shaped? Subtract the saturations: $98 - 40 =$ **58%** of the haemoglobin's oxygen is released in the muscle. The **S shape** comes from **cooperative binding** - the first oxygen to bind changes haemoglobin's shape so the next ones bind more easily, which is why the middle of the curve is so steep. That steepness is the point: a **small** fall in partial pressure in a respiring tissue causes a **large** release of oxygen. The extra carbon dioxide in an exercising muscle lowers the pH and shifts the curve **right**, so even more is unloaded at the same partial pressure - that is the **Bohr shift** doing its job.

The heart

Structure

The heart has four chambers. The two upper chambers are the **atria** 心房 (singular: atrium); they have thin walls because they only push blood down into the chambers below. The two lower chambers are the **ventricles** 心室; they have thick muscular walls because they pump blood out of the heart.

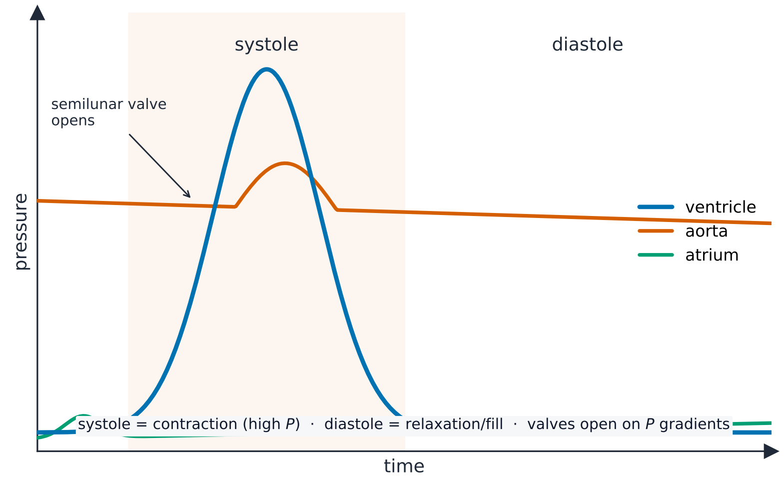
The left ventricle wall is thicker than the right ventricle wall, because the left side must pump blood all the way round the body, while the right side only pumps to the nearby lungs.



The four chambers, the valves and the main vessels; the left ventricle wall is the thickest

The cardiac cycle

One heartbeat is the **cardiac cycle** 心动周期. It has two parts: **systole** 收缩期 (when heart muscle contracts) and **diastole** 舒张期 (when it relaxes and fills). When a chamber contracts, the pressure inside rises; this pressure change opens and closes the valves so that blood flows one way only.

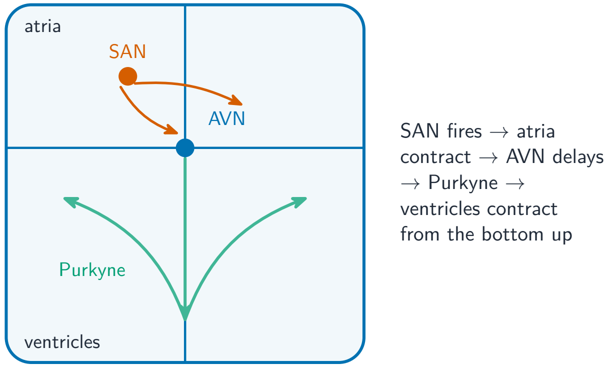


The ventricle pressure spikes in systole and pushes blood into the aorta; a valve opens or closes whenever two pressure curves cross

Controlling the heartbeat

The heart sets its own rhythm:

- the **sinoatrial node** 窦房结 in the right atrium is the pacemaker. It sends out a wave of electrical excitation that spreads across the atria and makes them contract.
- the **atrioventricular node** 房室结 picks up the wave, holds it back for a moment (so the atria empty first), then passes it on.
- the **Purkyne tissue** 浦肯野组织 carries the wave down and through the ventricle walls, so the ventricles contract from the bottom upwards and push blood out.



The SAN sets the rhythm; the wave passes to the AVN, then the Purkyne tissue makes the ventricles contract bottom-up

Exam tips

- Trace the **double circulation** and name the chambers, valves and vessels; the left ventricle wall is thicker (pumps further at higher pressure).
- Read the **cardiac-cycle** pressure graph: a valve opens/closes when the pressures across it cross over.
- Explain the **oxygen dissociation curve** (S-shaped) and the **Bohr shift** (more CO2 shifts it right, unloading more O2 to active tissue).
- Most CO2 is carried as **hydrogencarbonate** (via the chloride shift).

Gas exchange

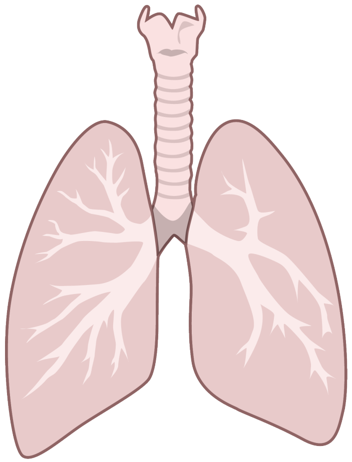
A-Level Biology

The gas exchange system

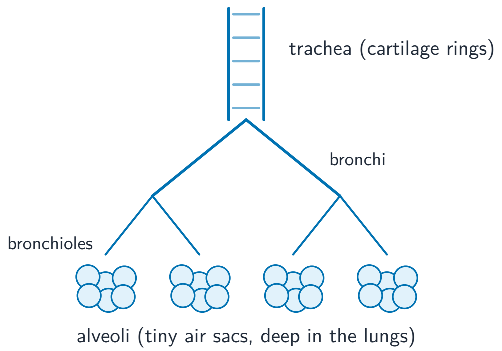
Your body needs to take in oxygen and get rid of carbon dioxide. This swap happens in the **gas exchange** 气体交换 system. Air follows this path into the body:

- down the **trachea** 气管 (the windpipe),
- into two **bronchi** 支气管 (one to each lung),
- into many smaller **bronchioles** 细支气管,
- and finally into tiny air sacs called **alveoli** 肺泡, deep in the **lungs** 肺.

Each alveolus is wrapped in a network of **capillaries** 毛细血管, so air and blood are brought very close together.



The human lungs, where gas exchange takes place across millions of alveoli

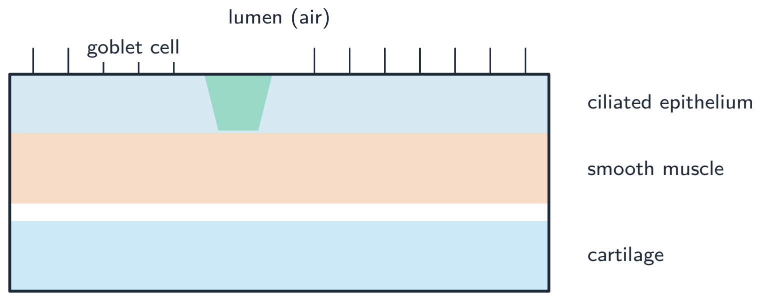


Air passes down the trachea, into the bronchi and bronchioles, to the alveoli

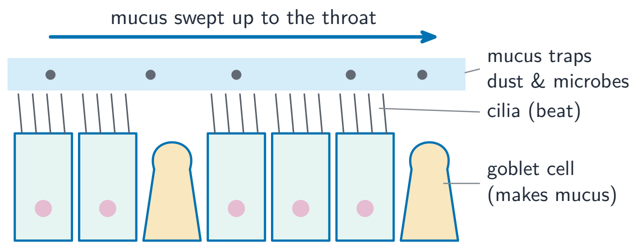
The tissues of the airways and what they do

Tissue	Where it is	Function
cartilage 软骨	C-shaped rings in the trachea and bronchi	holds the airway open so it cannot collapse when you breathe in
ciliated epithelium 纤毛上皮	lining the trachea and bronchi	tiny hairs called **cilia** 纤毛 beat to sweep **mucus** 黏液 up towards the throat, away from the lungs
goblet cells 杯状细胞 and **mucous glands** 黏液腺	in the lining of the airways	make the mucus, which traps dust and **microbes** 微生物 that you breathe in
smooth muscle 平滑肌	in the walls of bronchi and bronchioles	contracts to make the airway narrower
elastic fibres 弹性纤维	in the airway and alveolus walls	stretch when you breathe in, then spring back to help push air out
squamous epithelium 扁平上皮	the very thin, flat lining of the alveoli	gives a very short distance for gases to cross

The cilia, goblet cells and mucous glands work together to keep the lungs clean and healthy: the mucus traps dirt and microbes, and the cilia carry it away to be swallowed.



A section through the airway wall: cilia and goblet cells line the lumen, with smooth muscle and supporting cartilage behind



Goblet cells make mucus that traps dust and microbes; the cilia sweep it up to the throat

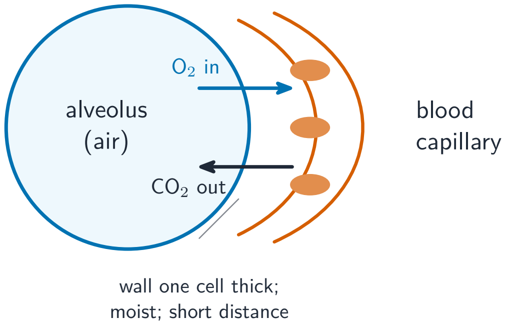
Gas exchange in the alveoli

The alveoli are excellent surfaces for exchanging gases, because they have:

- a very large total surface area (millions of tiny sacs),
- very thin walls — the squamous epithelium of the alveolus and the capillary wall are each only one cell thick, so the distance to cross is tiny,
- a rich blood supply from the capillary network,
- a moist lining, so gases dissolve before crossing.

Gases move by **diffusion** 扩散 down their **concentration gradients** 浓度梯度:

- **oxygen** 氧气 is at a high concentration in the alveolar air and a low concentration in the blood, so it diffuses from the air into the blood.
- **carbon dioxide** 二氧化碳 is at a high concentration in the blood and a low concentration in the alveolar air, so it diffuses from the blood into the air to be breathed out.



Across the thin, moist wall, oxygen diffuses into the blood and carbon dioxide diffuses out

Under the microscope, real lung tissue looks like a fine pink lace. The many open spaces are the alveoli, and the thin pink lines between them are the walls where gas exchange happens:

Real lung tissue stained for the microscope: the open spaces are alveoli and the thin pink walls are where gases cross; a small airway sits in the centre

Breathing keeps fresh air in the alveoli, and the flowing blood keeps carrying gases away. Both of these keep the concentration gradients steep, so gas exchange stays fast.

Worked example. Use Fick's law to explain why the alveoli allow such rapid gas exchange. Fick's law makes the rate of diffusion proportional to

$$\frac{\text{surface area} \times \text{concentration difference}}{\text{diffusion distance}}$$

so a fast rate needs all three terms working for it. **Surface area**: millions of alveoli give a huge total area, roughly 70 m^2. **Diffusion distance**: the alveolar epithelium and the capillary endothelium are each one flattened cell thick, so oxygen crosses in under 1 μm. **Concentration difference**: ventilation constantly refreshes the air while the circulation constantly carries oxygenated blood away, so a **steep gradient is maintained**. Tie each adaptation to the **term of the equation** it serves - listing "big surface area, thin walls, good blood supply" without linking them to Fick's law is the weaker answer.

Exam tips

- Link each **alveolar** feature to fast diffusion: large surface area, thin (one-cell) walls, moist surface, good blood supply — a "surface area, short distance, steep gradient" answer.
- Match airway tissue to function: cartilage (holds airways open), ciliated + goblet cells (trap and sweep mucus), smooth muscle and elastic fibres.
- Frame answers with **Fick's law** ideas: rate $\propto$ surface area $\times$ concentration difference $\div$ distance.

Infectious diseases

A-Level Biology

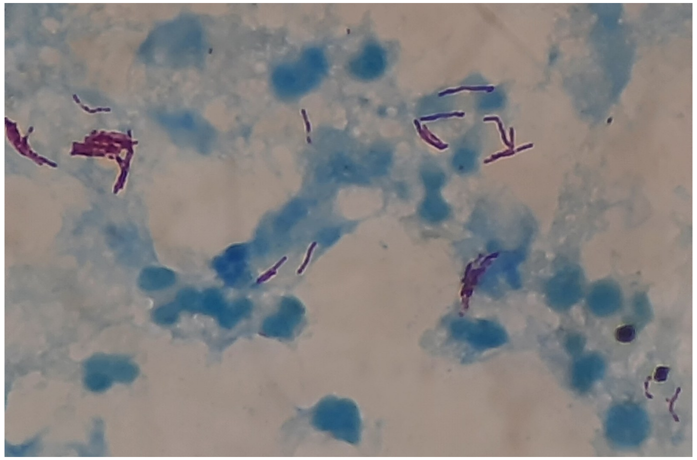
What causes infectious disease

An **infectious disease** 传染病 is caused by a **pathogen** 病原体 — an organism that lives in or on a host and causes harm. Infectious diseases are **transmissible**: the pathogen can be **transmitted** 传播 (passed) from one person to another.

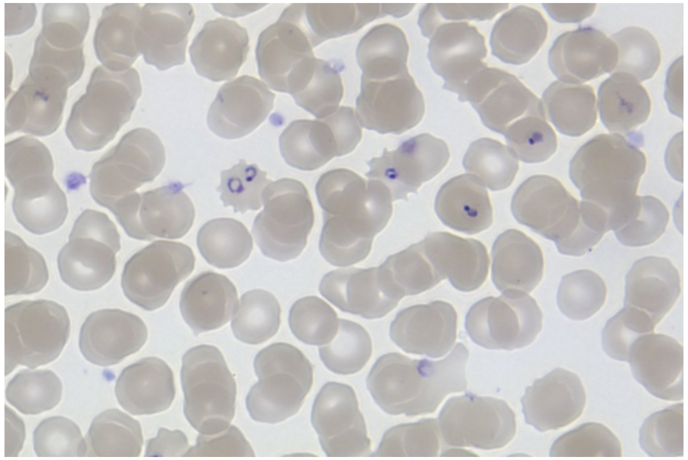
You need to know four diseases, the pathogen that causes each, and how each spreads.

Disease	Pathogen and type	How it spreads
cholera 霍乱	the **bacterium** 细菌 *Vibrio cholerae*	drinking water or food **contaminated** 污染 with **faeces** 粪便 (human waste)
malaria 疟疾	the **protoctist** 原生生物 *Plasmodium*	the bite of an infected **mosquito** 蚊子, which acts as a **vector** 媒介 (a carrier of the pathogen); also through infected blood
tuberculosis (TB) 结核病	the bacterium *Mycobacterium*	tiny airborne **droplets** 飞沫 from coughs and sneezes; spreads fast where people are crowded
HIV/AIDS	the **virus** 病毒 HIV (which leads to **AIDS** 艾滋病)	unprotected sex, infected blood (for example shared needles), and from mother to baby

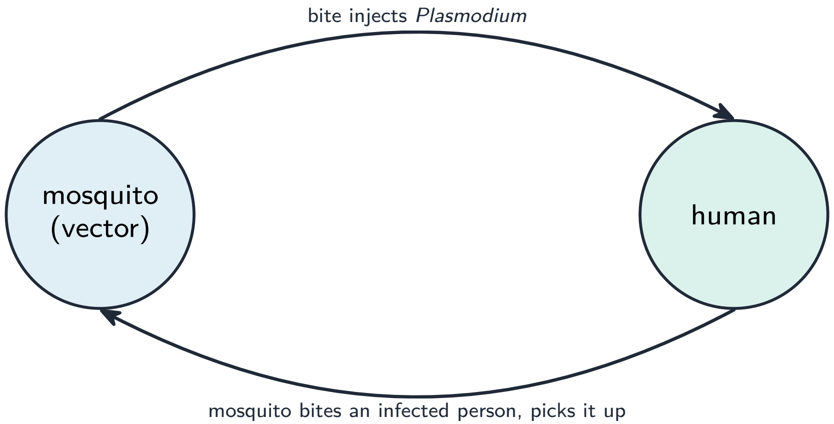
HIV infects and destroys certain white blood cells, so it slowly weakens the body's **immune system** 免疫系统.



The bacterium Mycobacterium (red rods) that causes tuberculosis, stained in a sputum sample



The protoctist Plasmodium (small dark rings) that causes malaria, living inside red blood cells



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

Preventing and controlling these diseases

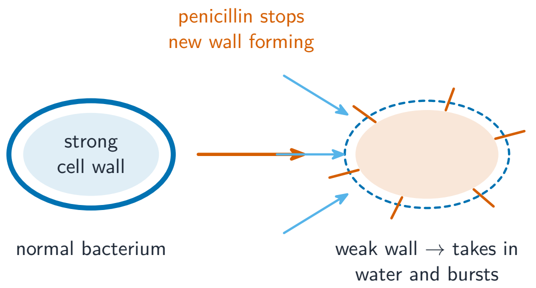
Control has **biological**, **social** and **economic** sides — the science of the pathogen, people's behaviour and education, and the money and resources available. Examples:

- **cholera**: provide clean water and proper sewage treatment; good hygiene; **vaccines** 疫苗 in some areas.
- **malaria**: sleep under nets; remove pools of still water where mosquitoes breed; spray **insecticides** 杀虫剂; take anti-malarial drugs.
- **TB**: find and treat infected people with a long course of antibiotics; give the BCG vaccine; reduce overcrowding; trace contacts of patients.
- **HIV**: use condoms; use clean needles; test donated blood; educate people. There is no cure and no vaccine yet, but drugs can slow the virus down.

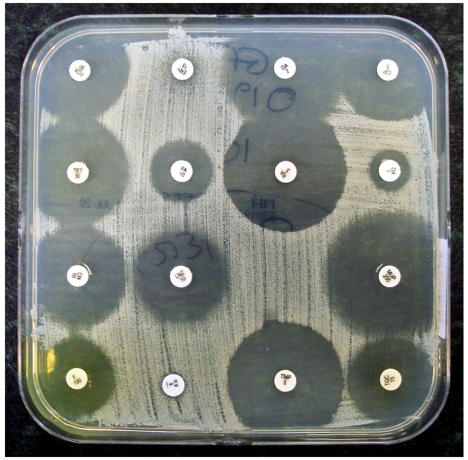
In every case, cost (economic), people's willingness to change behaviour (social) and the supply of drugs or vaccines (biological) all affect how well a disease can be controlled.

Antibiotics

An **antibiotic** 抗生素 is a drug that kills bacteria or stops them growing. For example, **penicillin** 青霉素 stops bacteria from building their **cell walls** 细胞壁. As the bacterium grows, its weak wall cannot hold it, so the cell takes in water and bursts.



Penicillin stops new cell wall forming, so the bacterium takes in water and bursts



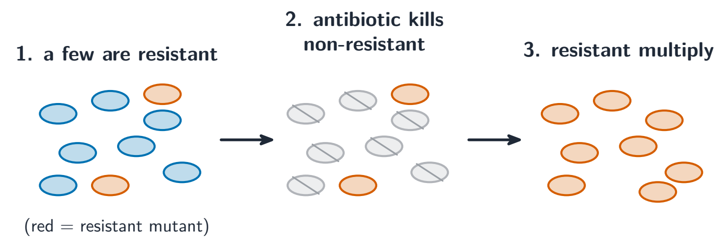
How we test which antibiotic works. Each paper disc holds a different antibiotic. A clear ring means that antibiotic killed the bacteria around it — the bigger the ring, the more effective the drug. Discs with no ring are ones the bacteria resist

Antibiotics do **not** work against **viruses**. A virus has no cell wall and no chemical reactions of its own to attack — it simply uses the machinery of the host cell. So there is no antibiotic target in a virus.

Antibiotic resistance

Sometimes a **mutation** 突变 makes a bacterium **resistant** to an antibiotic, which means the antibiotic no longer kills it. This **resistance** 耐药性 is a serious problem:

- when an antibiotic is used, the non-resistant bacteria die, but any resistant ones survive and multiply. Over time, more and more bacteria carry the resistance.
- some infections then become very hard, or impossible, to treat.



Antibiotic resistance spreads by natural selection: the antibiotic kills the rest, so the resistant survivors take over

Steps to slow resistance down:

- only use antibiotics when they are really needed (not for viral illnesses such as colds).
- always finish the full course, so no bacteria are left alive.
- use the correct antibiotic for the infection.
- reduce the heavy use of antibiotics in farming.

Worked example. A patient with influenza is prescribed an antibiotic. Explain why it will not help, and why it is actively harmful. Antibiotics work by attacking structures or processes that **bacteria** have and human cells do not - penicillin, for instance, blocks **cell wall** synthesis, so the growing bacterium bursts under osmotic pressure. A **virus** has no cell wall, no ribosomes of its own and no metabolism: it replicates **inside** the host's cells using the host's machinery, so there is simply no bacterial target for the drug to attack. Taking it anyway exposes the patient's harmless resident bacteria to the antibiotic, killing the susceptible ones and **selecting for resistant** ones - which is how resistance spreads through a population. Name the **target that is missing**: "viruses are not alive" is not the reason and earns nothing.

Exam tips

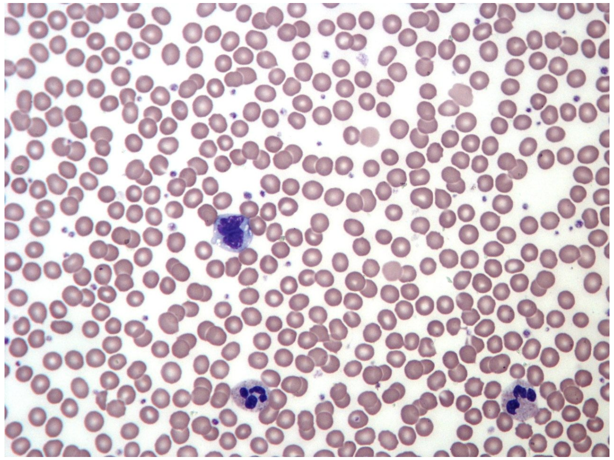
- For each named disease give the **pathogen and route** (cholera – bacterium, water; malaria – Plasmodium, mosquito vector; also TB, HIV/AIDS).
- Explain why **antibiotics** work on bacteria only (they target cell walls/enzymes, not viruses).
- Explain **antibiotic resistance** as natural selection: a resistant mutant survives and reproduces; reduce it by finishing courses and avoiding overuse.

Immunity

A-Level Biology

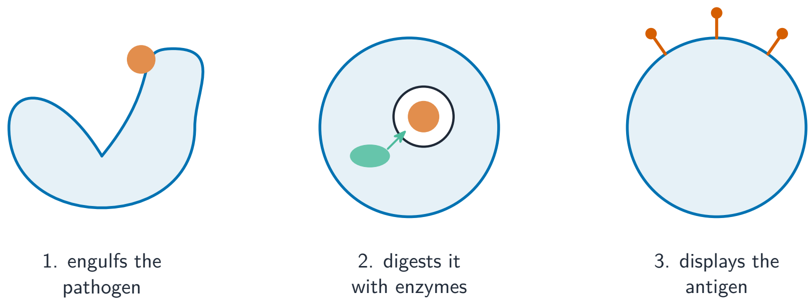
Phagocytes — the first defence

Your **immune system** 免疫系统 is the set of cells that defends the body against **pathogens** 病原体. The first cells to act are **phagocytes** 吞噬细胞, a group of white blood cells that includes **macrophages** 巨噬细胞 and **neutrophils** 中性粒细胞.



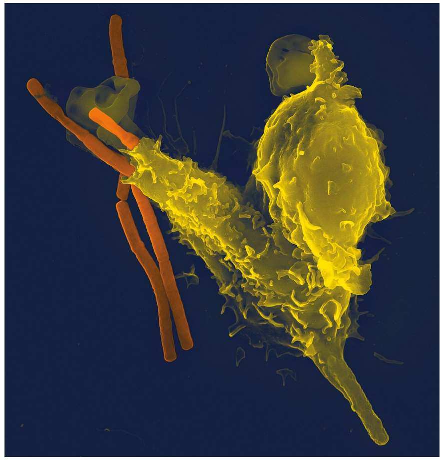
A blood smear: the large stained cells are white blood cells, scattered among the many red cells

A phagocyte destroys a pathogen by **phagocytosis** 吞噬作用: it surrounds the pathogen, takes it inside in a vesicle, and digests it with enzymes. After this, a macrophage displays parts of the pathogen on its own surface, ready to alert other immune cells.



Phagocytosis: the phagocyte engulfs the pathogen, digests it, then displays its antigen

This false-coloured electron micrograph captures the moment in real life: a phagocyte reaching out to grab and engulf rod-shaped bacteria.



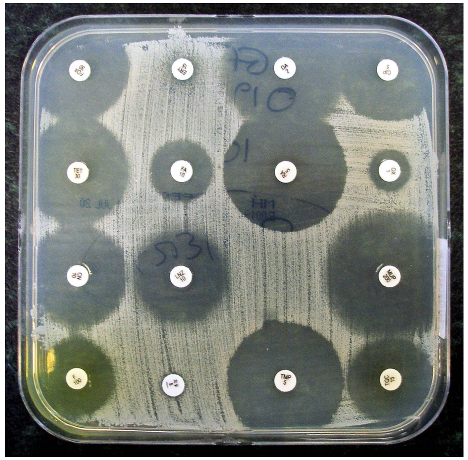
*A real **neutrophil** (yellow), one kind of phagocyte, reaching out to engulf rod-shaped bacteria (orange) by phagocytosis*

Antigens: self and non-self

An **antigen** 抗原 is a molecule (usually a protein) on a cell surface that the immune system can recognise.

- **self antigens** 自身抗原 are the body's own markers. The immune system learns to ignore them.

- **non-self antigens** 非自身抗原 are foreign, for example the antigens on a pathogen. These trigger an immune response.

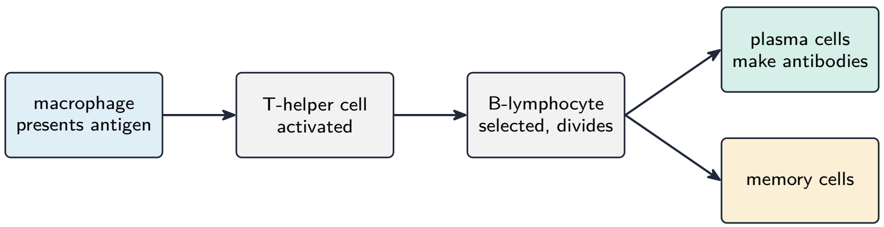


Clear zones on a culture plate: the immune system recognises non-self antigens and attacks foreign cells

The primary immune response

The first time a new pathogen enters, the body makes a slow **immune response** 免疫反应. The main steps are:

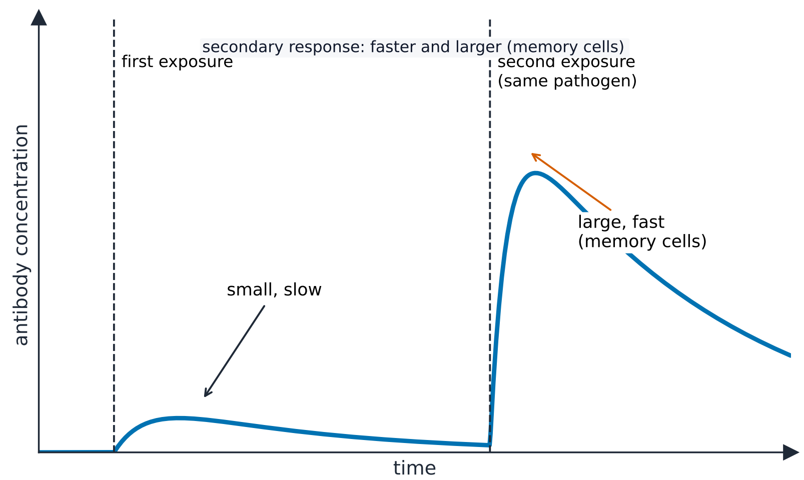
1. a macrophage engulfs the pathogen and displays its antigen.
2. **T-helper cells** 辅助性 T 细胞 recognise that antigen and become active. They release chemicals that switch on other cells.
3. **B-lymphocytes** 淋巴细胞 with a matching shape are selected. They divide to form **plasma cells** 浆细胞, which pour out **antibodies** 抗体, and **memory cells** 记忆细胞.
4. **T-killer cells** 杀伤性 T 细胞 destroy the body's own cells that have been infected.



Only the B-lymphocyte whose shape matches the antigen is selected and cloned — into antibody-making plasma cells and long-lived memory cells

Memory cells and long-term immunity

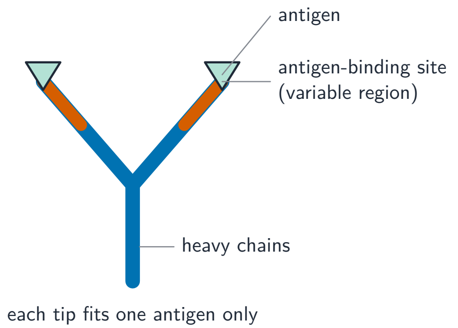
Memory cells stay in the body for years after the infection is over. If the **same** pathogen enters again, the memory cells start a **secondary** immune response that is much faster and larger than the first. The pathogen is destroyed before it can make you ill. This is what we mean by long-term immunity.



The secondary response is faster and larger, because memory cells are ready

Antibodies

An antibody is a Y-shaped protein made by plasma cells. The two tips of the Y are **antigen-binding sites** 抗原结合位点. Each site has a special shape, called the **variable region** 可变区, that fits one antigen only, like a lock and key.



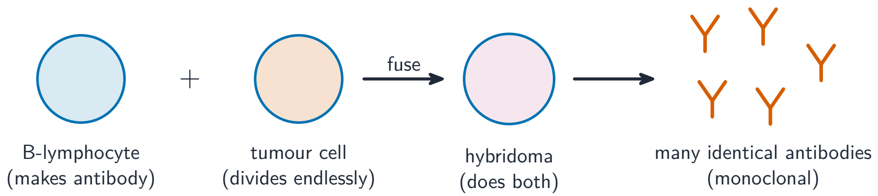
An antibody is Y-shaped; the two tips are the variable regions that bind one specific antigen

Antibodies help in several ways: they stick to antigens, clump pathogens together so they are easier to deal with, mark pathogens so phagocytes find them, and block harmful toxins.

Monoclonal antibodies

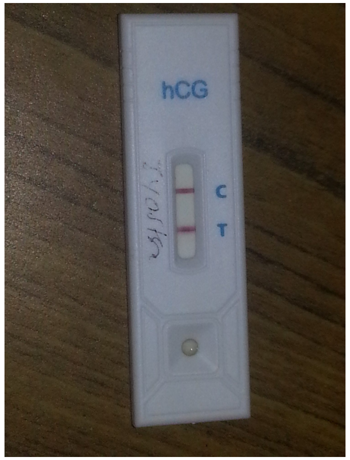
A **monoclonal antibody** 单克隆抗体 is a single type of antibody, all identical. They are made by the **hybridoma** 杂交瘤 method:

1. an animal is given an antigen, so it makes B-lymphocytes that produce the wanted antibody.
2. these B-lymphocytes are fused with tumour cells, which divide endlessly.
3. the fused cell (the hybridoma) both makes the antibody **and** divides without stopping, producing large amounts of one identical antibody.



Fusing a B-lymphocyte with a tumour cell makes a hybridoma that pours out one identical (monoclonal) antibody

Monoclonal antibodies are used in the **diagnosis** 诊断 of disease (to detect a specific molecule, as in a pregnancy test) and in treatment (to carry drugs to specific target cells, such as cancer cells).



A pregnancy test is monoclonal antibodies at work. The antibodies are fixed at the T line and grab only one molecule — the pregnancy hormone hCG. The T line turns red only if hCG is in the urine; the C line always appears, to show the test ran properly

Types of immunity

Immunity can be active or passive, and natural or artificial.

- **active immunity** 主动免疫 — your own body meets an antigen and makes its own antibodies and memory cells. It is slow to start but long-lasting.
- **passive immunity** 被动免疫 — ready-made antibodies are given to you from outside. It works at once but does not last, because there are no memory cells.
- **natural immunity** 天然免疫 — gained in a natural way (active: after an infection; passive: antibodies passed from mother to baby).
- **artificial immunity** 人工免疫 — gained on purpose (active: your body is made to respond to a safe dose of antigen; passive: you are injected with ready-made antibodies).

	natural	**artificial**
active	after an infection (your body responds)	vaccination (safe dose of antigen)
passive	antibodies passed from mother to baby	injection of ready-made antibodies

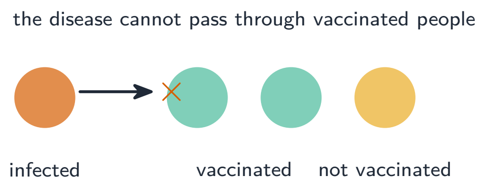
active = your body makes its own antibodies (slow, long-lasting);
passive = ready-made antibodies given (fast, short-lived)

Active immunity (your body responds) lasts; passive immunity (ready-made antibodies) is fast but short

Vaccination

A **vaccine** 疫苗 contains antigens — often a dead or weakened pathogen, or part of one. The antigens trigger a primary immune response and make memory cells, so you gain long-term immunity **without** becoming ill.

Vaccination 疫苗接种 programmes can control the spread of a disease across a population. If enough people are vaccinated, the pathogen cannot pass easily from person to person. This protects even the people who are not vaccinated, an effect called **herd immunity** 群体免疫.



Herd immunity: when enough people are vaccinated, the pathogen cannot reach the few who are not

Worked example. Classify each as active or passive, natural or artificial: (a) a baby receives antibodies in breast milk; (b) a child is vaccinated against measles; (c) someone recovers from chickenpox; (d) a patient bitten by a snake is given antivenom. Ask two questions each time. **Did the person make the antibodies themselves?** If yes it is **active**; if they were handed ready-made ones, it is **passive**. **Did it happen by chance or deliberately?** Naturally, or artificially. So (a) is **natural passive** - ready-made antibodies by a natural route; (b) is **artificial active** - the vaccine's antigens make the child produce their own; (c) is **natural active** - the infection made them produce their own; (d) is **artificial passive** - ready-made antibodies given deliberately. Only **active** immunity makes **memory cells**, which is exactly why passive immunity acts immediately but is **short-lived**.

Exam tips

- Distinguish **phagocytes** (engulf, non-specific) from lymphocytes: B cells → antibodies (humoral), T cells (helper/killer, cell-mediated).
- Label an **antibody** (variable region, antigen-binding site) and explain agglutination and neutralisation.
- Compare the **primary and secondary response** on a graph — memory cells make the secondary faster and larger.

- Distinguish **active vs passive** and **natural vs artificial** immunity with an example of each; explain vaccination and herd immunity.

Energy and respiration

A-Level Biology

Why living things need energy

Cells need a steady supply of **energy** 能量, which they get from **respiration** 呼吸作用. Energy is needed for:

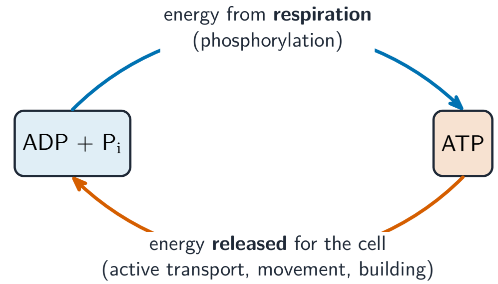
- **active transport** 主动运输 (moving substances against a gradient),
- movement (for example muscle contraction),
- **anabolic** 合成代谢 reactions — the building of large molecules, such as in DNA replication and protein synthesis.

During exercise, muscles need a constant supply of energy released by respiration

ATP — the energy currency

ATP is the molecule that carries energy to where it is needed. It is made from ADP and a phosphate group; when it loses that phosphate again, it releases a small, usable burst of energy. ATP suits this job well, so we call it the **universal energy currency**:

- it releases energy quickly, in small amounts that match a cell's needs.
- it is easily made and re-made, again and again.
- it is small and soluble, so it moves easily around the cell.

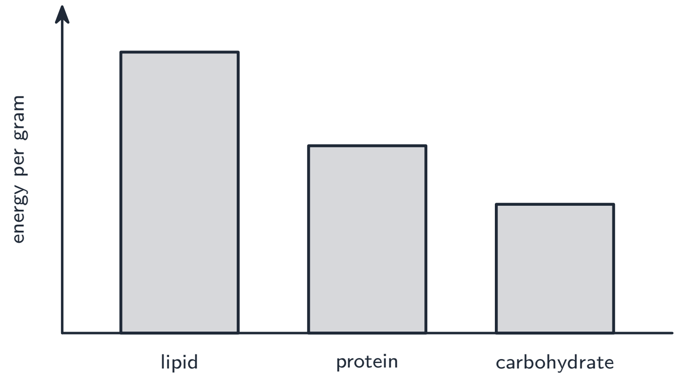


Respiration adds a phosphate to make ATP; the cell breaks it off again to release energy

ATP is made in two ways: by direct transfer of a phosphate group in **phosphorylation** 磷酸化 reactions, and by **chemiosmosis** 化学渗透 across the membranes of **mitochondria** 线粒体 and chloroplasts.

Respiratory substrates and RQ

A **respiratory substrate** 呼吸底物 is a molecule that is broken down to release energy. Per gram, **lipids** release the most energy (they have the most hydrogen), proteins are next, and carbohydrates the least.



Lipids release the most energy per gram, then proteins, then carbohydrates

The **respiratory quotient** 呼吸商 (RQ) compares the gases exchanged:

$$RQ = \frac{\text{molecules of carbon dioxide produced}}{\text{molecules of oxygen taken in}}$$

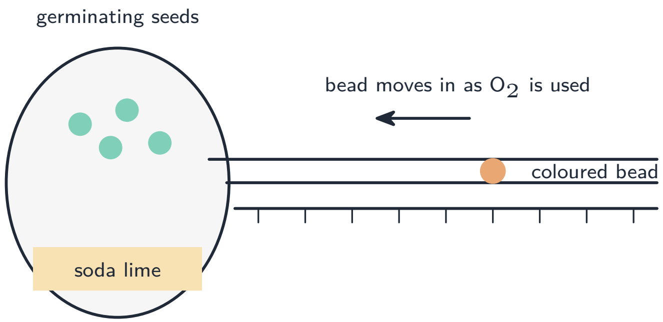
You can work out the RQ from a respiration equation. Carbohydrates give an RQ of about 1.0, lipids about 0.7 and proteins about 0.9.

Worked example. Find the RQ for the aerobic respiration of glucose: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$.

$$RQ = \frac{CO_2 \text{ produced}}{O_2 \text{ taken in}} = \frac{6}{6} = 1.0.$$

This is why an RQ near 1.0 suggests the organism is respiring carbohydrate; a lower RQ (about 0.7) suggests it is using lipid, which needs more oxygen per molecule of CO_2.

A **respirometer** 呼吸计 measures the **oxygen** 氧气 taken in by living things, such as **germinating** 萌发 seeds or small **invertebrates** 无脊椎动物, and is used to find their RQ.

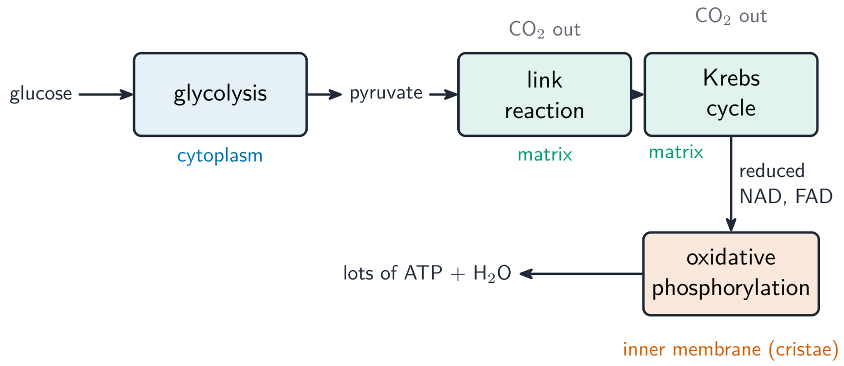


The soda lime absorbs the CO_2 given off, so the gas volume falls only by the oxygen used — and the bead moves in by that amount

Aerobic respiration: the four stages

Aerobic 有氧 respiration (with oxygen) has four stages, each in a set place in the cell:

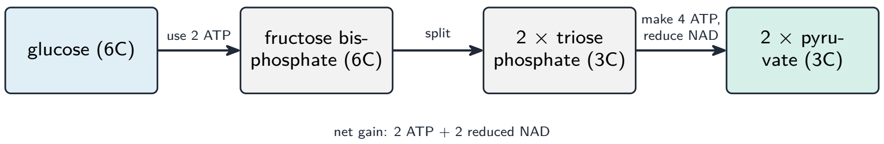
Stage	Where it happens
glycolysis 糖酵解	the **cytoplasm** 细胞质
link reaction 连接反应	the **matrix** 基质 of the mitochondria
Krebs cycle 克雷布斯循环	the matrix of the mitochondria
oxidative phosphorylation 氧化磷酸化	the inner membrane of the mitochondria



The four stages and where each happens; reduced NAD and FAD carry hydrogen to the inner membrane where most ATP is made

Glycolysis

Glucose 葡萄糖 (6 carbons) is first phosphorylated, using 2 ATP, to form fructose bisphosphate (6C). This 6C molecule is split into two triose phosphate molecules (3C each). These are then **oxidised** 氧化 to **pyruvate** 丙酮酸 (3C). Glycolysis makes a net gain of 2 ATP and some **reduced** 还原 NAD (NAD is a **coenzyme** 辅酶, a helper molecule).



Glycolysis spends 2 ATP to start but makes 4, so the net gain is 2 ATP (plus reduced NAD) — and it needs no oxygen

The link reaction

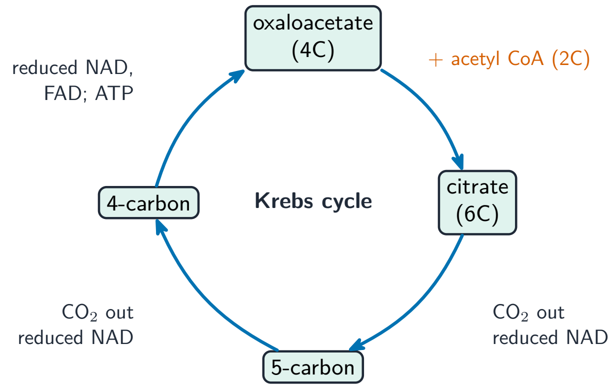
When oxygen is available, pyruvate enters the mitochondria. There each pyruvate loses a **carbon dioxide** 二氧化碳 and is turned into a 2-carbon **acetyl** 乙酰基 group. This group is carried by **coenzyme A** 辅酶 A to form acetyl coenzyme A. Some carbon dioxide is released and NAD is reduced.

The Krebs cycle

The 2C acetyl group joins a 4-carbon molecule, **oxaloacetate** 草酰乙酸, to make a 6-carbon molecule, **citrate** 柠檬酸. Citrate is then changed back to oxaloacetate in a series of small steps, ready to accept the next acetyl group. During these steps:

- **decarboxylation** 脱羧 removes carbon as carbon dioxide.
- **dehydrogenation** 脱氢 removes hydrogen, which **reduces** the coenzymes NAD and FAD.

The reduced NAD and FAD then carry the hydrogen to the carriers in the inner mitochondrial membrane.

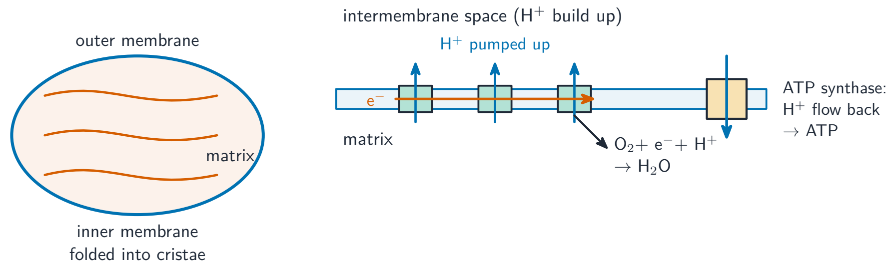


Each turn releases carbon dioxide (decarboxylation) and reduced NAD and FAD (dehydrogenation)

Oxidative phosphorylation

This stage makes most of the ATP:

1. the hydrogen atoms split into **protons** 质子 and energetic **electrons** 电子.
2. the electrons pass along the **electron transport chain** 电子传递链, releasing energy as they go.
3. this energy is used to pump protons across the inner membrane.
4. the protons flow back into the matrix through a channel called **ATP synthase** ATP 合酶. This flow provides the energy to make ATP (this is chemiosmosis).
5. **oxygen** is the final electron acceptor: it joins with electrons and protons to form water.



Electrons pump protons (H^+) into the intermembrane space; they flow back through ATP synthase to make ATP (chemiosmosis)

The structure of mitochondria

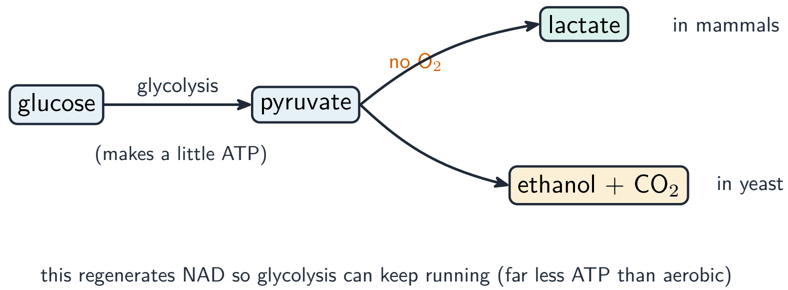
The inner membrane is folded into **cristae** 嵴, giving a large surface for the electron transport chain and ATP synthase. The matrix inside holds the substances and helpers for the link reaction and the Krebs cycle.

Two real mitochondria, photographed with an electron microscope. The dark stripes crossing the inside are the cristae — all that folding is what makes the surface for the electron transport chain so large

Anaerobic respiration

When there is no oxygen, only glycolysis can run. To keep glycolysis going, the cell must use up the reduced NAD. This happens by **fermentation** 发酵:

- in mammals, pyruvate is turned into **lactate** 乳酸 (lactate fermentation). The lactate is later broken down when oxygen returns.
- in **yeast** 酵母, pyruvate is turned into **ethanol** 乙醇 and carbon dioxide (ethanol fermentation).

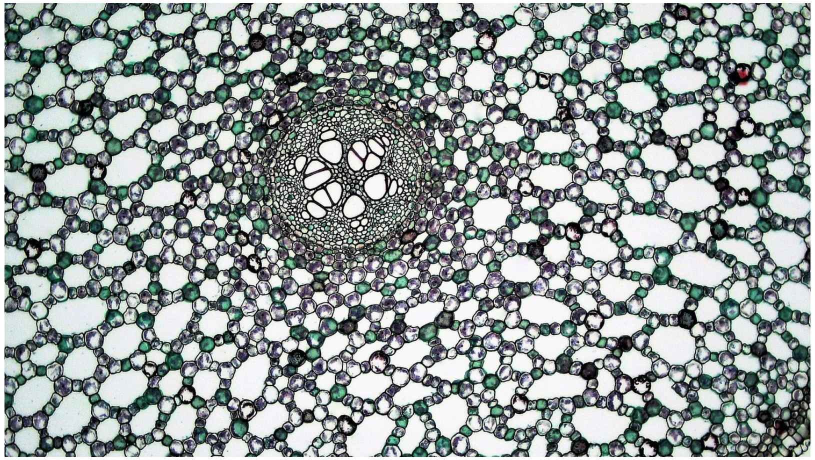


Without oxygen, pyruvate becomes lactate (mammals) or ethanol (yeast); this regenerates NAD for glycolysis

Anaerobic 无氧 respiration gives far less energy than aerobic respiration. Aerobic respiration also runs the Krebs cycle and oxidative phosphorylation, which release a lot more ATP, while anaerobic respiration gains only the small amount from glycolysis.

Rice and waterlogged roots

Rice can grow with its roots under water, where there is little oxygen. It is adapted in three ways: it develops **aerenchyma** 通气组织 (air-filled spaces) in the roots to carry air down; the roots use ethanol fermentation to keep making some ATP; and the stems grow faster to reach the air above the water.



A root of a plant that grows in water, seen in cross-section. The big white gaps are the aerenchyma — connected air channels that let oxygen diffuse all the way down to roots sitting in oxygen-poor mud

Investigating the rate of respiration

A redox **indicator** 指示剂 such as DCPIP or methylene blue loses its colour when it gains hydrogen from respiring cells. The faster the colour is lost, the faster the yeast is respiring, so you can test the effect of temperature or substrate concentration. A respirometer can also be used to measure how temperature changes the rate of oxygen uptake.

Exam tips

- State **where** each stage happens and its ATP yield: glycolysis (cytoplasm), link reaction + Krebs (matrix), oxidative phosphorylation (inner membrane, most ATP).
- Explain the roles of **NAD/FAD** (carry hydrogen to the electron transport chain) and of oxygen (the final electron acceptor).

- **RQ** = CO2 produced ÷ O2 used (≈ 1.0 carbohydrate, 0.7 lipid); know how a respirometer measures it.
- Anaerobic respiration gives lactate (animals) or ethanol + CO2 (yeast/plants) and far less ATP (glycolysis only).

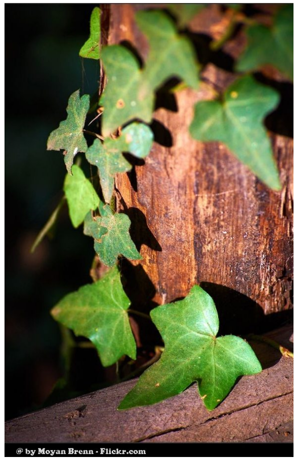
Photosynthesis

A-Level Biology

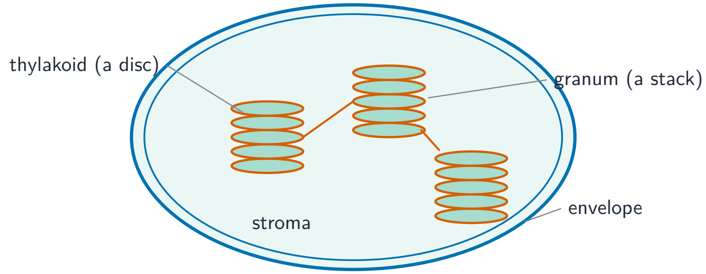
The chloroplast

Photosynthesis 光合作用 happens inside the **chloroplast** 叶绿体. Its structure suits its two stages:

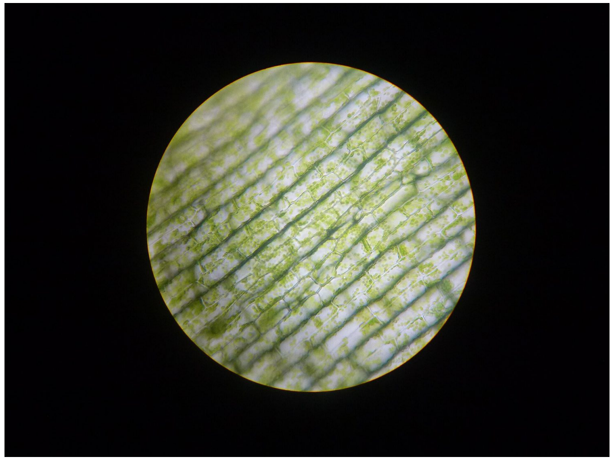
- inside are stacks of flat sacs called **thylakoids** 类囊体. A stack of thylakoids is a **granum** (plural **grana** 基粒). The thylakoid membranes hold the light-trapping pigments and are the site of the first stage.
- the fluid around the thylakoids is the **stroma** 基质, the site of the second stage.



Leaves are green because their chloroplasts are full of the pigment chlorophyll



Thylakoids stack into grana (the first stage happens here); the stroma around them is where the second stage happens

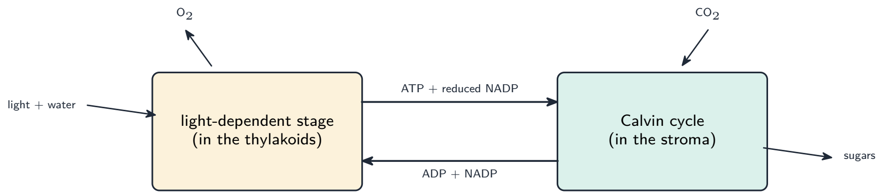


Chloroplasts (the small green discs) inside the cells of an Elodea (pondweed) leaf, seen under a microscope

The two stages of photosynthesis

Photosynthesis has two linked stages:

1. the **light-dependent stage** 光反应阶段 happens in the thylakoids. It uses light energy to make ATP and **reduced** 还原 NADP.
2. the **light-independent stage** 暗反应阶段, also called the **Calvin cycle** 卡尔文循环, happens in the stroma. It uses the ATP and reduced NADP from the first stage to build complex organic molecules from **carbon dioxide** 二氧化碳.



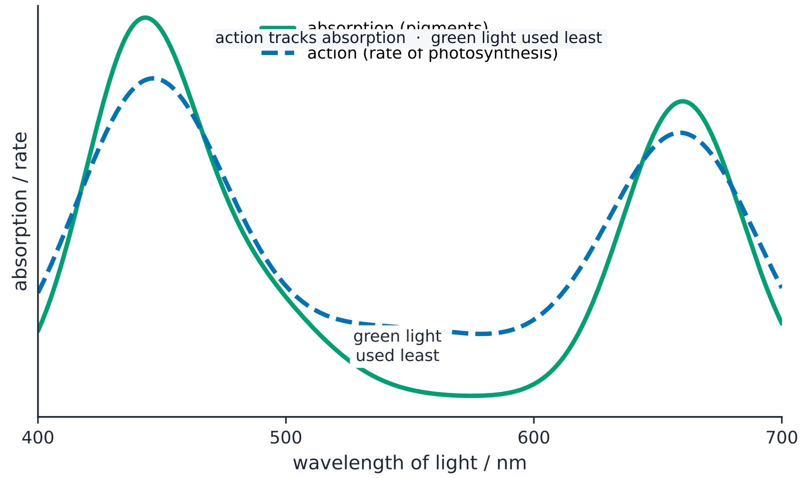
The two stages are linked: the first makes the ATP and reduced NADP that the second spends to turn CO_2 into sugars

Chloroplast pigments

A **pigment** 色素 is a coloured substance that absorbs light. The thylakoids hold several pigments that work together to trap as much light as possible:

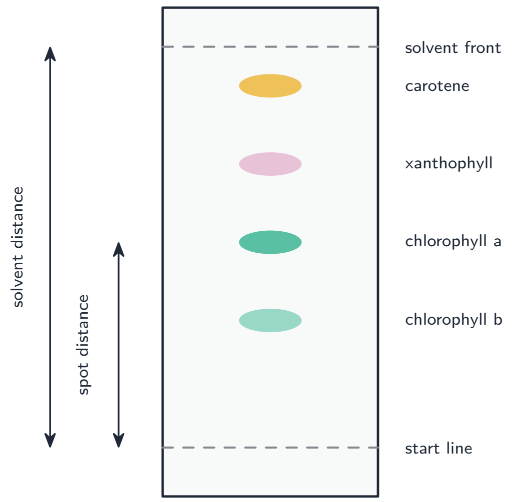
- **chlorophyll** 叶绿素 a and chlorophyll b (which absorb mainly red and blue light),
- **carotene** 胡萝卜素 and **xanthophyll** 叶黄素 (which absorb other colours and pass the energy on).

We study them with two graphs. An **absorption spectrum** 吸收光谱 shows how much light each pigment absorbs at each wavelength. An **action spectrum** 作用光谱 shows how fast photosynthesis goes at each wavelength. The two graphs match closely, which shows the pigments drive photosynthesis.



The absorption spectrum and action spectrum match: blue and red light are used most, green light least

You can separate the pigments by **chromatography** 色谱法: the pigments travel different distances up the paper. Each pigment is identified by its **Rf value** 比移值 (the distance the pigment moved divided by the distance the solvent moved).



Each pigment travels its own distance up the paper; its Rf is the spot distance divided by the solvent distance

The light-dependent stage

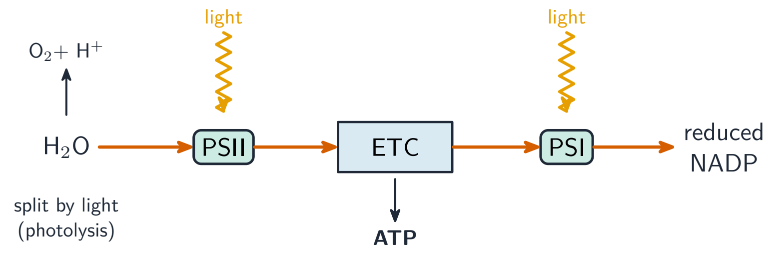
In the thylakoids, light is used to make ATP. This is **photophosphorylation** 光合磷酸化, and it comes in two forms.

In **cyclic photophosphorylation** 循环光合磷酸化:

- only **photosystem** 光系统 I (PSI) is used.
- **photoactivation** 光激活 of chlorophyll occurs (light boosts its **electrons** 电子 to a higher energy).
- only ATP is made.

In **non-cyclic photophosphorylation** 非循环光合磷酸化:

- both photosystem I (PSI) and photosystem II (PSII) are used.
- photoactivation of chlorophyll occurs.
- the **oxygen-evolving complex** 放氧复合体 carries out the **photolysis** 光解 (splitting by light) of water, which releases **oxygen** 氧气.
- both ATP and reduced NADP are made.



In non-cyclic photophosphorylation, photolysis splits water; electrons flow PSII → PSI, making ATP and reduced NADP

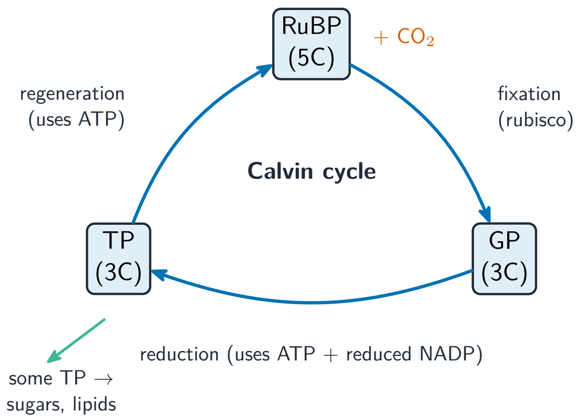
In both forms, energy is released in the same way:

1. energetic electrons pass along an **electron transport chain** 电子传递链, releasing energy as they go.
2. this energy is used to pump **protons** 质子 across the thylakoid membrane.
3. the protons flow back into the stroma through **ATP synthase** ATP 合酶, and this flow provides the energy to make ATP.

The Calvin cycle

The light-independent stage builds sugars in three main steps:

1. **fixation** 固定 — the **enzyme** 酶 rubisco joins carbon dioxide to a 5-carbon molecule, RuBP (ribulose bisphosphate). This makes two molecules of a 3-carbon compound, GP (glycerate 3-phosphate).
2. **reduction** — GP is reduced to TP (triose phosphate) using reduced NADP and ATP from the light-dependent stage.
3. **regeneration** — most of the TP is used to **regenerate** 再生 the RuBP (using more ATP), so the cycle can keep running.



Fixation adds CO_2 to RuBP; reduction makes TP using ATP and reduced NADP; regeneration remakes RuBP; some TP becomes sugars

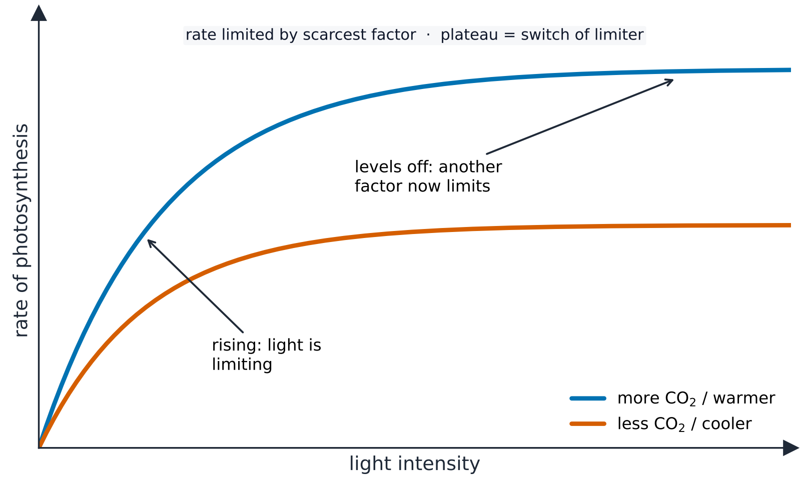
Some TP leaves the cycle to make useful molecules. GP can be used to make some **amino acids** 氨基酸, and TP can be used to make **carbohydrates** 碳水化合物, **lipids** 脂质 and amino acids.

Limiting factors

A **limiting factor** 限制因素 is the one in shortest supply that holds back the rate of photosynthesis. The three main ones are **light intensity** 光照强度, **carbon dioxide concentration** 浓度, and **temperature** 温度.

- raising light intensity speeds up photosynthesis, until some other factor becomes limiting.

- raising carbon dioxide concentration speeds it up, until some other factor becomes limiting.
- raising temperature speeds it up, but only to an optimum; too high and the enzymes denature.



While the rate rises, light is the limiting factor; where it levels off, another factor (CO_2 or temperature) limits it

You can measure the rate of the light-dependent stage with a redox **indicator** 指示剂 such as DCPIP or methylene blue and a suspension of chloroplasts: the dye loses its colour as the chloroplasts work, and you can test different light intensities or light **wavelengths** 波长. With a whole **aquatic plant** 水生植物 you can count the bubbles of oxygen given off to compare rates under different conditions.

Worked example. A plant photosynthesising steadily is suddenly deprived of carbon dioxide. What happens to the levels of GP and RuBP? Follow the cycle one step at a time. Carbon dioxide is fixed when **RuBP** combines with it, catalysed by rubisco, to make **GP**. Remove the carbon dioxide and that reaction stops, so GP is **no longer being made** - yet GP continues to be **used up**, reduced to TP using ATP and reduced NADP. So **GP falls**. Meanwhile RuBP is still being **regenerated** from TP but is no longer being **consumed**, so **RuBP rises**. The method never changes: find the reaction that stops, then ask of each substance whether it is still being **made** and still being **used**. Removing the **light** instead gives the mirror image: with no ATP or reduced NADP, GP cannot be reduced, so **GP rises and RuBP falls**.

Exam tips

- Separate the two stages: **light-dependent** (thylakoid — photolysis, ATP, reduced NADP, O2) and the **Calvin cycle** (stroma — CO2 fixed by rubisco, GP → TP).
- Read **limiting-factor** graphs: the plateau is where a different factor (light, CO2 or temperature) limits the rate.
- Interpret **chromatography** with the R_f value to identify pigments.
- Link chloroplast structure to function (thylakoid stacks for the light reactions; stroma for the Calvin cycle).

Homeostasis

A-Level Biology

What homeostasis is

Homeostasis 稳态 means keeping the conditions inside the body steady, even when the outside changes. Keeping things like temperature, water and blood glucose steady lets enzymes and cells work properly all the time.

A blood glucose meter: homeostasis keeps blood glucose within narrow limits

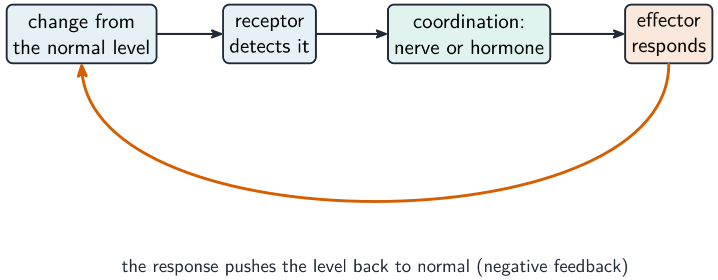
The principles of homeostasis

Most homeostasis follows the same plan:

- a change (an internal or external **stimulus** 刺激) is detected by a **receptor** 受体.
- a coordination system carries the message — either the **nervous system** 神经系统 (using nerve signals) or the **endocrine system** 内分泌系统 (using **hormones** 激素).
- an **effector** 效应器 (a muscle or a **gland** 腺体) makes a response that corrects the change.

Sweating cools the body — part of temperature homeostasis, with the skin as the effector

This works by **negative feedback** 负反馈: a change away from the normal level triggers a response that pushes it back towards normal.



Negative feedback: a receptor detects a change and an effector corrects it, returning to normal

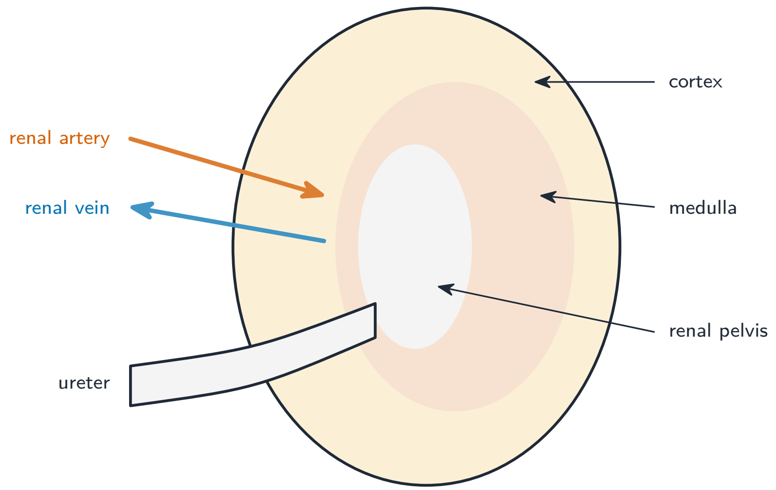
The liver and urea

The body cannot store extra amino acids. In the **liver** 肝脏, the process of **deamination** 脱氨基作用 removes the amino group from excess **amino acids** 氨基酸, and this is turned into **urea** 尿素. The urea is carried in the blood to the kidneys to be removed.

The kidney

The **kidney** 肾脏 cleans the blood and controls its water content. Its parts are:

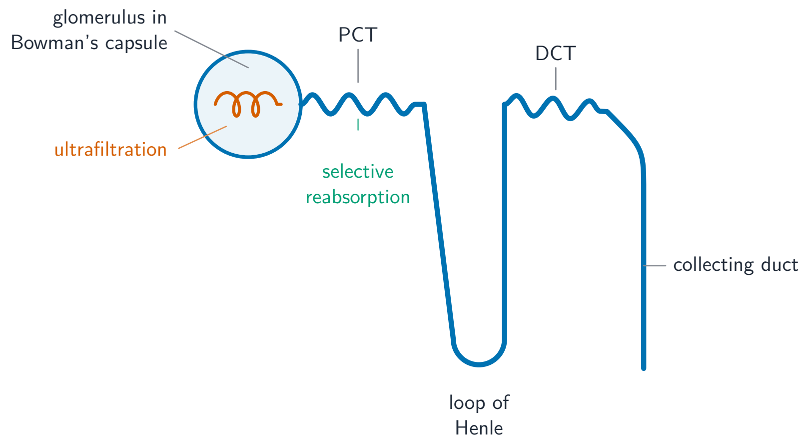
- an outer **fibrous capsule**,
- an outer region, the **cortex** 皮质,
- an inner region, the **medulla** 髓质,
- a central space, the **renal pelvis** 肾盂, which collects urine,
- the **ureter** 输尿管, which carries urine to the bladder,
- branches of the renal artery (bringing blood in) and renal vein (taking blood out).



A section through the kidney: blood is cleaned in the cortex and medulla, and urine collects in the renal pelvis before leaving down the ureter

The nephron

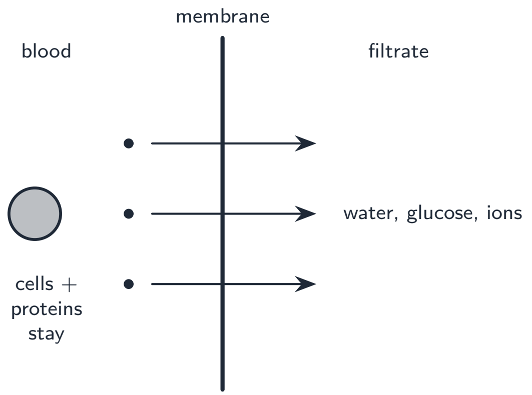
Each kidney holds about a million tiny tubes called **nephrons** 肾单位. Along a nephron are: the **glomerulus** 肾小球 (a knot of capillaries), the **Bowman's capsule** 鲍曼囊 around it, the **proximal convoluted tubule** 近曲小管, the **loop of Henle** 亨利环, the **distal convoluted tubule** 远曲小管, and the **collecting duct** 集合管.



Ultrafiltration happens in the Bowman's capsule; selective reabsorption happens in the proximal convoluted tubule

Making urine

1. **Ultrafiltration** 超滤 happens in the Bowman's capsule. The blood in the glomerulus is under high pressure, so water and small molecules (**glucose** 葡萄糖, **ions** 离子, urea) are pushed out into the capsule, forming the **filtrate** 滤液. Blood cells and large proteins are too big to pass, so they stay in the blood.
2. **Selective reabsorption** 选择性重吸收 happens in the proximal convoluted tubule. Useful substances are taken back into the blood. All the glucose and much of the water and ions are reabsorbed here. The tubule wall is well suited to this: its cells have **microvilli** 微绒毛 to give a large surface area, and many **mitochondria** 线粒体 to power **active transport** 主动运输.

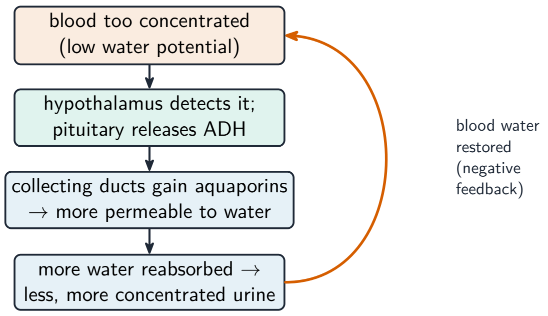


Ultrafiltration keeps blood cells and proteins in the blood

Osmoregulation

Osmoregulation 渗透调节 controls the water content of the blood. It is run by the brain:

- the **hypothalamus** 下丘脑 detects the **water potential** 水势 of the blood.
- when the blood is too concentrated, the **pituitary gland** 垂体 releases **antidiuretic hormone** 抗利尿激素 (ADH).
- ADH makes the collecting ducts more permeable to water by adding water channels called **aquaporins** 水通道蛋白.
- more water is then reabsorbed back into the blood, so less, more concentrated urine is made. This is negative feedback.

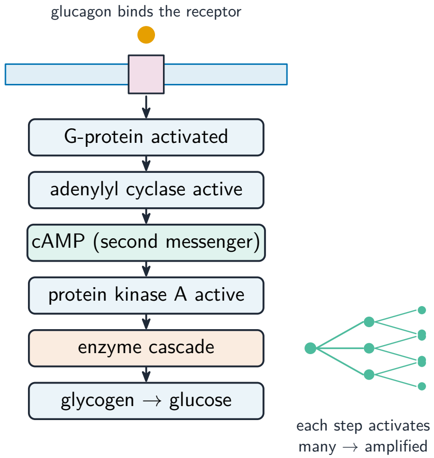


ADH makes the collecting ducts reabsorb more water, restoring the blood's water content by negative feedback

Controlling blood glucose by cell signalling

When blood glucose falls, the hormone **glucagon** 胰高血糖素 is released. It shows how a hormone passes its message into a cell — **cell signalling** 细胞信号传递:

1. glucagon binds to a receptor on the liver cell surface, causing a **conformational change** 构象变化 (a change in the receptor's shape).
2. this activates a **G-protein** G 蛋白, which switches on the enzyme **adenylyl cyclase** 腺苷酸环化酶.
3. adenylyl cyclase makes a **second messenger** 第二信使 inside the cell, called **cyclic AMP** 环腺苷酸 (cAMP).
4. cAMP activates **protein kinase A** 蛋白激酶 A, which starts an **enzyme cascade** 酶级联反应 — one **enzyme** 酶 switches on the next, by **phosphorylation** 磷酸化.
5. because each enzyme switches on many of the next, the signal is greatly **amplified** 放大.
6. the final enzyme breaks down **glycogen** 糖原 into glucose, which raises the blood glucose level.

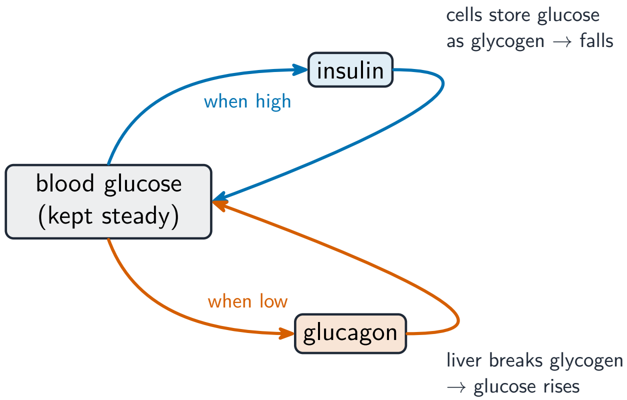


The signal passes through a second messenger (cAMP) and an enzyme cascade — each step activates many, so the signal is amplified

Negative feedback and blood glucose

Blood glucose is held steady by two hormones working against each other:

- when glucose is **high**, **insulin** 胰岛素 makes muscle and liver cells take in glucose and store it as glycogen, lowering the level.
- when glucose is **low**, glucagon makes liver cells break glycogen back into glucose, raising the level.



Insulin and glucagon work against each other to keep blood glucose steady

Measuring glucose

Test strips 试纸 and **biosensors** 生物传感器 measure glucose in blood or urine. They use the enzymes **glucose oxidase** 葡萄糖氧化酶 and **peroxidase** 过氧化物酶, which react with glucose to give a colour change (or an electric signal in a biosensor) that shows how much glucose is present.

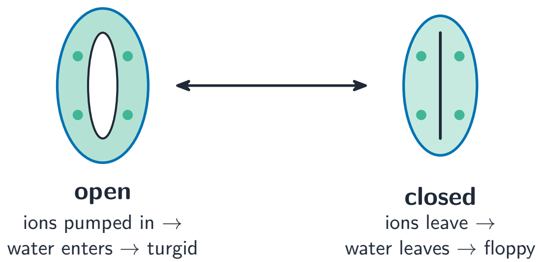
Worked example. A person drinks a large volume of water. Trace the homeostatic response. The blood's water potential **rises** (becomes less negative). **Osmoreceptors** in the hypothalamus detect this, so the posterior pituitary releases **less ADH**. With less ADH, fewer **aquaporins** are inserted into the collecting duct's membranes, so the duct becomes **less permeable** to water. Less water is reabsorbed, so a **large volume of dilute urine** is produced and the blood's water potential falls back towards normal. That return to the set point is what makes it **negative feedback** - the response reverses the original change. Name the **receptor**, the **hormone**, the **effector** and the **correction**: an answer that jumps from "drinks water" straight to "more urine" skips every marking point in between.

Homeostasis in plants: the stomata

Stomata 气孔 are pores in a leaf. The plant opens and closes them to balance two needs: letting in **carbon dioxide** 二氧化碳 for **photosynthesis** 光合作用, and limiting water loss by **transpiration** 蒸腾作用. Stomata usually open by day and close at night, following a daily rhythm.

Each stoma is opened and closed by two **guard cells** 保卫细胞 around it:

- to **open**: the guard cells pump in ions, so their water potential falls and water enters by **osmosis** 渗透. They swell and bend apart, opening the pore.
- to **close**: ions leave, water follows out, the guard cells go floppy, and the pore closes.



Guard cells open the stoma by taking in water and turgid; they close it by losing water and going floppy

When the plant is short of water (**water stress** 水分胁迫), the hormone **abscisic acid** 脱落酸 is released. It makes the guard cells lose ions and water so the stomata close, saving water. In this signalling, **calcium ions** 钙离子 act as a second messenger inside the guard cells.

Exam tips

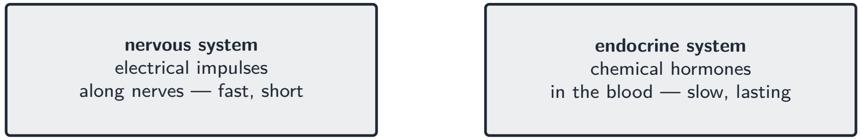
- Frame every answer as **negative feedback**: receptor → coordinator → effector → correction; name each part.
- **Blood glucose**: insulin lowers it (uptake, glycogenesis), glucagon raises it (glycogenolysis) — explain through cell signalling.
- **Kidney**: know ultrafiltration (Bowman's capsule), selective reabsorption (proximal tubule) and the role of **ADH** in osmoregulation.
- **Stomata** open when guard cells become turgid (K+ enters, water follows).

Control and coordination

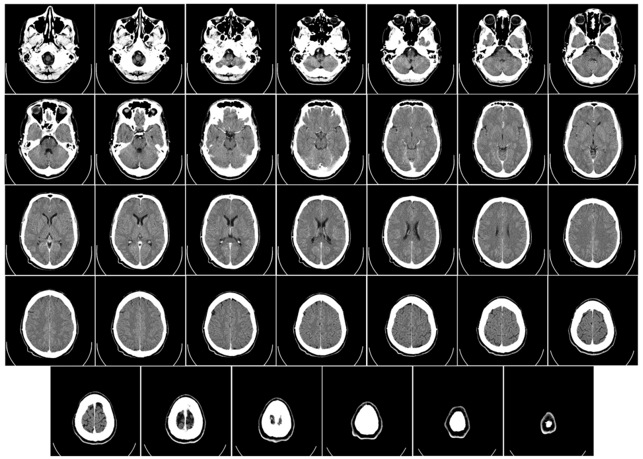
A-Level Biology

Two systems for control

The body has two coordination systems. The **endocrine system** 内分泌系统 sends chemical **hormones** 激素 (such as ADH, glucagon and insulin) in the blood. The **nervous system** 神经系统 sends fast electrical signals along nerve cells.



Nervous control is fast and electrical; hormonal control is slow and chemical



A scan of the human brain, the control centre of the nervous system

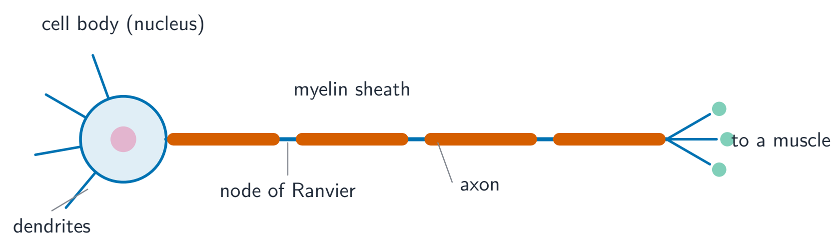
Feature	Nervous system	Endocrine system
signal	electrical **impulse** 冲动	chemical hormone
transport	along nerve cells	in the blood
speed	very fast	slower
how long it lasts	short	longer

Neurones

A **neurone** 神经元 is a nerve cell. There are three kinds:

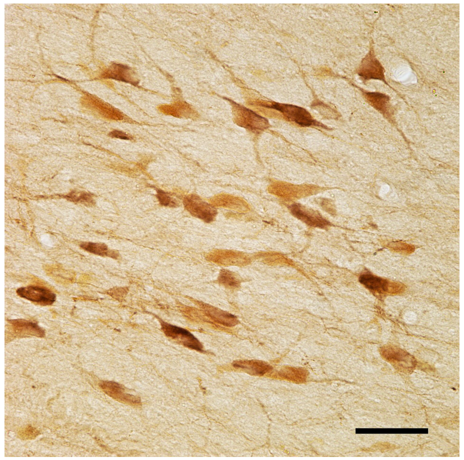
- a **sensory neurone** 感觉神经元 carries impulses from a receptor towards the brain or spinal cord.
- a **motor neurone** 运动神经元 carries impulses out to an effector, such as a **muscle** 肌肉.
- **intermediate neurones** 中间神经元 connect sensory neurones to motor neurones.

A neurone has a long fibre (the axon) along which the impulse travels.



A motor neurone: the impulse travels along the axon, jumping between the gaps (nodes of Ranvier) in the myelin sheath

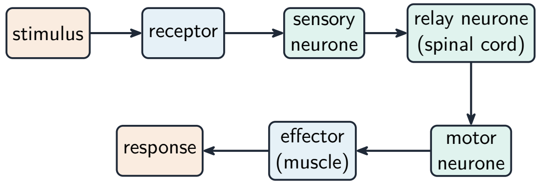
This is what real neurones look like in a stained slice of brain tissue:



*Real **neurones** stained brown: you can see the cell bodies and the thin processes that carry signals to and from each cell*

Detecting a stimulus

A **sensory receptor** 感受器 cell detects a **stimulus** 刺激 and starts an impulse in a sensory neurone. For example, a **chemoreceptor** 化学感受器 cell in a **taste bud** 味蕾 detects chemicals in food, and this triggers an **action potential** 动作电位 in the sensory neurone.

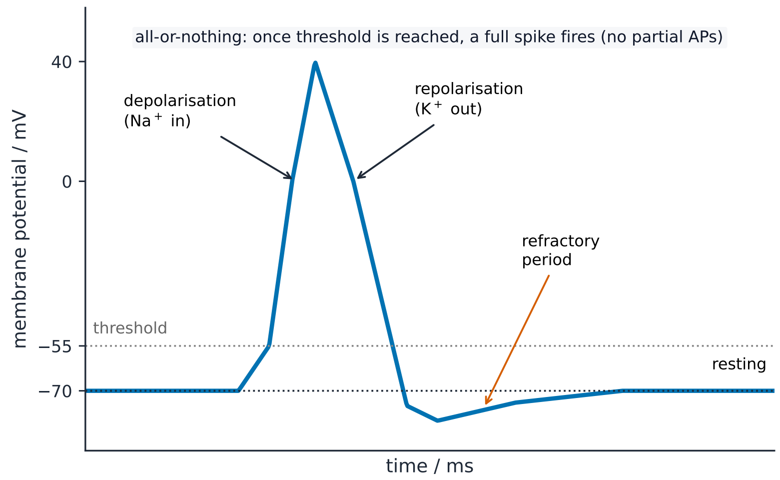


A reflex arc: stimulus → receptor → sensory neurone → relay → motor neurone → effector → response

The nerve impulse

The impulse is a change in the voltage across the neurone's membrane.

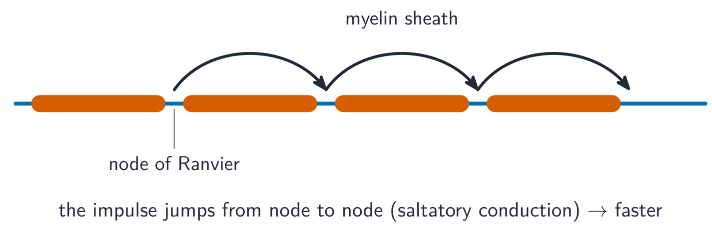
- **resting potential** 静息电位 — when no impulse passes, the inside is negative compared to the outside. This is maintained by a pump that moves sodium ions out and potassium ions in, and by the membrane being more permeable to potassium.
- **action potential** — a stimulus makes sodium channels open, so sodium ions rush in and the inside briefly becomes positive (depolarisation). Then potassium channels open, potassium ions leave, and the **membrane potential** 膜电位 returns to negative (repolarisation).
- **refractory period** 不应期 — just after an action potential, the sodium channels cannot open again for a short time. This restores the resting potential and sets a limit on how often impulses can be sent (their frequency).



An action potential: sodium in causes depolarisation; potassium out causes repolarisation; then a refractory period

Faster impulses: myelin

Some neurones are wrapped in a fatty **myelin sheath** 髓鞘. The impulse cannot cross the sheath, so it jumps from one gap to the next. This jumping, called **saltatory conduction** 跳跃式传导, makes the impulse travel much faster.

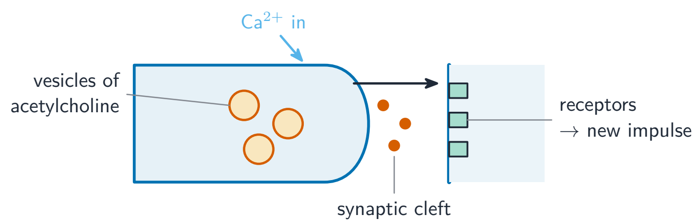


The impulse jumps node to node — saltatory conduction — so a myelinated neurone conducts much faster

The synapse

A **synapse** 突触 is a tiny gap between two neurones. A **cholinergic synapse** 胆碱能突触 passes the signal like this:

1. the impulse arrives and makes **calcium ions** 钙离子 enter the first neurone.
2. this makes vesicles release a **neurotransmitter** 神经递质 called **acetylcholine** 乙酰胆碱.
3. the acetylcholine diffuses across the gap and binds to receptors on the next neurone.
4. this starts a new impulse in the next neurone.

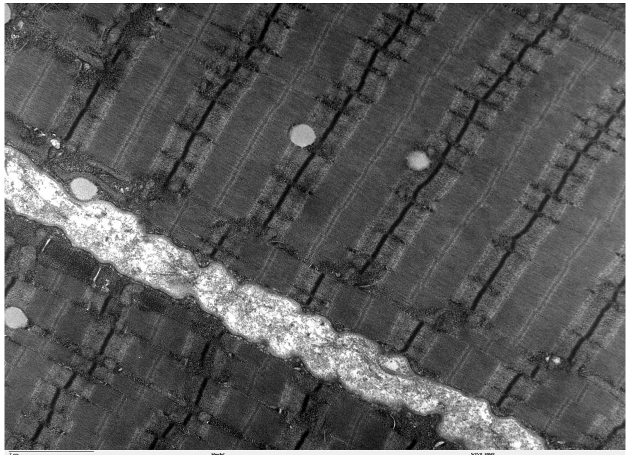


At a synapse, acetylcholine diffuses across the cleft and binds receptors to start a new impulse in the next neurone

Muscles and how they contract

A **neuromuscular junction** 神经肌肉接头 is like a synapse, but between a motor neurone and a muscle.

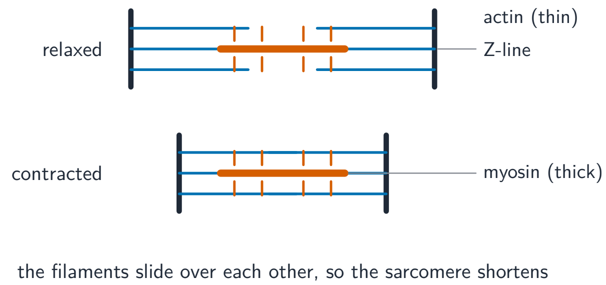
Striated muscle 横纹肌 is made of long fibres. Each fibre is divided into repeating units called **sarcomeres** 肌节. Inside are two kinds of **filament** 肌丝: thick ones (myosin) and thin ones (actin). The **T-tubule** T 小管 system carries the impulse deep into the fibre, and the **sarcoplasmic reticulum** 肌质网 stores and releases calcium ions.



This is where the name "striated" comes from. Each repeating dark-light block is one sarcomere; the bands are the thick and thin filaments overlapping by different amounts. When the muscle contracts, the filaments slide past each other and each sarcomere gets shorter

The **sliding filament model** 肌丝滑动模型 explains contraction:

1. an impulse causes the sarcoplasmic reticulum to release calcium ions.
2. the calcium ions bind to **troponin** 肌钙蛋白, which makes **tropomyosin** 原肌球蛋白 move and uncover the binding sites on the actin.
3. the myosin heads attach to the actin and pull it inwards, using energy from ATP.
4. the thin filaments slide over the thick ones, so each sarcomere gets shorter and the muscle contracts.



Sliding filament model: thin actin slides over thick myosin, so the sarcomere shortens

Control and coordination in plants

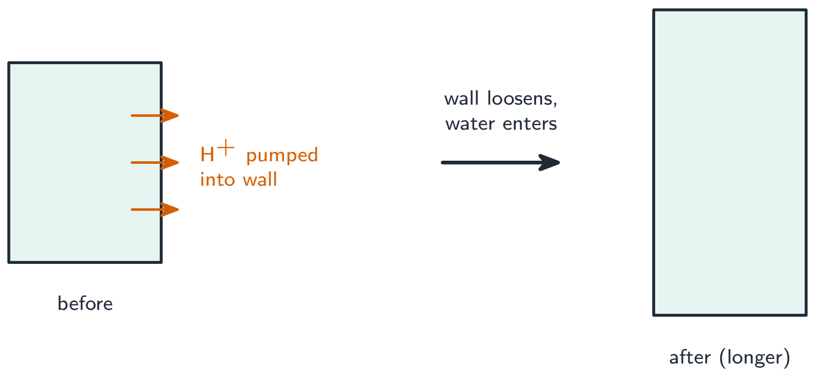
The Venus fly trap

The **Venus fly trap** 捕蝇草 has tiny hairs on its trap-like leaves. When an insect touches the hairs, a fast electrical signal spreads, the cells quickly lose water and change shape, and the trap snaps shut to catch the insect.

An open trap. The long spikes around the edge only cage the insect — it is the few short, stiff trigger hairs standing on the red surface that must be touched to fire the signal

Auxin and growth

Auxin 生长素 is a plant hormone that makes cells grow longer (**elongation** 伸长 growth). It does this by making the cell pump **protons** 质子 (hydrogen ions) into the **cell wall** 细胞壁. This **acidifies** 酸化 the wall, which loosens it, so the cell can stretch as water enters.



Auxin's "acid growth": H^+ pumped into the wall loosens it, so the cell stretches longer as water enters

Gibberellin and germination

Gibberellin 赤霉素 controls the **germination** 萌发 of **barley** 大麦 seeds. It switches on the genes that make amylase, which then breaks down stored starch into sugars to feed the growing seedling.

Worked example. Explain why a nerve impulse crosses a synapse in **one direction only**, and why myelination speeds it up along an axon. At a synapse the **vesicles** of neurotransmitter are found only in the **presynaptic** neurone, and the **receptors** only on the **postsynaptic** membrane - so transmitter can only ever cross one way, which makes the synapse a one-way valve. Along a **myelinated** axon the myelin sheath **insulates** the membrane, so ions can only cross at the **nodes of Ranvier**; the impulse therefore jumps from node to node (**saltatory conduction**) instead of depolarising every part of the membrane in turn, which is far faster and uses less ATP. Locate the **structure** responsible for each effect: vesicles and receptors give the direction, insulation and nodes give the speed.

Exam tips

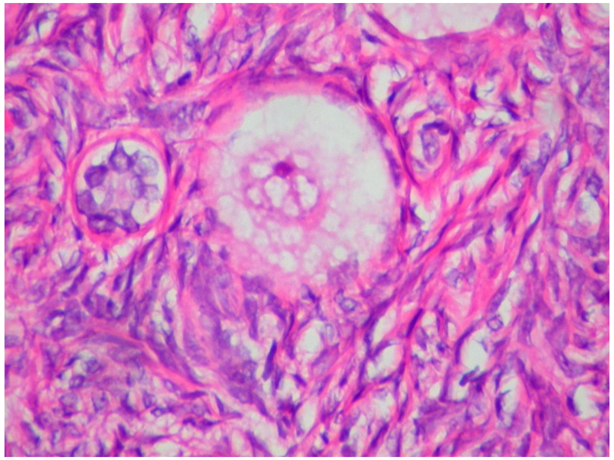
- Explain the **resting potential** (Na+/K+ pump; more negative inside) then the **action potential** (depolarisation → repolarisation) as all-or-nothing.
- **Saltatory conduction** (myelin, nodes of Ranvier) speeds the impulse; the refractory period makes it one-way and discrete.
- Describe the **synapse** in order: Ca2+ enters → vesicles fuse → neurotransmitter → receptors → new impulse.
- Muscle contraction follows the **sliding-filament** model (actin, myosin, ATP, Ca2+).

Inheritance

A-Level Biology

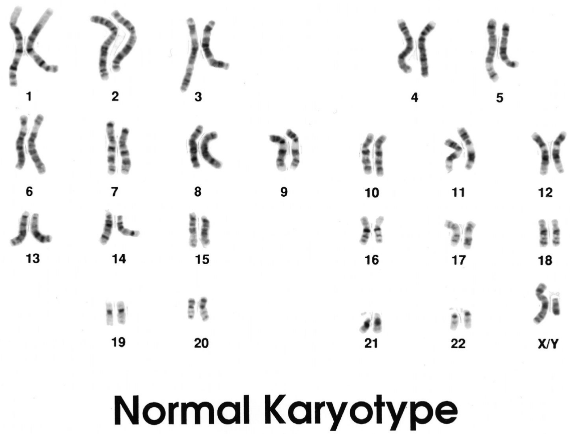
Meiosis and how it creates variation

A **diploid** 二倍体 cell (2n) has two full sets of **chromosomes** 染色体 — one set from each parent. A **haploid** 单倍体 cell (n) has just one set.

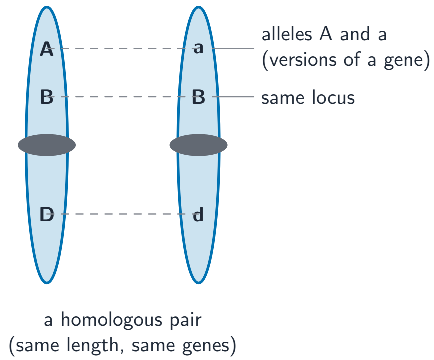


A human egg cell (ovum) — a haploid gamete produced by meiosis

Chromosomes come in **homologous chromosomes** 同源染色体 pairs: the two chromosomes in a pair are the same length and carry the same **genes** 基因 (though they may carry different versions of them).



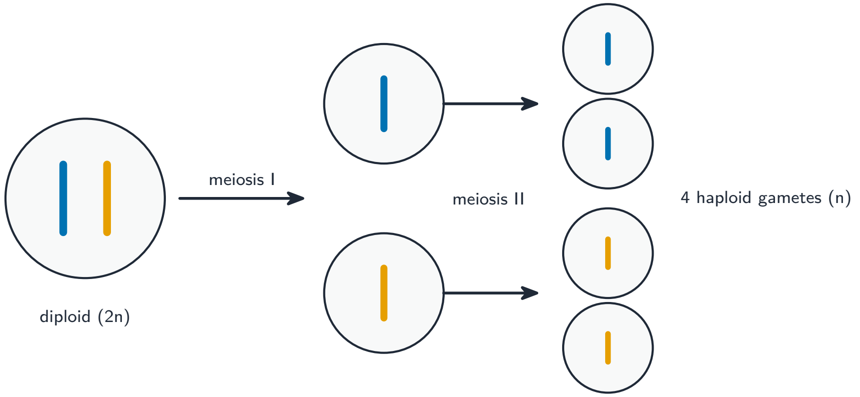
*A human **karyotype**: the 46 chromosomes sorted into 23 homologous pairs (the last pair, X and Y, shows this is a male)*



A homologous pair carries the same genes at the same loci, but the alleles (versions) may differ

Gametes 配子 (sex cells) must be haploid. If they were diploid, the chromosome number would double at every generation. So gametes are made by a special division, **meiosis** 减数分裂, which halves the chromosome number.

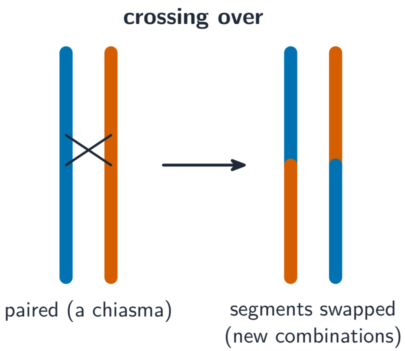
Meiosis has two divisions, one after the other, so there are eight named stages: prophase I, metaphase I, anaphase I and telophase I, then prophase II, metaphase II, anaphase II and telophase II. As in mitosis, the **nuclear envelope** 核膜 breaks down, a **spindle** 纺锤体 forms, and the chromosomes are moved by the spindle.



Two divisions halve the chromosome number: meiosis I separates the homologous pair, meiosis II separates the chromatids — giving four haploid gametes

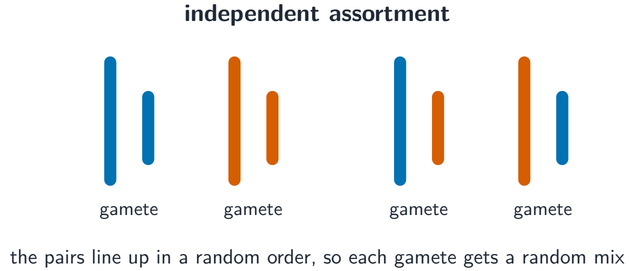
Meiosis makes the gametes **genetically different** from each other in two ways:

- **crossing over** 交叉互换 — homologous chromosomes swap matching pieces, mixing the alleles.



Crossing over: paired chromosomes swap matching segments at a chiasma, making new allele combinations

- **independent assortment** 自由组合 — the pairs line up in a random order, so each gamete gets a random mix of the parent's chromosomes.



Independent assortment: chromosome pairs line up in a random order, so gametes get many different mixes

Then at **fertilisation** 受精, any gamete can fuse with any other. This random fusion makes every new individual genetically different.

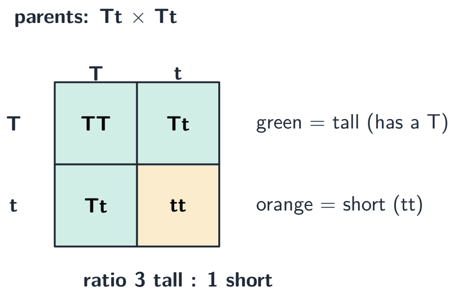
The language of genetics

You must know these terms exactly:

- a **gene** is a length of DNA that codes for a **protein** 蛋白质. Its position on a chromosome is its **locus** 基因座.
- an **allele** 等位基因 is one version of a gene.
- a **dominant** 显性 allele shows its effect even when only one copy is present; a **recessive** 隐性 allele only shows when two copies are present.
- **codominant** 共显性 alleles both show their effect together.
- the **genotype** 基因型 is the alleles an organism has; the **phenotype** 表现型 is the features you can see.
- **homozygous** 纯合 means the two alleles are the same; **heterozygous** 杂合 means they are different.
- a **test cross** 测交 crosses an organism with the recessive homozygote to find its unknown genotype.

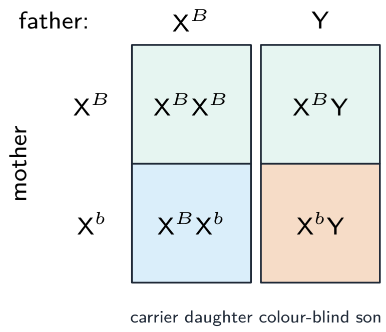
Genetic diagrams and crosses

You show a cross with a genetic diagram, often using a **Punnett square** 庞纳特方格 — a grid that shows all the ways the gametes can combine.



A Punnett square for Tt × Tt: the offspring are 3 tall : 1 short (T is dominant)

- a **monohybrid cross** 单基因杂交 follows one gene; a **dihybrid cross** 双基因杂交 follows two genes at once.
- some genes have **multiple alleles** 复等位基因 (more than two versions in the population), such as the alleles for human blood groups.
- in **sex linkage** 伴性遗传, the gene is on the X chromosome, so the result is different for males and females.
- in **linkage** 连锁, genes on the same **autosome** 常染色体 (a non-sex chromosome) tend to be inherited together.
- in **epistasis** 上位性, one gene affects how another gene is shown.



Because the gene is on the X chromosome, a carrier mother's sons may be colour-blind while her daughters are only carriers — a different result by sex

The chi-squared test

The **chi-squared test** 卡方检验 compares the results you actually counted (the *observed* numbers, O) with the results you expected from the genetic diagram (the *expected* numbers, E). It tells you whether the difference is small enough to be due to chance, or large enough to mean something else is going on.

You add up, for every group, the squared difference between observed and expected, divided by the expected:

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

Then you compare this χ^2 value with a **critical value** from a table. The row you use is set by the *degrees of freedom* (the number of groups minus 1). If χ^2 is **less than** the critical value, the difference is not significant — the results fit the expected ratio, and any difference is just chance. If χ^2 is **greater than** the critical value, the difference is significant, so some other factor is involved.

Worked example. A Tt × Tt cross gives 160 offspring: 114 tall and 46 short. Test whether this fits the expected 3 : 1 ratio.

The expected numbers are $\frac{3}{4} \times 160 = 120$ tall and $\frac{1}{4} \times 160 = 40$ short. Then:

$$\chi^2 = \frac{(114-120)^2}{120} + \frac{(46-40)^2}{40} = \frac{36}{120} + \frac{36}{40} = 0.30 + 0.90 = 1.20.$$

There are 2 groups, so degrees of freedom $= 2 - 1 = 1$. The critical value at $p = 0.05$ is 3.84. Because $1.20 < 3.84$, the difference is **not significant**: the results fit a 3 : 1 ratio, and the small difference is due to chance.

From genes to proteins to phenotype

A gene codes for a protein, and that protein affects the phenotype. If the gene is faulty, the protein is faulty, and the phenotype changes:

Gene	Protein	Effect of a faulty allele
TYR	the **enzyme** 酶 tyrosinase	**albinism** 白化病 (no pigment made)
HBB	**haemoglobin** 血红蛋白	**sickle cell anaemia** 镰状细胞贫血
F8	factor VIII (helps blood clot)	**haemophilia** 血友病
HTT	huntingtin	**Huntington's disease** 亨廷顿病

Gibberellin and stem height

In pea plants, the dominant allele *Le* codes for a working enzyme that makes **gibberellin** 赤霉素, so the plant grows tall by stem **elongation** 伸长. The recessive allele *le* codes for a broken enzyme, so little gibberellin is made and the plant is short.

Gene control

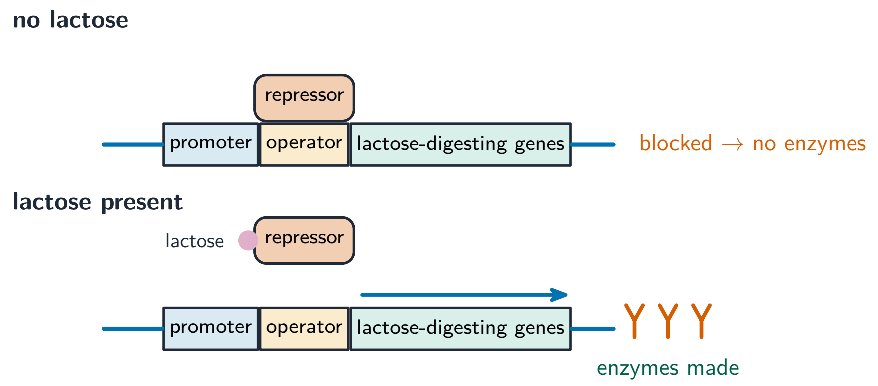
Not all genes are switched on all the time. Cells control which proteins they make.

- **structural genes** 结构基因 code for useful proteins such as enzymes; **regulatory genes** 调节基因 control whether other genes are switched on.
- an **inducible enzyme** 可诱导酶 is made only when it is needed; a **repressible enzyme** 可抑制酶 is normally made but can be switched off.

The lac operon

In a **prokaryote** 原核生物 such as a bacterium, a group of genes called the **lac operon** 乳糖操纵子 controls the digestion of lactose:

- when there is **no** lactose, a **repressor** 阻遏物 protein binds to the **operator** (a short control sequence within the operon) and blocks **transcription** 转录, so the lactose-digesting enzymes are not made.
- when lactose **is** present, it binds to the repressor and pulls it off. Transcription can now happen, and the enzymes are made. The enzymes are therefore inducible.



The lac operon: a repressor blocks the genes until lactose pulls it off, so the enzymes are inducible

Control in eukaryotes

In eukaryotes, **transcription factors** 转录因子 are proteins that bind to DNA and control **gene expression** 基因表达, by increasing or decreasing the rate of transcription.

Gibberellin switches genes on in this way: it causes the breakdown of **DELLA** protein repressors. These DELLA proteins normally block the factors that turn on transcription, so removing them lets those genes be expressed.

Exam tips

- Set out a cross fully: **parental genotypes → gametes (in circles) → Punnett square → offspring ratio and phenotypes**.
- Use the **chi-squared** test to compare observed with expected; degrees of freedom = classes −1, compare with 3.84 at $p = 0.05$.
- Recognise codominance, multiple alleles, sex linkage, epistasis and linkage — each alters the expected ratio.
- **Meiosis** creates variation by crossing over and independent assortment — state both.

Selection and evolution

A-Level Biology

Variation

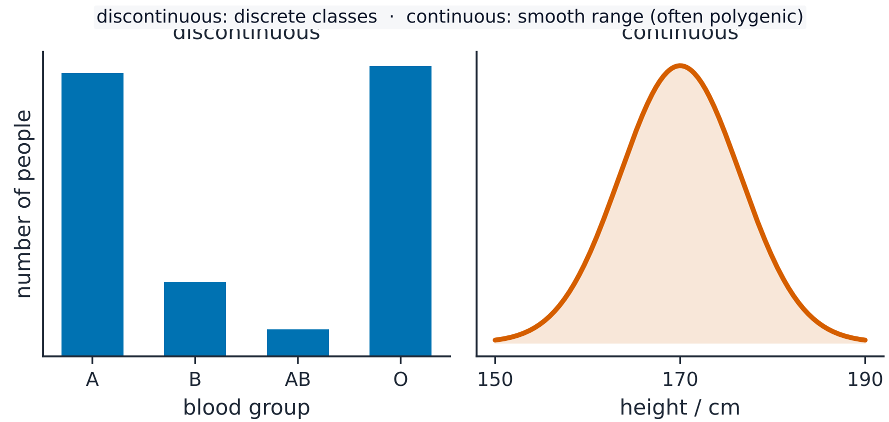
Variation 变异 means the differences between individuals. It has three possible causes:

- **genetic** factors only — set by the **alleles** 等位基因 you inherit (for example human blood group).
- **environmental factors** 环境因素 only — set by your surroundings (for example a scar, or the language you speak).
- a **combination** of both — most features, such as height and body mass, depend on genes **and** on diet and lifestyle.

Banded snails (Cepaea nemoralis) show striking variation in shell colour and banding

There are two patterns of variation:

- **discontinuous variation** 不连续变异 — clear, separate groups with nothing in between (for example blood group A, B, AB or O). It is usually controlled by one or a few **genes** 基因, with little effect from the environment.
- **continuous variation** 连续变异 — a smooth range from one extreme to the other (for example height). It is controlled by many genes together, plus the environment.



Discontinuous variation falls into separate groups; continuous variation is a smooth range

To compare the means of two samples (for example the heights of plants in sun and in shade), you use the **t-test**, which tells you whether the difference is large enough to be real, or just due to chance.

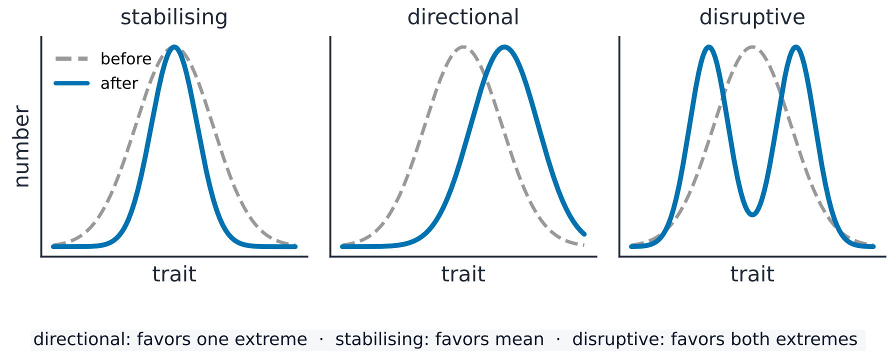
Natural selection

A **population** 种群 produces far more **offspring** 后代 than can survive, so the offspring must **compete** 竞争 for resources such as food and space. This is the "struggle for existence". The individuals that are best **adapted** 适应 are most likely to survive, **reproduce** 繁殖, and pass on their alleles to the next generation. Over many generations, the helpful alleles become more common in the population. This is **natural selection** 自然选择.

*The **peppered moth** shows natural selection: the dark form hides on dark, sooty bark, while the pale speckled form hides on pale **lichen** — birds eat whichever stands out*

Environmental conditions can push selection in three ways:

- **stabilising selection** 稳定选择 favours the average and removes the extremes (the population stays the same).
- **directional selection** 定向选择 favours one extreme, so the mean shifts that way.
- **disruptive selection** 分裂选择 favours both extremes and removes the average.



Stabilising narrows the range, directional shifts the mean, disruptive splits it in two

Allele frequencies can also change in other ways:

- the **founder effect** 奠基者效应 — a few individuals start a new population, so they carry only some of the alleles of the original group.
- **genetic drift** 遗传漂变 — in a small population, allele frequencies change by chance from generation to generation.
- the **bottleneck effect** 瓶颈效应 — a sudden fall in population size leaves few survivors, reducing the variety of alleles.

A bottleneck: only a few survive a disaster, so the recovered population has less genetic variety

Antibiotic resistance as natural selection

A chance **mutation** 突变 makes a few bacteria **resistant** to an **antibiotic** 抗生素. When the antibiotic is used, the non-resistant bacteria die, but the resistant ones survive and reproduce. Over time the **resistance** 耐药性 spreads through the population. This is natural selection in action.

The Hardy–Weinberg principle

The **Hardy–Weinberg principle** 哈迪-温伯格原理 lets you calculate the **allele frequencies** 等位基因频率 and **genotype** 基因型 frequencies in a population. It only holds true when there is a large population, mating is random, and there is no mutation, no migration and no natural selection.

Call the frequency of the dominant allele p and the frequency of the recessive allele q. There are only two alleles, so:

$$p + q = 1.$$

The genotype frequencies then add up to 1, where p^2 is homozygous dominant, $2pq$ is heterozygous (the carriers), and q^2 is homozygous recessive:

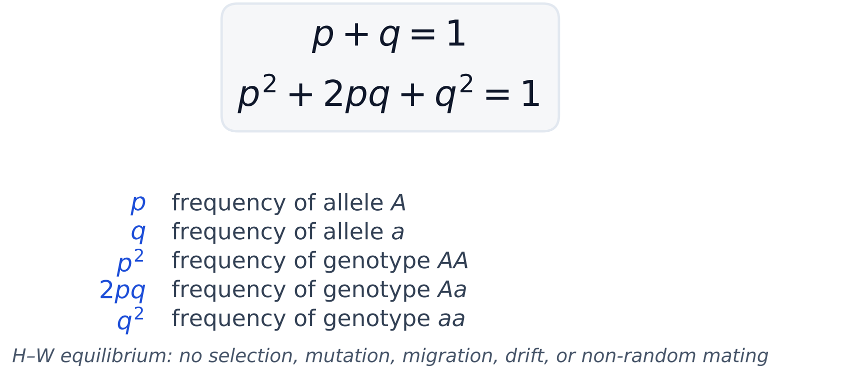
$$p^2 + 2pq + q^2 = 1.$$

Worked example. A recessive condition affects 1 in every 100 people. Find the frequency of carriers.

Only the homozygous recessive genotype (q^2) shows the condition, so $q^2 = \frac{1}{100} = 0.01$, giving $q = \sqrt{0.01} = 0.1$. Then $p = 1 - q = 0.9$. The carriers are the heterozygotes:

$$2pq = 2 \times 0.9 \times 0.1 = 0.18.$$

So about 18% of the population are carriers — far more than the 1% who show the condition.

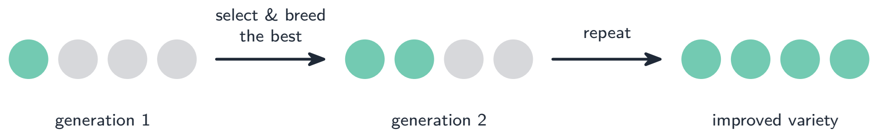


Hardy–Weinberg: allele frequencies p and q give genotype frequencies p^2, $2pq$, q^2

Selective breeding (artificial selection)

In **selective breeding** 选择育种, also called **artificial selection** 人工选择, humans (not nature) choose which organisms breed, so that useful features are passed on. Examples:

- breeding **disease resistance** 抗病性 into varieties of wheat and rice.
- using **inbreeding** 近交 and **hybridisation** 杂交 (crossing different lines) to make vigorous, uniform maize.
- breeding dairy cattle to improve their milk **yield** 产量.



Selective breeding: choosing only the best to breed each generation makes the wanted feature more and more common

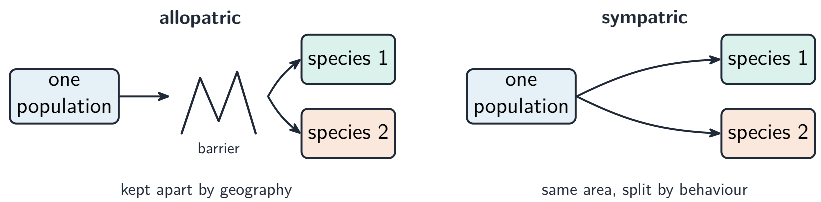
Evolution

Evolution 进化 is the slow formation of new **species** 物种 from earlier ones, as the **gene pool** 基因库 (all the alleles in a population) changes from generation to generation.

DNA **sequence** 序列 data can show how closely related two species are: the more similar their DNA sequences, the more recently they shared a common ancestor.

Speciation 物种形成 happens when two populations become genetically separated, so they can no longer breed together. This genetic **isolation** 隔离 can come about in two ways:

- **allopatric speciation** 异域物种形成 — the populations are kept apart by a **geographical separation** 地理隔离, such as a sea or a mountain range.
- **sympatric speciation** 同域物种形成 — the populations live in the same area but are separated by differences in behaviour or way of life.



Allopatric speciation needs a physical barrier; sympatric speciation happens in the same area

Exam tips

- Explain **natural selection** as a sequence: variation → selection pressure → the better-adapted survive and reproduce → allele frequency changes.
- Use the **Hardy–Weinberg** equations ($p + q = 1$, $p^2 + 2pq + q^2 = 1$); q^2 is the recessive-phenotype frequency — a common calculation.
- Distinguish **stabilising, directional and disruptive** selection with an example of each.
- Distinguish **allopatric vs sympatric** speciation (geographic vs reproductive isolation).

Classification, biodiversity and conservation

A-Level Biology

Classifying living things

A **species** 物种 can be defined in more than one way:

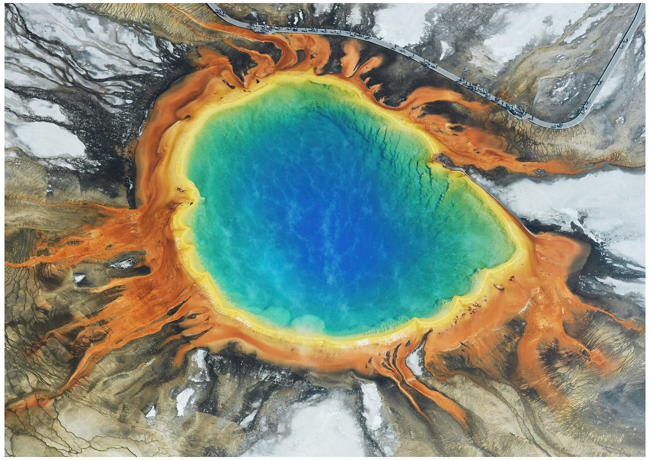
- the **biological** species concept — a group whose members can breed together to produce fertile offspring.
- the **morphological** species concept — a group whose members look alike.
- the **ecological** species concept — a group that fills the same role in its surroundings.

A museum insect collection: classification groups organisms by their shared features

The three domains

The largest groups in **classification** 分类 are three **domains** 域:

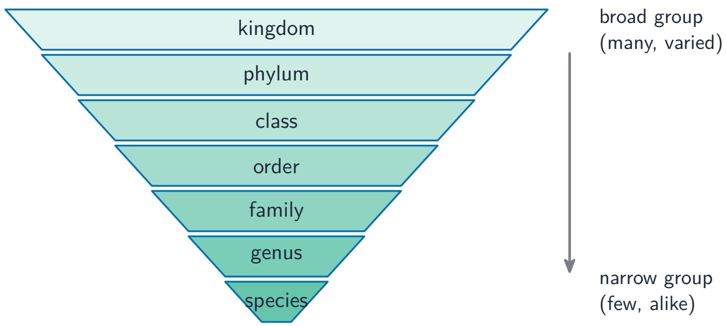
- **Archaea** 古菌 and **Bacteria** 细菌 — both are **prokaryotes** 原核生物 (no nucleus). They look similar but differ in their membrane lipids, their ribosomal RNA, and the make-up of their **cell walls** 细胞壁.
- **Eukarya** 真核生物 — all organisms whose cells have a nucleus.



Each coloured ring around this scalding spring is a different community of microbes living at a different temperature. Archaea like these — thriving where almost nothing else can — were the clue that they form a domain of their own, separate from ordinary bacteria

The taxonomic hierarchy

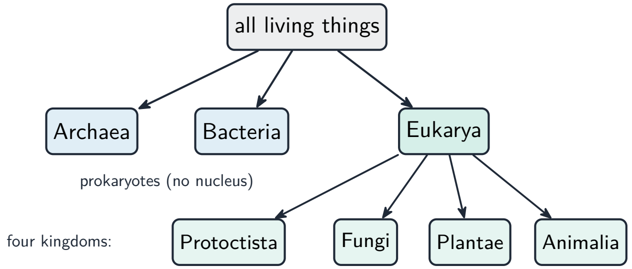
Inside the Eukarya domain, organisms are sorted into a **taxonomic hierarchy** 分类层级 — a set of smaller and smaller groups: **kingdom** 界, **phylum** 门, **class** 纲, **order** 目, **family** 科, **genus** 属 and species.



Each level of the taxonomic hierarchy is a smaller, more closely related group, ending at a single species

The Eukarya are split into four kingdoms:

- **Protoctista** 原生生物界 — mostly single-celled (such as *Amoeba*).
- **Fungi** 真菌界 — feed by absorbing food; have cell walls of chitin.
- **Plantae** 植物界 — make their own food by photosynthesis.
- **Animalia** 动物界 — feed on other organisms.



The three domains: Archaea and Bacteria are prokaryotes; the Eukarya split into four kingdoms

Viruses are not placed in these groups. They are classified by the type of **nucleic acid** 核酸 they contain (DNA or RNA) and whether it is **single-stranded** 单链 or **double-stranded** 双链.

Biodiversity

An **ecosystem** 生态系统 is all the living things in an area together with their non-living surroundings. A **niche** 生态位 is the particular role and place of a species within it.

A coral reef is a good picture of high biodiversity — many different corals, fish and other species living together:

*A **coral reef** is one of the most biodiverse habitats on Earth: many species of coral and fish share one small area*

Biodiversity 生物多样性 can be measured at three levels:

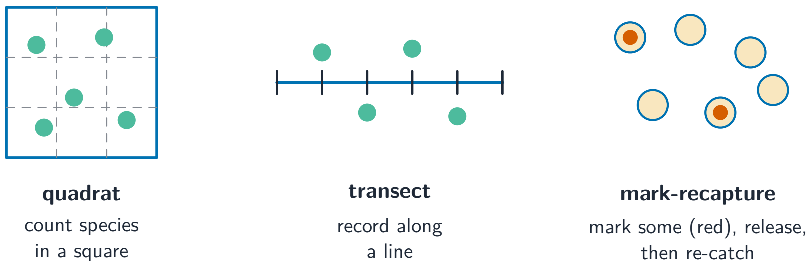
- the number and range of different ecosystems and **habitats** 栖息地.
- the number of species and their relative **abundance** 丰度 (how common each one is).
- the genetic variation within each species.

Biodiversity is measured at three levels: the range of ecosystems, the number of species, and the genetic variation within a species

Sampling an area

You cannot count every organism, so you take samples. **Random sampling** 随机取样 (choosing positions by chance) avoids bias and gives a fair picture. Useful methods are:

- **quadrats** 样方 — square frames placed to count or estimate the species inside them.
- **transects** 样带 — counting along a line across the area (a line transect records what touches the line; a belt transect counts within a strip).
- **mark-release-recapture** 标志重捕法 — for moving animals: catch, mark and release some, then later see what fraction of a new catch is marked (the Lincoln index).



Quadrats and transects sample fixed plants; mark-release-recapture estimates numbers of moving animals

To link the spread of a species to **biotic factors** 生物因素 (living) or **abiotic factors** 非生物因素 (non-living), you can use Spearman's rank or Pearson's **correlation** 相关

性. To measure the diversity of an area as a single number, you use **Simpson's index of diversity** 辛普森多样性指数: a higher value means more diverse and usually more stable.

Worked example. 60 snails are caught, marked and released. Later, 80 snails are caught, of which 15 are marked. Estimate the population. The Lincoln index assumes the marked animals have **mixed back in evenly**, so the fraction marked in the second sample equals the fraction marked in the whole population:

$$N = \frac{\text{first sample} \times \text{second sample}}{\text{number marked in the second}} = \frac{60 \times 80}{15} = 320$$

So there are about **320** snails. The estimate is only as good as its assumptions, so state them: no births, deaths or migration between the two catches; the marks neither rub off nor make the animal easier for a predator to spot; and enough time is allowed for mixing. Break one and the estimate breaks with it - a mark that attracts predators lowers the recapture count and therefore **overestimates** the population.

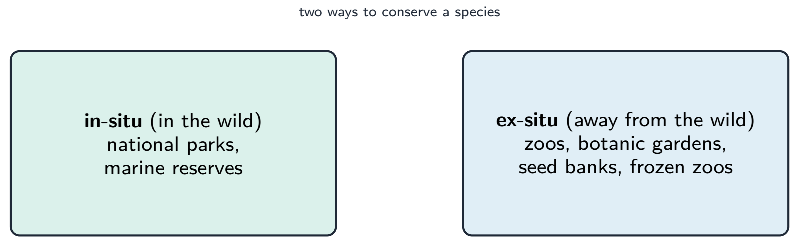
Conservation

A species can become **extinct** 灭绝 (die out completely) because of **climate change** 气候变化, competition (often from new species), hunting by humans, or the damage and loss of its habitats.

We try to protect biodiversity because other species give us food, medicines and materials, help keep ecosystems stable, and have value in themselves.

Ways to conserve species

- **zoos** 动物园 and **botanic gardens** 植物园 keep and breed **endangered species** 濒危物种.
- protected **conservation** 保护 areas, such as national parks and marine parks, keep habitats safe.
- 'frozen zoos' store frozen cells, eggs and sperm, and **seed banks** 种子库 store seeds for the future.



Conservation is either in-situ (protecting species in their own habitat) or ex-situ (keeping and breeding them away from the wild)

For rare mammals, **assisted reproduction** can boost numbers: **in vitro fertilisation** 体外受精 (IVF), **embryo transfer** 胚胎移植, and **surrogacy** 代孕 (another female carries the young).

Conservationists also control **invasive species** 入侵物种, which are brought in from elsewhere and out-compete native species.

Two organisations help worldwide: the IUCN, which lists how threatened each species is, and CITES, which controls the international trade in endangered animals and plants.

Exam tips

- Learn the **taxonomic hierarchy** (domain → kingdom → ... → species) and the three domains; a species interbreeds to give **fertile** offspring.
- Measure biodiversity with **Simpson's index** (a higher value = more diverse) and explain why high biodiversity aids stability.
- Give **in-situ vs ex-situ** conservation methods with the advantage of each.

Genetic technology

A-Level Biology

Principles of genetic technology

Recombinant 重组 DNA is DNA that has been made by joining together DNA from two different sources. **Genetic engineering** 基因工程 is the deliberate changing of an organism's genetic material — often by transferring a **gene** 基因 into an organism so that the gene is **expressed** (switched on to make its **protein** 蛋白质).

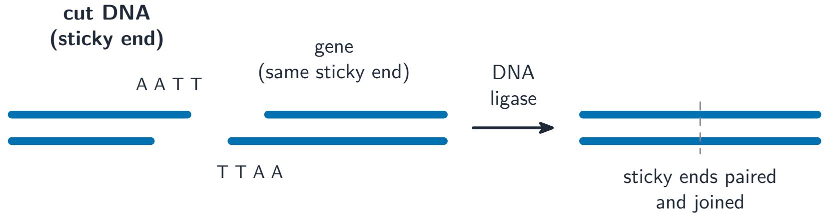
A thermal cycler (PCR machine) makes many copies of a DNA sample

The gene to be transferred can be obtained in three ways:

- cut out of the DNA of a **donor** 供体 organism,
- made from the donor's mRNA, using the enzyme **reverse transcriptase** 逆转录酶,
- built chemically from **nucleotides** 核苷酸.

The tools

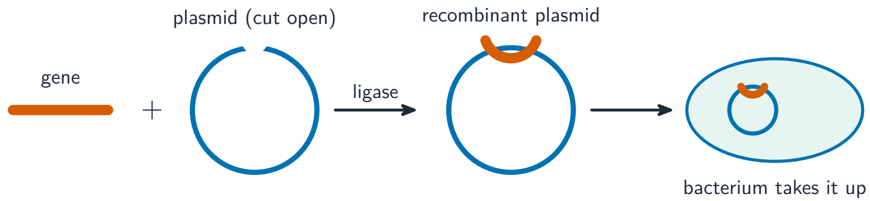
Tool	Role
restriction endonuclease 限制性内切酶	cuts DNA at a specific base sequence, leaving "sticky ends"
DNA **ligase** 连接酶	joins pieces of DNA together
plasmid 质粒	a small ring of bacterial DNA used as a **cloning vector** 载体 to carry the gene into a cell
DNA **polymerase** 聚合酶	copies DNA
reverse transcriptase	makes DNA from an mRNA template



A restriction endonuclease leaves matching sticky ends; DNA ligase joins a gene to the cut DNA

A **promoter** 启动子 often has to be transferred along with the gene. The promoter is the "switch" that lets the gene be transcribed in its new organism, so without it the gene would stay silent.

To check the gene has gone in and is working, scientists add a **marker gene** 标记基因 next to it — for example one that codes for a **fluorescent** 荧光 (glowing) product. If the cells glow, the transfer worked.



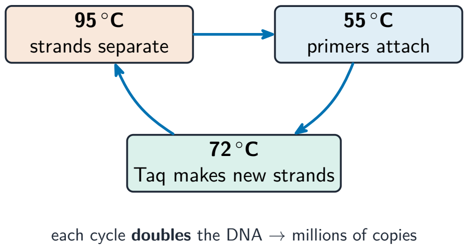
A plasmid acts as a cloning vector: the gene is joined into it, and the recombinant plasmid is taken up by a bacterium

Gene editing

Gene editing 基因编辑 is a precise form of genetic engineering. It inserts, deletes or replaces DNA at an exact site in the **genome** 基因组.

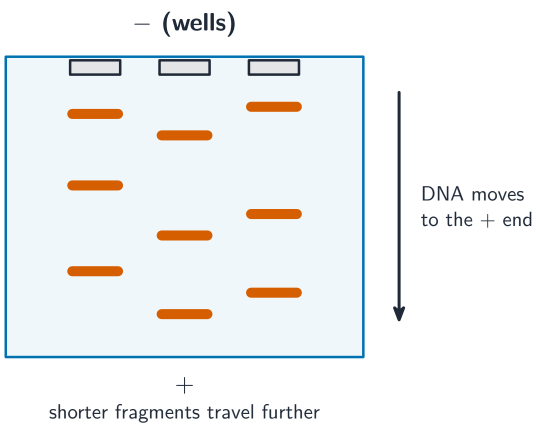
Copying and sorting DNA

- the **polymerase chain reaction** 聚合酶链式反应 (PCR) is used to **clone** 克隆 and **amplify** 扩增 DNA — to make millions of copies. It repeats cycles of heating and cooling, using a heat-stable enzyme called Taq polymerase.

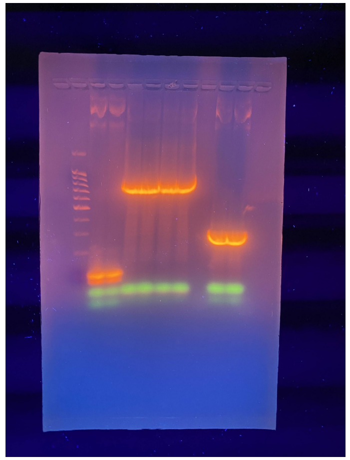


PCR repeats heat-and-cool cycles; each cycle doubles the DNA, making millions of copies

- **gel electrophoresis** 凝胶电泳 separates DNA **fragments** 片段 by length. The fragments move through a gel in an electric field, and shorter fragments move further, so the lengths spread out into bands.



Gel electrophoresis: DNA moves towards the + end, and shorter fragments travel further, sorting them by length



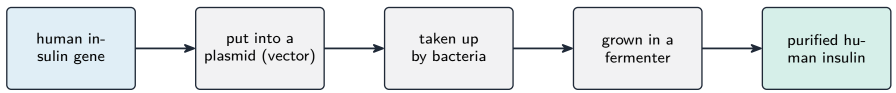
*A real gel under **UV light**: the left lane is a DNA ladder, and the glowing bands show how the fragments have separated by length*

- **microarrays** 微阵列 are used to study whole **genomes** and to detect which genes are switched on, by picking up their mRNA.
- **databases** 数据库 store the nucleotide sequences of genes and the **amino acid** 氨基酸 sequences of proteins, so scientists anywhere can compare them.

Genetic technology in medicine

Recombinant human proteins

A human gene can be put into bacteria or other cells so that they make a **recombinant** human **protein** — an exact copy of the human one. This is safer and never in short supply, and it avoids using proteins taken from animals or donors. Examples are **insulin** 胰岛素 (for **diabetes** 糖尿病), factor VIII (for haemophilia) and adenosine deaminase (for a faulty immune system).



The same tools make a human protein: the insulin gene goes into bacteria, which become living factories — so the insulin is an exact human copy and never in short supply

Genetic screening

Genetic screening 基因筛查 tests a person's DNA for disease alleles before symptoms appear. Examples are the BRCA1 and BRCA2 alleles (which raise the risk of **breast cancer** 乳腺癌), **Huntington's disease** 亨廷顿病, and **cystic fibrosis** 囊性纤维化. Knowing the result helps people make informed choices about treatment and family.

Gene therapy

Gene therapy 基因治疗 treats a genetic disease by putting a working copy of a gene into the patient's cells. It has been used for SCID (a disease in which the immune system fails) and for some inherited eye diseases.

Social and ethical questions

Genetic screening and gene therapy raise concerns: who should see your genetic results, whether insurers or employers could misuse them, whether changes are safe and permanent, and who decides. These **ethical** 伦理 and social questions must be weighed against the benefits.

Genetically modified organisms in agriculture

Genetic engineering can help feed a growing world by improving farmed animals and crops. Examples of **genetically modified organisms** 转基因生物 (GMOs) are:

- **GM salmon** 鲑鱼 that grow to size faster.
- **soybean** 大豆 made resistant to a **herbicide** 除草剂, so weeds can be sprayed without harming the crop.
- **cotton** 棉花 made resistant to insect **pests** 害虫, because it makes a protein that kills the insects.

Both plants faced the same insects. The insect-resistant GM cotton on the left is barely touched; the ordinary cotton on the right has been stripped — because the GM plant makes a protein that kills the pests as they feed

GMOs also raise ethical and social questions: whether they are safe to eat, what effect they have on the environment and wild species, whether the engineered genes might spread, and whether a few large companies should control the food supply.

Worked example. A tiny DNA sample from a crime scene must be amplified and then compared with a suspect's. Outline the two techniques and what each achieves. **PCR** copies the DNA in repeated cycles: **denaturation** at about 95 °C separates the strands, **annealing** at about 55 °C lets primers bind at each end of the target, and **extension** at about 72 °C has **Taq polymerase** build the new strands. Each cycle **doubles** the amount, so n cycles give 2^n copies - 30 cycles turn one molecule into roughly a billion. **Gel electrophoresis** then separates the fragments: DNA is **negatively charged** because of its phosphate groups, so it moves towards the **anode**, and **shorter fragments travel further** through the gel. Matching band patterns point to the same source. Taq polymerase is used because it is **thermostable** - an ordinary polymerase would denature at 95 °C in the very first cycle.

Exam tips

- Outline the toolkit: **restriction enzymes** (cut at specific sequences, sticky ends), **ligase** (join), **plasmid vectors**, and **PCR** (amplify).
- Explain **gel electrophoresis**: DNA separates by size, smaller fragments travel further — used in genetic fingerprinting.
- Give a balanced **benefit vs concern** for GMOs and gene therapy.