Course Companion

AP Biology

Every topic handout in one volume

全部专题讲义合集

exercises.lol

Contents 目录

Chemistry of Life

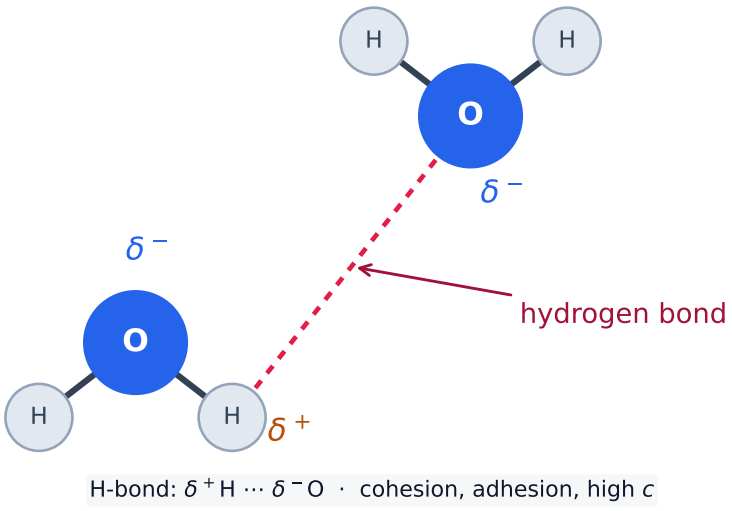
AP Biology

Structure of Water and Hydrogen Bonding

Ice floats on water because hydrogen bonding makes solid water less dense than liquid water

Water is **polar** 极性: its oxygen pulls electrons more strongly than its hydrogens, giving a slightly negative O and slightly positive H. This lets water molecules form **hydrogen bonds** 氢键 with each other, which explains water's life-supporting properties:

- **Cohesion** 内聚力 and **adhesion** 附着力 (surface tension, capillary action, water rising in plants),
- high **specific heat** 比热容 (resists temperature change, stabilizing organisms),
- high heat of vaporization (evaporative cooling),
- ice floating (less dense solid), and being a great **solvent** for polar and ionic substances.



A hydrogen bond between two polar water molecules

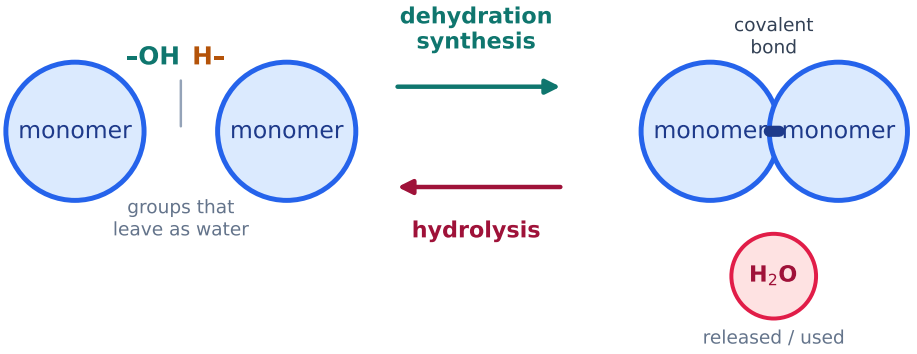
Elements of Life

Living matter is built mostly from a few elements – carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur. **Carbon** 碳 is central because it forms four stable covalent bonds, building long chains, branches, and rings – the skeletons of all biological molecules.

Carbohydrates and fats contain carbon, hydrogen, and oxygen; proteins also contain nitrogen

Introduction to Macromolecules

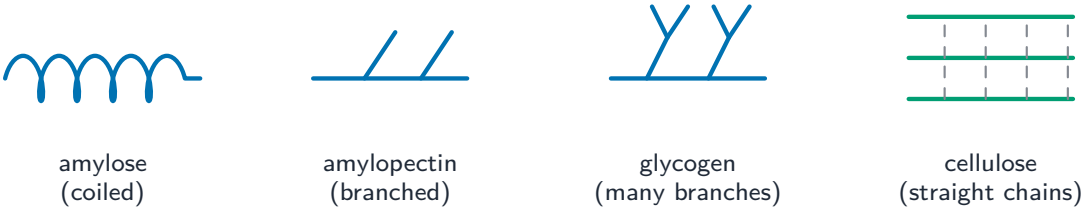
Large biological molecules – **macromolecules** 大分子 – are **polymers** 聚合物 built from repeating **monomers** 单体. Cells join monomers by **dehydration synthesis** 脱水缩合 (removing water to form a bond) and break polymers by **hydrolysis** 水解 (adding water). Four classes: carbohydrates, lipids, nucleic acids, and proteins.



Dehydration synthesis builds polymers and releases water; hydrolysis reverses it

Carbohydrates

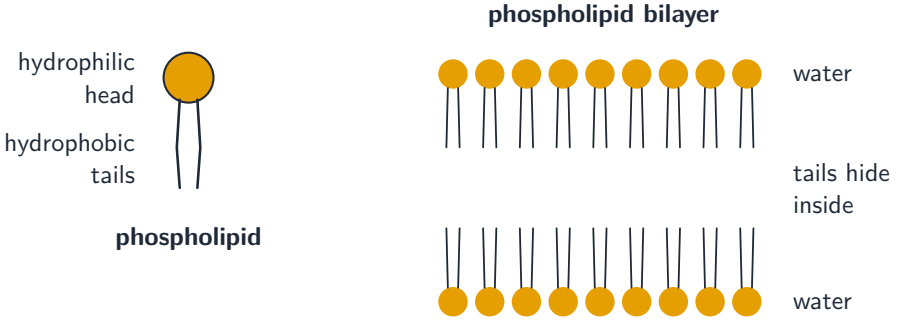
Carbohydrates 碳水化合物 are made of sugar monomers (**monosaccharides** 单糖 like glucose). They store energy (starch, glycogen) and provide structure (**cellulose** 纤维素 in plant walls). Their many hydroxyl groups make them polar and water-soluble.



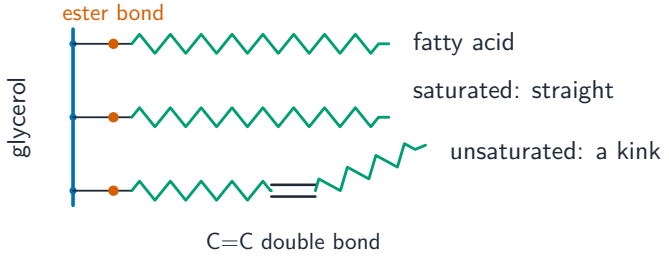
The shapes of storage polysaccharides (starch, glycogen) and structural cellulose

Lipids

Lipids 脂质 are **nonpolar** and do not mix with water (**hydrophobic** 疏水). They include fats (long-term energy storage), **phospholipids** 磷脂 (which build membranes), and steroids. A phospholipid has a polar "head" and nonpolar "tails," the key to the cell membrane.



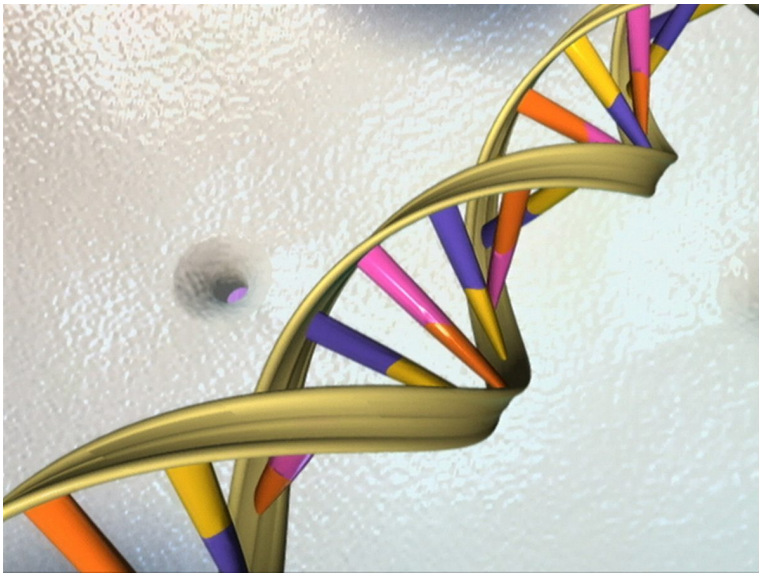
A phospholipid has a polar head and two nonpolar tails, so phospholipids form a bilayer



3 ester bonds form $\rightarrow$ 3 H_2O removed (condensation)

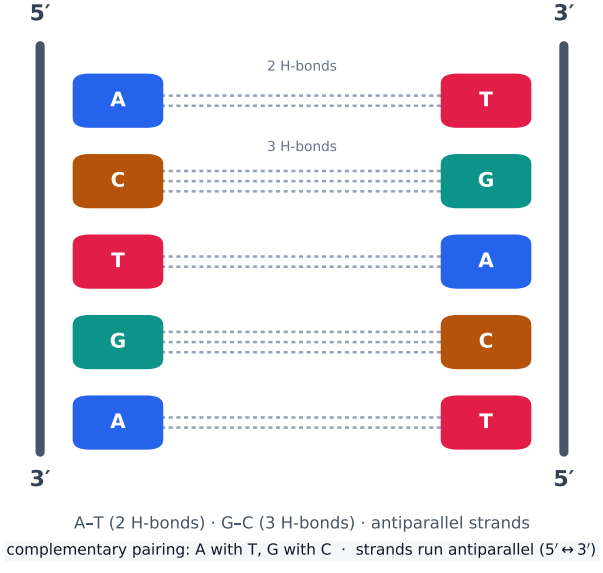
A triglyceride: glycerol joined to three fatty acids

Nucleic Acids



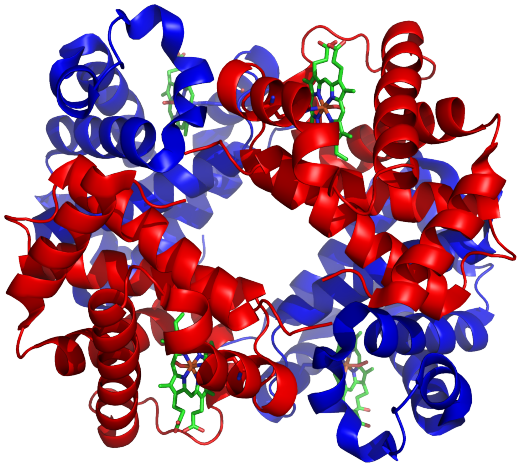
Space-filling model of the DNA double helix (NHGRI)

Nucleic acids 核酸 (DNA and RNA) store and carry genetic information. Their monomers are **nucleotides** 核苷酸, each a sugar, a phosphate, and a nitrogen base. The base sequence encodes instructions; DNA is double-stranded, RNA single-stranded.



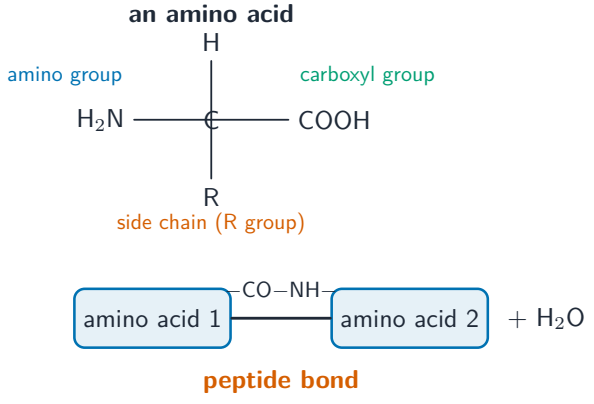
Complementary base pairing holds the two antiparallel strands of DNA together

Proteins

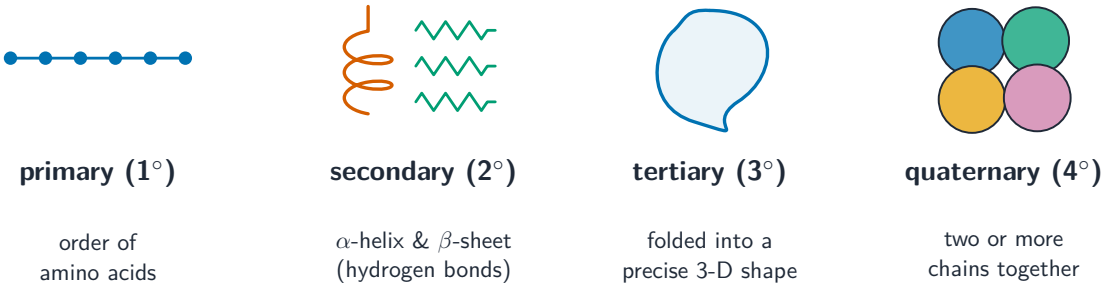


Haemoglobin quaternary structure: four folded polypeptide chains, each holding a haem group

Proteins 蛋白质 are polymers of **amino acids** 氨基酸 joined by **peptide bonds** 肽键. Their sequence folds into a specific 3-D shape at four levels (primary, secondary, tertiary, quaternary), and **shape determines function** – as enzymes, transporters, receptors, and structural parts. Changing the environment (heat, pH) can **denature** 变性 a protein, unfolding it and stopping its function.



An amino acid, and the peptide bond formed by condensation



The four levels of protein structure

Worked example. Building a polymer from **10 monomers** by dehydration synthesis forms 9 bonds and releases **9 water molecules** — one per bond, so N monomers release $N - 1$ waters. Hydrolysis reverses this exactly: adding those 9 waters breaks the polymer back into 10 monomers. This is why biosynthesis (dehydration) and digestion (hydrolysis) are chemical opposites.

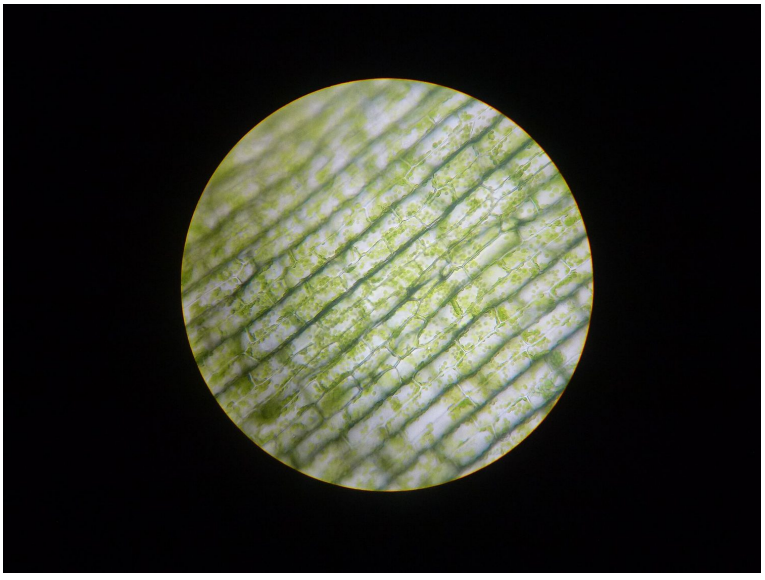
Exam tips

- Trace every property of water back to its **polarity and hydrogen bonding** (cohesion, high specific heat, solvent power).
- Know the four macromolecule classes and their monomers; polymers are built by **dehydration synthesis** and broken by **hydrolysis**.
- For proteins, **structure (shape) determines function** — heat or a pH change **denatures** them and stops them working.
- In DNA the bases pair A–T and C–G on **antiparallel** strands; RNA is single-stranded and uses U.
- Link each molecule to its role (carbohydrates: energy/structure; lipids: membranes/storage; nucleic acids: information).

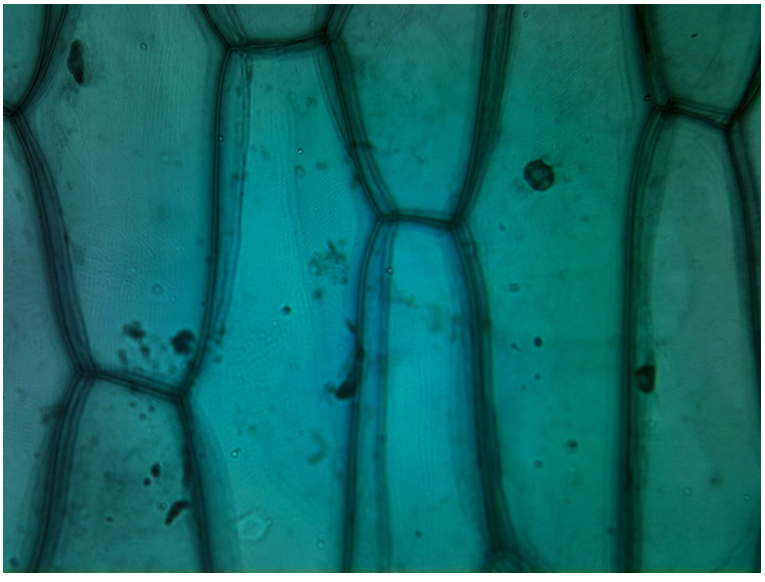
Cell Structure and Function

AP Biology

Organelles and the Endomembrane System



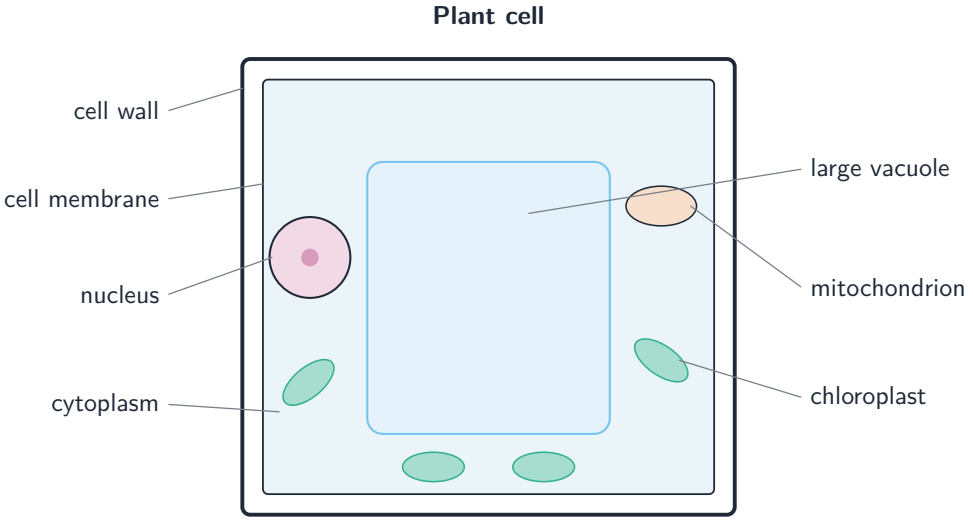
Elodea leaf cells packed with green chloroplasts (light micrograph)



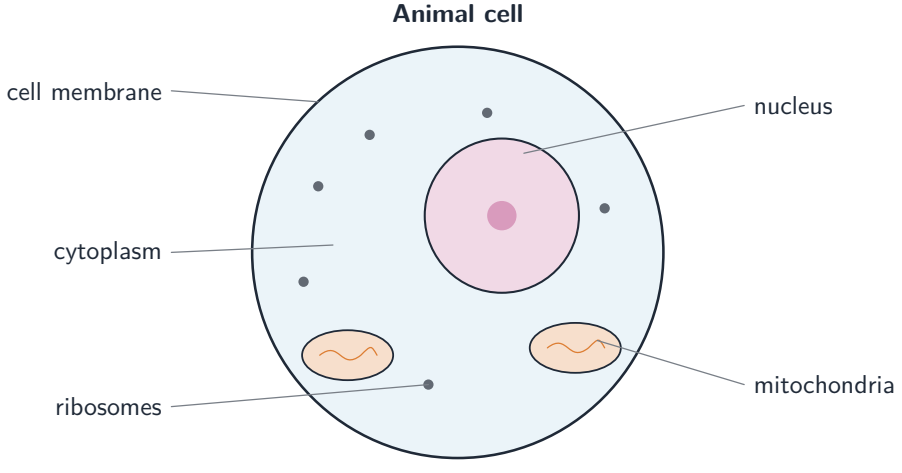
Onion epidermis cells under a light microscope — cell walls and nuclei clearly visible

A eukaryotic cell divides its work among **organelles** 细胞器. The **endomembrane system** 内膜系统 is a connected set that makes, modifies, and ships molecules: the

nucleus 细胞核 (holds DNA), rough and smooth **endoplasmic reticulum** 内质网 (protein and lipid synthesis), the **Golgi** 高尔基体 (modifies and packages), **lysosomes** 溶酶体 (digestion), and vesicles that carry material between them. **Mitochondria** 线粒体 (respiration) and **chloroplasts** 叶绿体 (photosynthesis) have their own membranes.

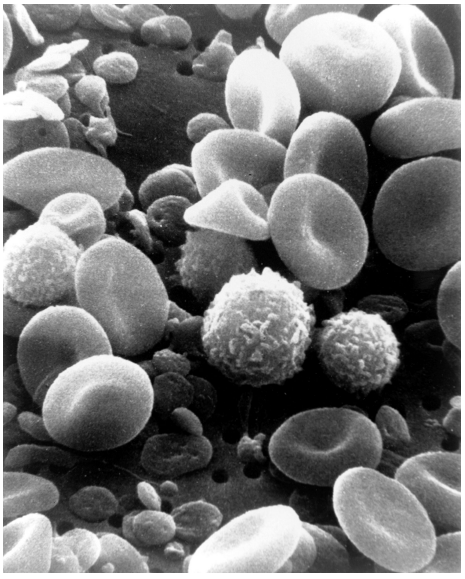


A plant cell also has a cell wall, a large vacuole, and chloroplasts



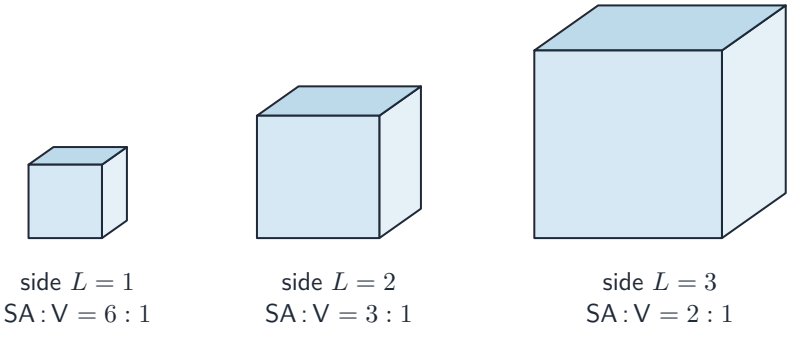
A generalised animal cell and its organelles

Why Cells Stay Small



Scanning electron micrograph of red blood cells — no nucleus, high surface area for gas exchange

Cells stay small because of the **surface-area-to-volume ratio** 表面积与体积比. As a cell grows, its volume rises faster than its surface area, so its membrane cannot exchange materials fast enough for the interior. Staying small (or being flat or folded) keeps enough surface to serve the volume.



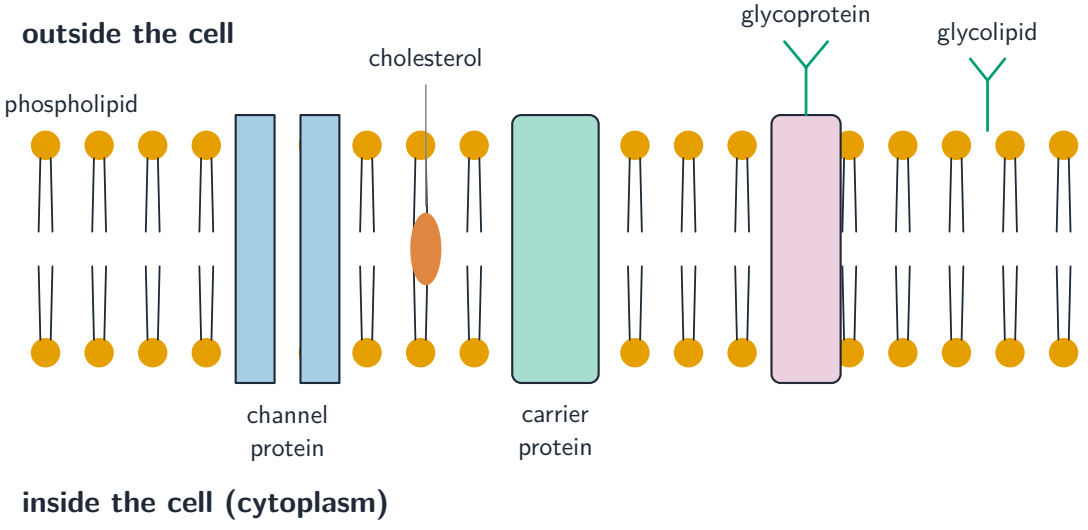
The surface-area-to-volume ratio falls as a cell gets bigger

Worked example. A cube-shaped cell 2 μm on a side has surface area $6 \times 2^2 = 24\ \mu\text{m}^2$ and volume $2^3 = 8\ \mu\text{m}^3$, so its surface-area-to-volume ratio is $\frac{24}{8} = 3$. Double the side to 4 μm: surface area $= 6 \times 4^2 = 96$, volume $= 4^3 = 64$, ratio $= \frac{96}{64} = 1.5$. Doubling

the size **halved** the ratio – the larger cell has far less membrane per unit of interior, which is why cells stay small.

The Fluid Mosaic Model of the Membrane

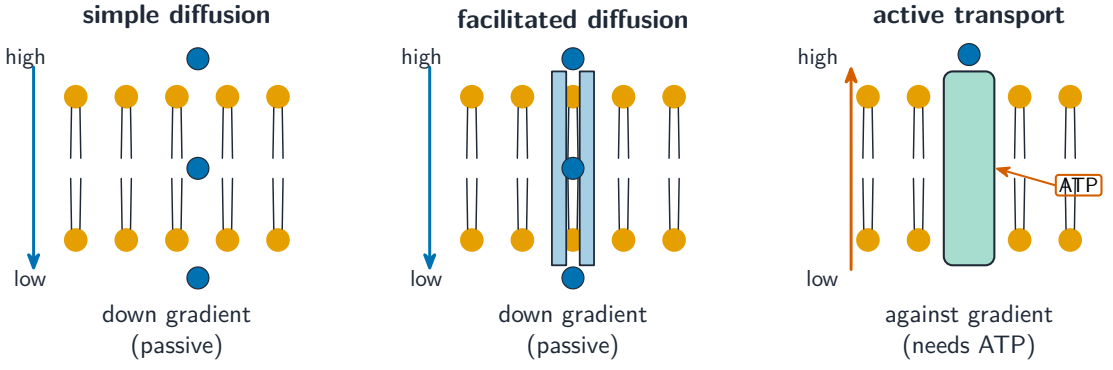
The cell membrane is a **phospholipid bilayer** 磷脂双分子层 – polar heads facing the water, nonpolar tails inside – studded with proteins. The **fluid mosaic model** 流动镶嵌模型 pictures it as a fluid sheet in which lipids and proteins drift. **Cholesterol** and the degree of unsaturation tune its fluidity.



The fluid mosaic model of the cell membrane

What Can Cross the Membrane

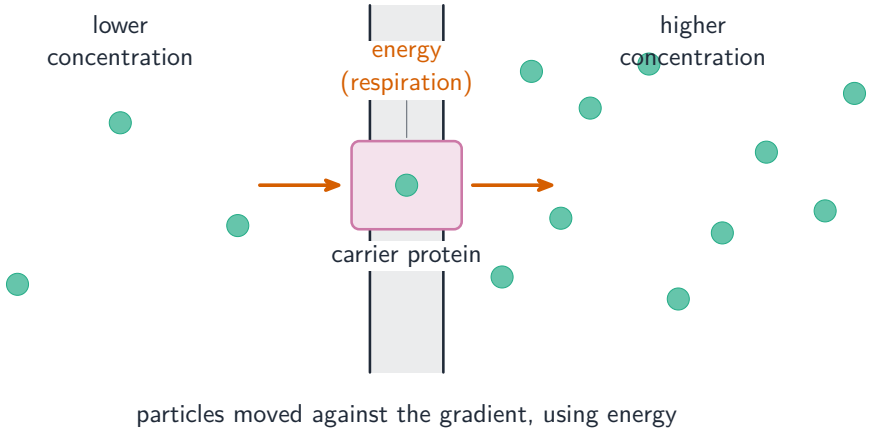
The membrane is **selectively permeable** 选择透过性. Small nonpolar molecules (O_2, CO_2) and water cross easily; large or charged/polar particles (ions, glucose) cannot pass the nonpolar core without help. This selectivity lets the cell control its internal environment.



Three ways substances cross the membrane

Passive and Active Transport

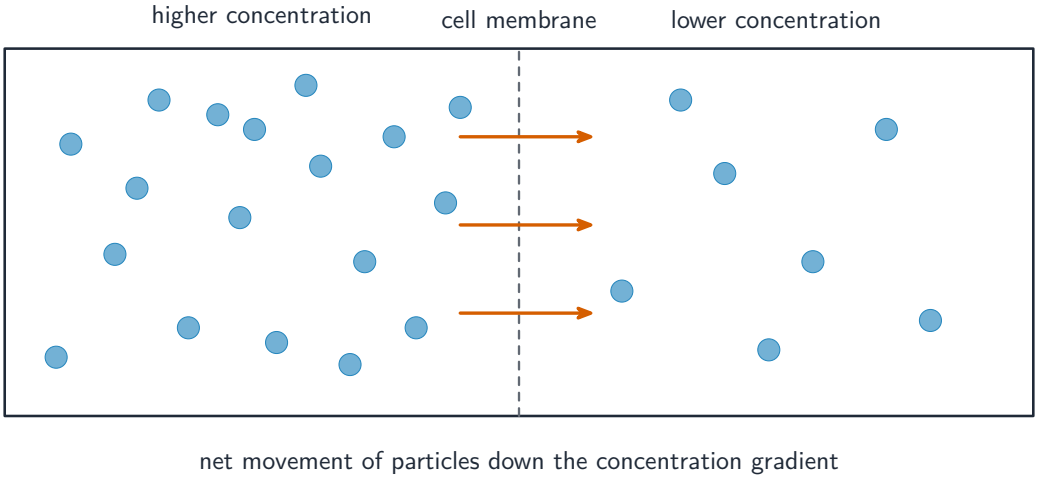
- **Passive transport** 被动运输 moves substances **down** their concentration gradient (high → low) with **no energy** – **diffusion** 扩散.
- **Active transport** 主动运输 moves substances **against** the gradient (low → high), requiring energy (ATP), via protein pumps like the sodium–potassium pump.



Active transport moves particles against the gradient, using ATP and a carrier protein

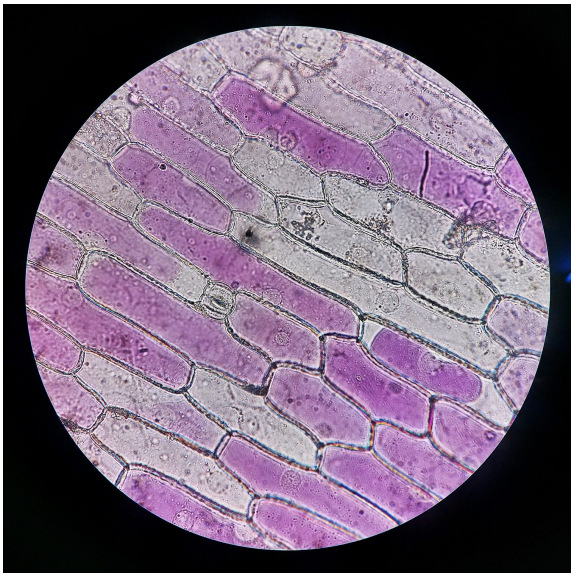
Facilitated Diffusion

Facilitated diffusion 易化扩散 is passive transport through a membrane protein – a **channel** or **carrier** 载体 – for particles that cannot cross the lipid alone. It still goes down the gradient and needs no energy, but its rate can saturate when all the proteins are busy.



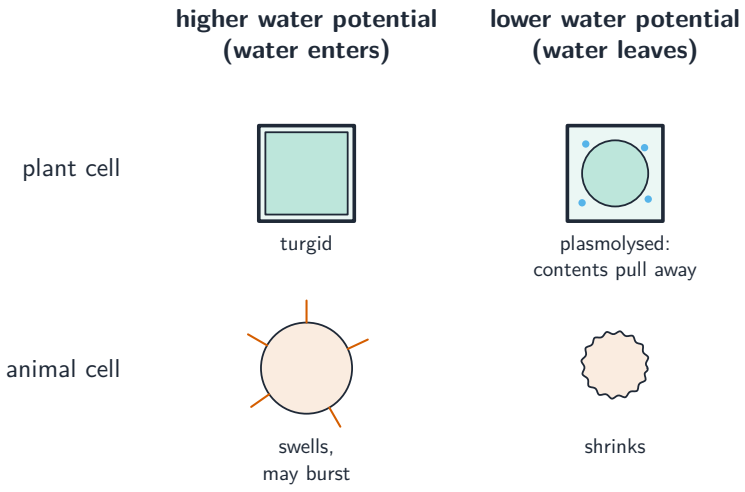
Diffusion: particles spread from higher to lower concentration, down the gradient

Tonicity, Water Potential, and Osmoregulation



Red onion cells in hypertonic solution: the membrane pulls away from the wall (plasmolysis)

Osmosis 渗透 is the diffusion of water across a membrane. **Tonicity** 张力 compares solute concentrations: in a **hypotonic** 低渗 solution a cell gains water (may burst); in a **hypertonic** 高渗 one it loses water (shrinks); in an **isotonic** 等渗 one there is no net change. **Water potential** 水势 predicts the direction of water movement (water moves to lower water potential), and is the sum of a pressure term and a solute term: $\Psi = \Psi_p + \Psi_s$, where the solute potential $\Psi_s = -iCRT$. **Osmoregulation** 渗透调节 is how organisms control this balance.

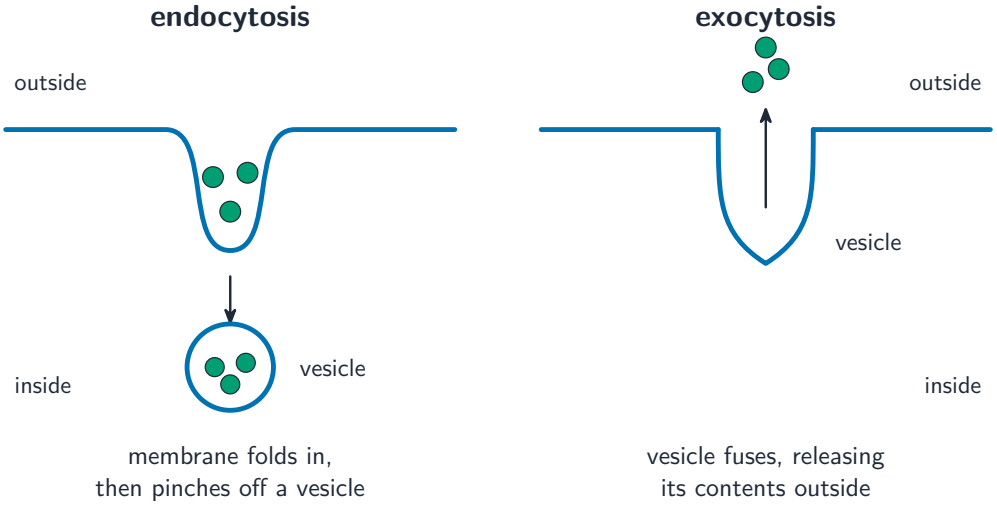


How plant and animal cells respond to solutions of different water potential

Worked example. For a 0.1 M sucrose solution ($i = 1$) in an open beaker (so pressure potential $\Psi_p = 0$) at 25 °C ($T = 298$ K, $R = 0.0831$ L · bar/mol · K): $\Psi_s = -iCRT = -(1)(0.1)(0.0831)(298) \approx -2.48$ bar, so $\Psi \approx -2.48$ bar. A plant cell whose interior is $\Psi = -1.0$ bar sits in this solution: since the solution is **more negative**, water moves *out* of the cell into the solution, and the cell loses turgor.

Mechanisms of Membrane Transport

Large materials move in bulk by **vesicles**: **endocytosis** 内吞 brings material **in** (the membrane engulfs it), and **exocytosis** 外排 sends material **out** (a vesicle fuses with the membrane). Both require energy and let cells import and secrete large molecules.



Endocytosis brings material in; exocytosis releases it out

Compartmentalization Inside the Cell

Membranes create separate **compartments** 区室 so incompatible reactions can run at once and conditions (pH, ion levels) can be tuned locally. This organization boosts efficiency – the internal membranes also add surface area for reactions.

The Origins of Cell Compartmentalization

The **endosymbiotic theory** 内共生学说 explains mitochondria and chloroplasts: they arose when a larger cell engulfed free-living prokaryotes that then lived inside it. The evidence – their own circular DNA, their own ribosomes, and double membranes – supports this shared evolutionary origin.

Exam tips

- Use the two AP-formula skills: **surface-area-to-volume ratio** (why cells stay small) and **water potential** $\Psi = \Psi_p + \Psi_s$ ($\Psi_s = -iCRT$).

- Water moves toward the **lower (more negative) water potential**; predict swelling or shrinking from tonicity (hypo/hyper/isotonic).
- **Passive transport and osmosis need no energy** (down the gradient); **active transport** needs ATP (against the gradient).
- Distinguish diffusion, facilitated diffusion (a channel/carrier protein), and active transport.
- Explain membrane selectivity from the **phospholipid bilayer** — small non-polar molecules cross, large/charged ones need help.

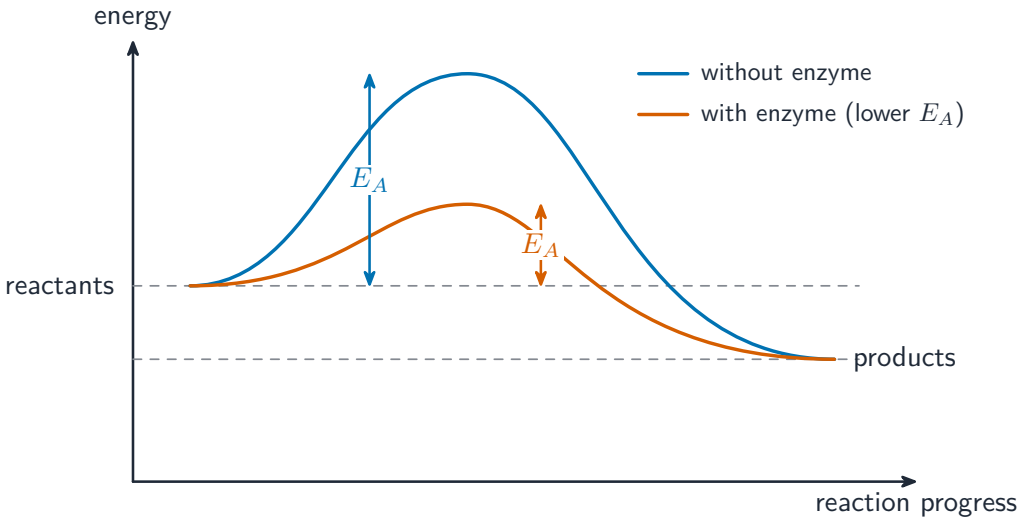
Cellular Energetics

AP Biology

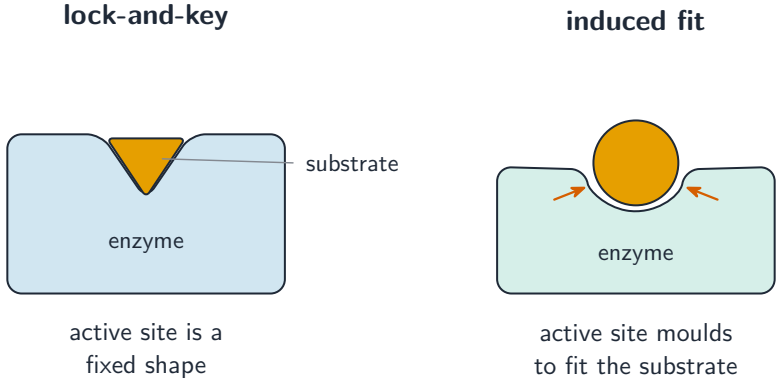
Enzymes as Biological Catalysts

Biological washing powder uses enzymes that work at moderate temperature and pH

An **enzyme** 酶 is a protein **catalyst** 催化剂 that speeds a reaction by lowering its **activation energy** 活化能, without being used up. Each enzyme has an **active site** 活性位点 that binds a specific **substrate** 底物 (the "lock and key" or induced fit), so enzymes are highly specific. They do not change whether a reaction is favorable – only how fast it goes.



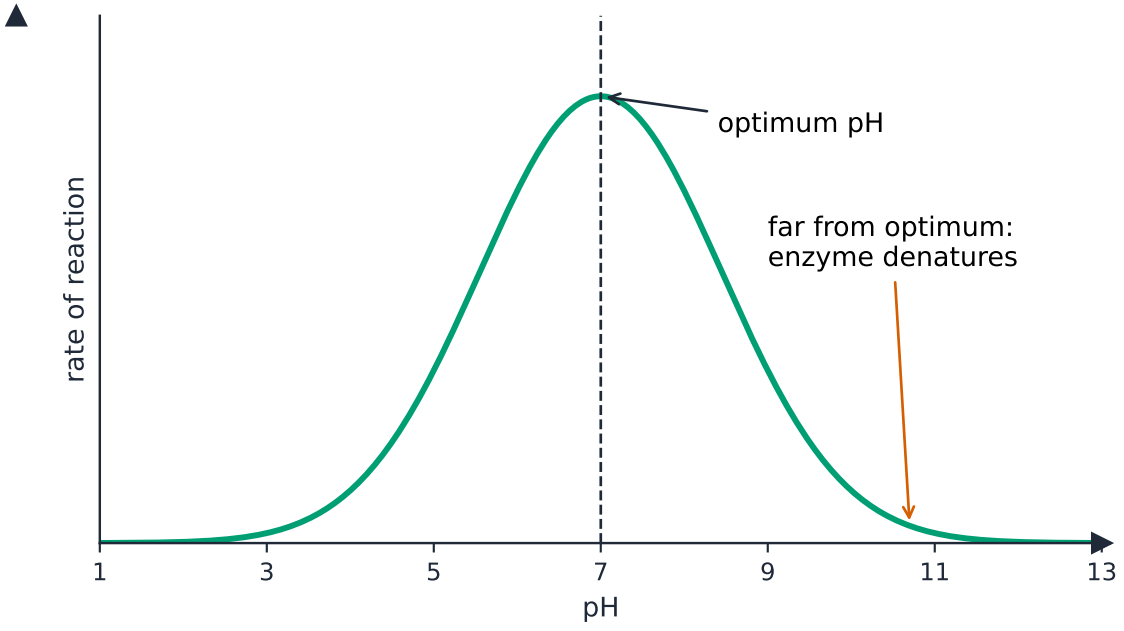
An enzyme lowers the activation energy of a reaction



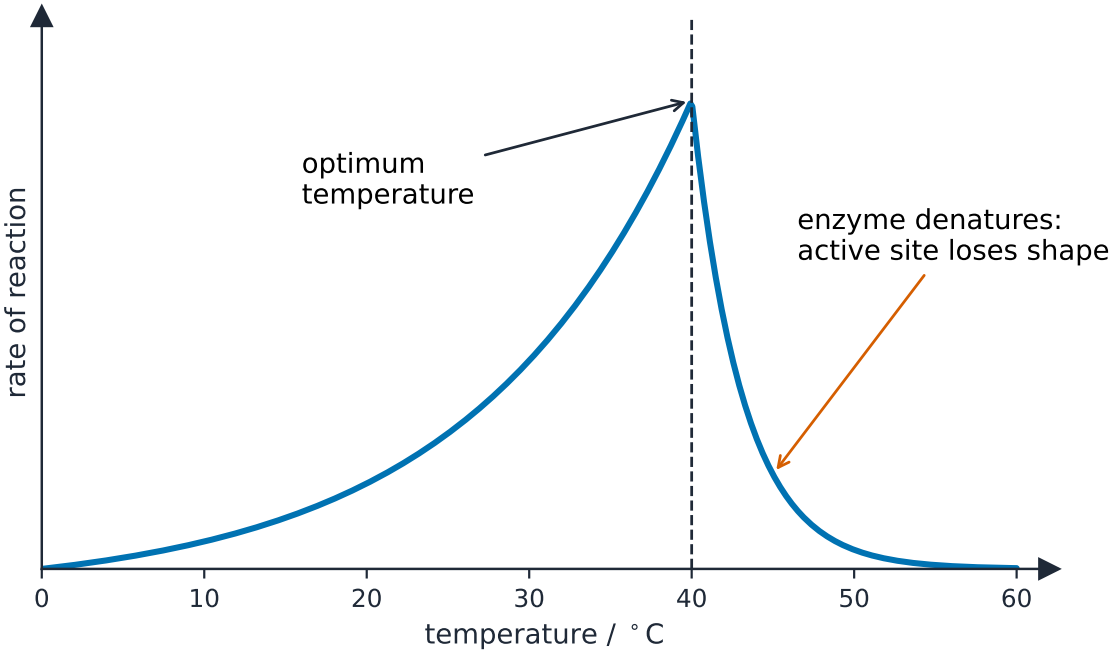
The lock-and-key and induced-fit models of enzyme action

Environmental Impacts on Enzyme Function

Enzyme activity depends on conditions. Each enzyme has an **optimal** temperature and pH; beyond it, the protein **denatures** 变性 (loses shape) and stops working. **Substrate concentration** raises the rate until the enzyme saturates. **Inhibitors** 抑制剂 slow enzymes – **competitive** ones block the active site, **noncompetitive** ones bind elsewhere and change the shape.



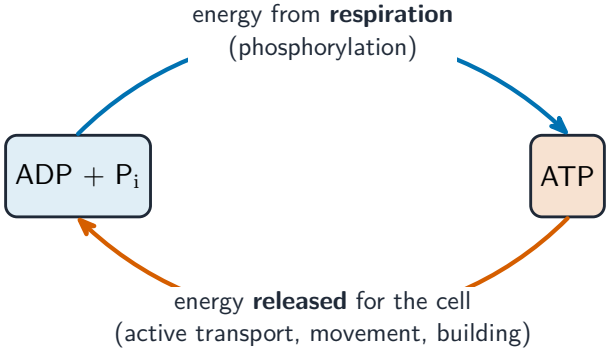
Each enzyme has an optimum pH



Rate rises to an optimum temperature, then falls as the enzyme denatures

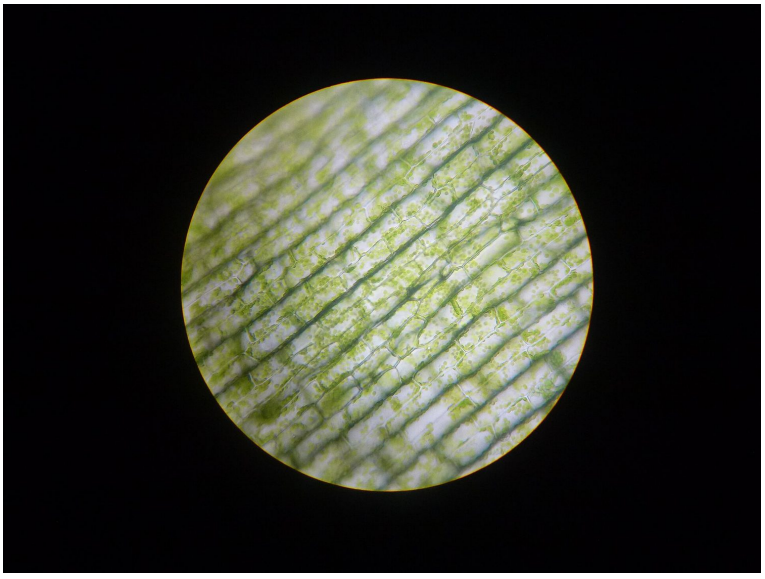
Cellular Energy and ATP

ATP (adenosine triphosphate) is the cell's energy currency. Energy is stored in its phosphate bonds; breaking off a phosphate (ATP → ADP) **releases** energy to power cellular work, and reattaching one stores energy. Cells constantly recycle ATP, coupling energy-releasing reactions to energy-requiring ones.



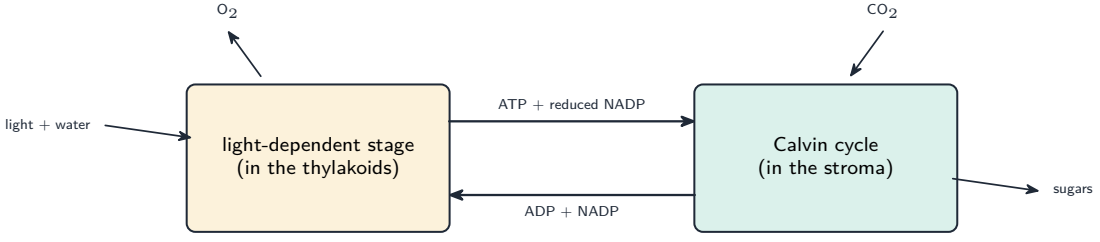
The ATP-ADP cycle stores and releases energy

Photosynthesis



Chloroplasts fill plant mesophyll cells — the organelles of photosynthesis

Photosynthesis 光合作用 captures light energy to build sugar from CO_2 and water, releasing O_2. It has two stages:

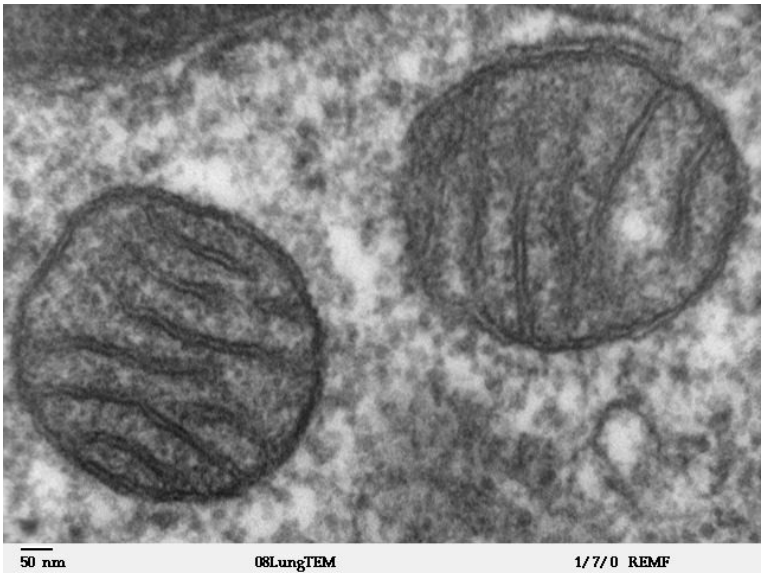


The two stages of photosynthesis are linked by ATP and NADPH

- The **light reactions** (in the thylakoid membranes) use light to make ATP and NADPH and split water, releasing oxygen.
- The **Calvin cycle** 卡尔文循环 (in the stroma) uses that ATP and NADPH to fix CO_2 into sugar.

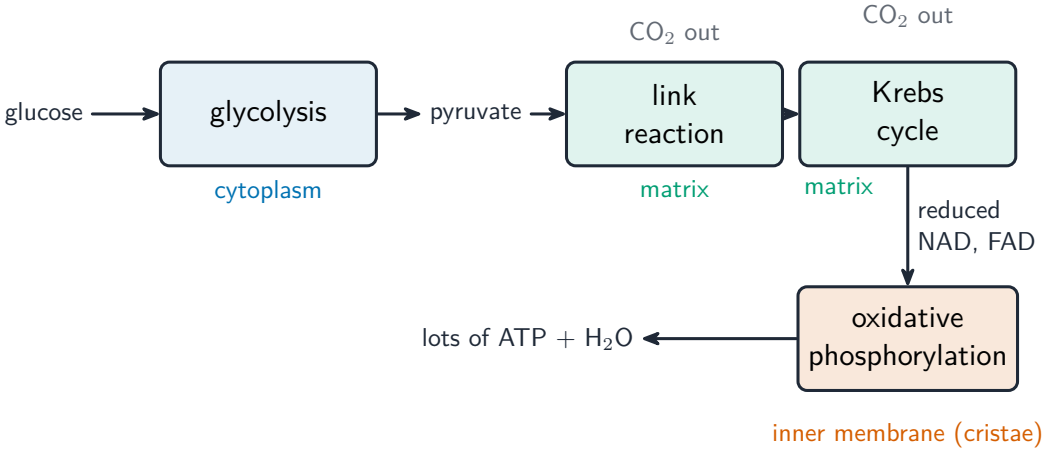
So light energy becomes chemical energy stored in glucose.

Cellular Respiration



TEM of a mitochondrion: folded inner membrane (cristae) multiplies surface for respiration

Cellular respiration 细胞呼吸 releases the energy in glucose to make ATP, mostly using oxygen. Its stages:



The stages of aerobic respiration and where in the cell they happen

- **Glycolysis** 糖酵解 (in the cytoplasm) splits glucose, making a little ATP.
- The **Krebs cycle** 克雷布斯循环 (mitochondrial matrix) releases CO_2 and loads electron carriers.

- The **electron transport chain** 电子传递链 (inner membrane) uses those electrons to pump protons and make most of the ATP, with oxygen as the final electron acceptor.

Without oxygen, cells use **fermentation** 发酵 to keep glycolysis running, making far less ATP. Photosynthesis and respiration are complementary – the products of one are the reactants of the other.

Worked example. Aerobic respiration of one glucose nets about **2 ATP** from glycolysis, **2 ATP** from the Krebs cycle, and about **28 ATP** from oxidative phosphorylation, for $\approx$ **32 ATP** total. With no oxygen only glycolysis runs, so fermentation nets just **2 ATP** per glucose — roughly 16 times less energy, which is why aerobic pathways dominate in oxygen-rich cells.

Exam tips

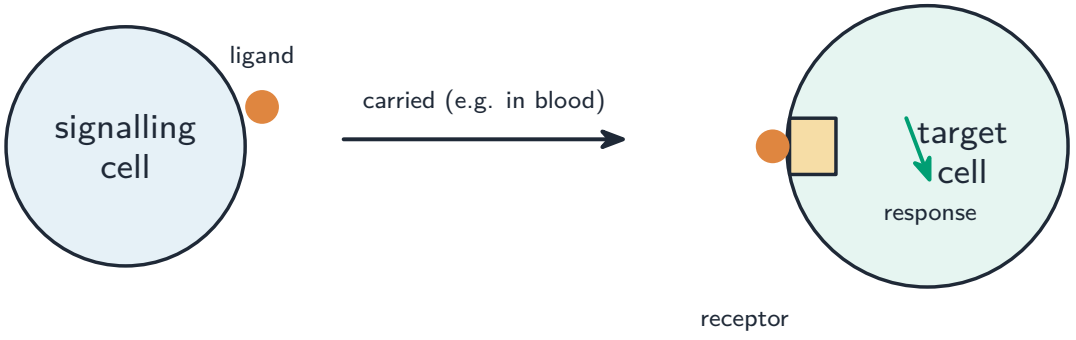
- An **enzyme lowers the activation energy** and is not used up; its **active site** is specific to one substrate (lock and key).
- Rate rises with temperature only up to the **optimum** — beyond it the enzyme **denatures** and the rate falls (unlike an ordinary reaction).
- Know the ATP$\leftrightarrow$ADP cycle: breaking a phosphate **releases** energy to power the cell.
- Write the overall equations: photosynthesis **stores** energy (builds glucose); respiration **releases** it (breaks glucose down) — they are opposites.
- Match each stage to its location and whether it needs oxygen.

Cell Communication and Cell Cycle

AP Biology

Cell Communication

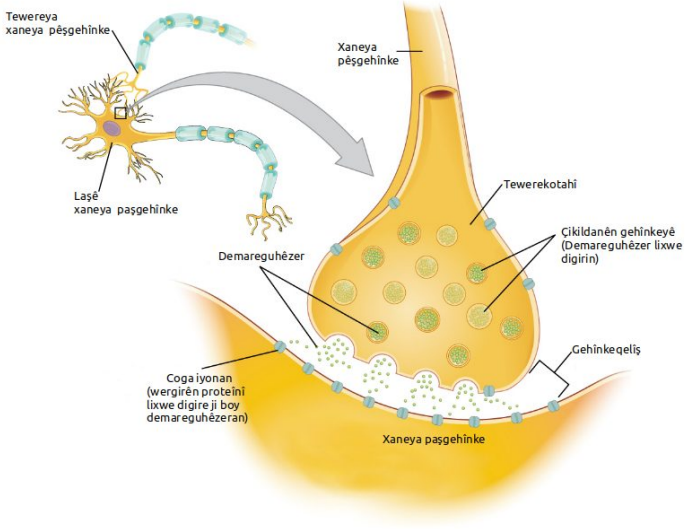
Cells coordinate by sending and receiving chemical **signals** 信号. A signaling cell releases a **ligand** 配体 that binds a **receptor** 受体 on a target cell. Signals travel over different ranges: **direct contact** (cell junctions), **local** signaling (nearby cells, like neurotransmitters), and **long-distance** signaling (**hormones** 激素 through the blood).



A signal molecule (ligand) binds a matching receptor on the target cell

Introduction to Signal Transduction

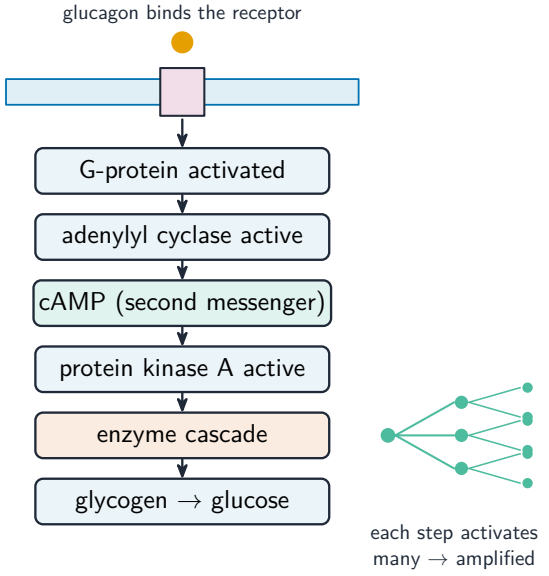
Signal transduction 信号转导 converts an outside signal into a cellular response in three stages: **reception** (ligand binds receptor), **transduction** (a relay of molecules inside the cell), and **response** (a change in the cell's activity, such as switching on a gene). Receptors are specific, so a cell only responds to signals it can receive.



A chemical synapse: signal transduction passes a message across a gap with a ligand and receptor

Signal Transduction Pathways

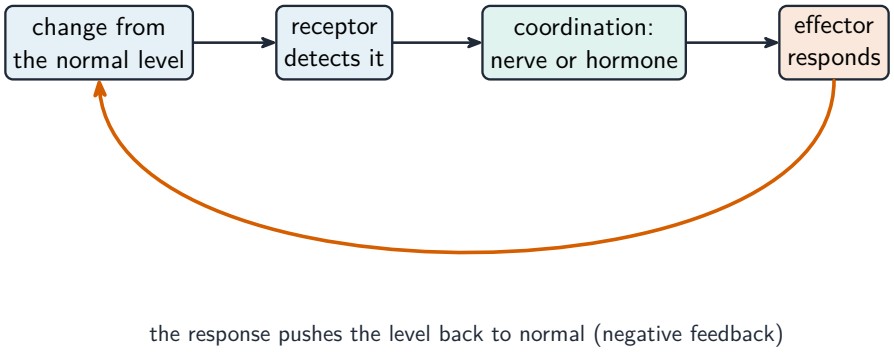
In the transduction stage, the signal passes through a **pathway** – often a cascade of proteins that activate one another, frequently amplifying the signal so a few ligands trigger a large response. **Second messengers** (like cyclic AMP or calcium ions) spread the signal quickly through the cell. A change in one step can alter the whole outcome.



A signalling cascade amplifies the message inside the cell

Feedback

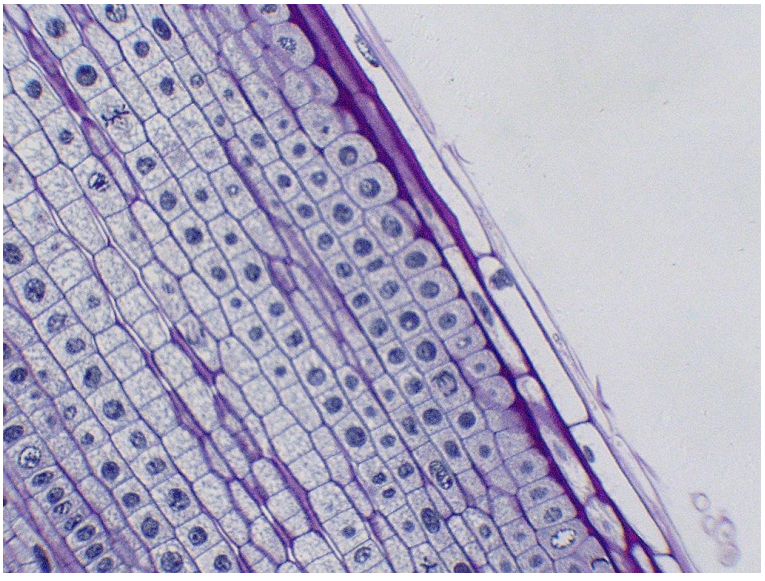
Feedback 反馈 keeps systems balanced:



Negative feedback detects and corrects a change

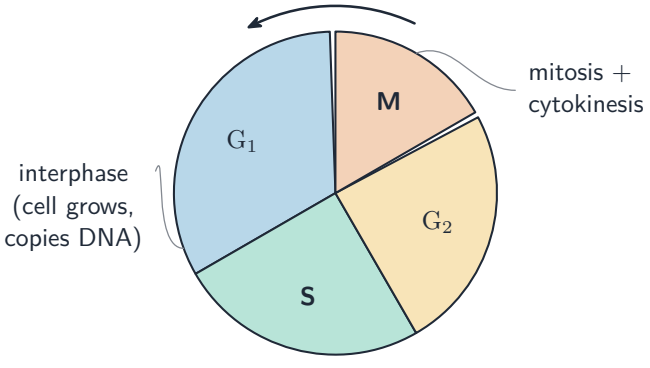
- **Negative feedback** 负反馈 counteracts a change to restore a set point (like a thermostat) – it maintains **homeostasis** 稳态.
- **Positive feedback** 正反馈 amplifies a change to push a process to completion (like childbirth contractions or blood clotting).

Cell Cycle

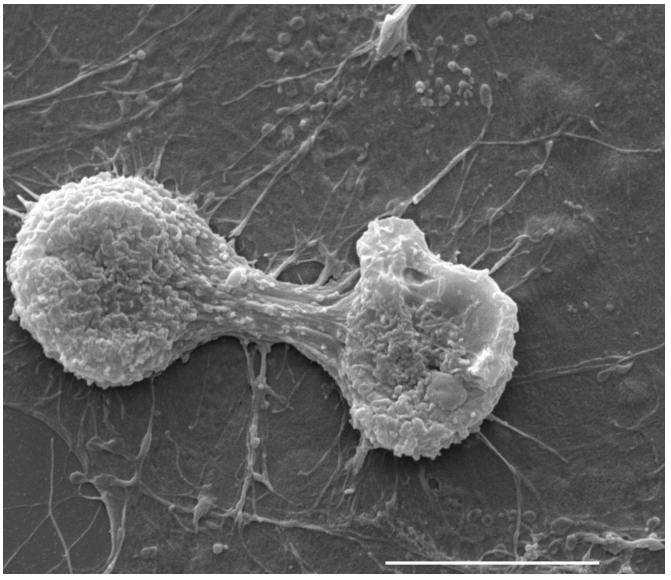


Onion root-tip cells at different stages of mitosis (light micrograph)

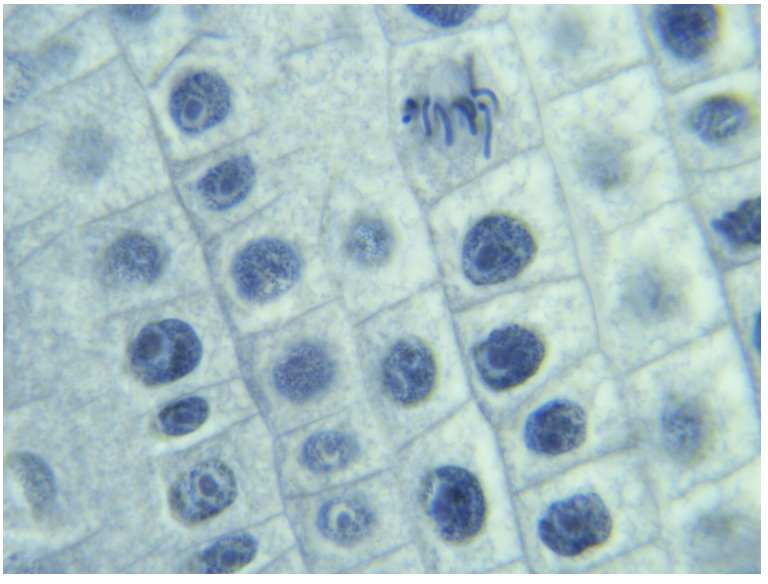
The **cell cycle** 细胞周期 is the life of a cell from one division to the next: **interphase** 间期 (G1 growth, S DNA replication, G2 preparation) followed by **mitosis** 有丝分裂 (M) and cytokinesis, which produce two identical daughter cells. Interphase takes most of the time; DNA is copied only in S phase.



The cell cycle: interphase, then mitosis and cytokinesis



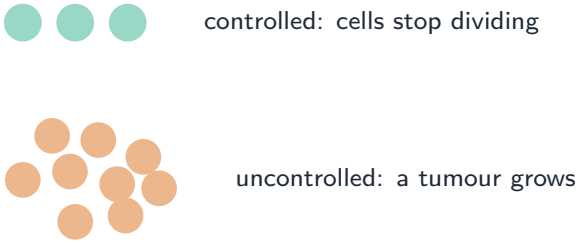
A fibroblast dividing: cytokinesis splits one cell into two after mitosis finishes



Onion root tip at metaphase: chromosomes line up before sister chromatids separate

Regulation of Cell Cycle

The cycle is controlled at **checkpoints** 检查点 that verify conditions before proceeding (Is the DNA intact? Are chromosomes attached?). Internal signals (cyclins and their kinases) and external signals drive the cycle forward. When this control fails – for example, a mutation that ignores a checkpoint – cells divide uncontrollably, which underlies **cancer** 癌症.



Uncontrolled division from failed checkpoints forms a tumour

Worked example. Signal amplification in a cascade: one hormone activates one receptor, which switches on about 100 relay proteins, and each of those makes about 1,000 second-messenger molecules — so a single signal produces roughly $100 \times 1000 = 10^5$ product molecules. This is why a hormone concentration as low as 10^{-9} M can trigger a large cellular response.

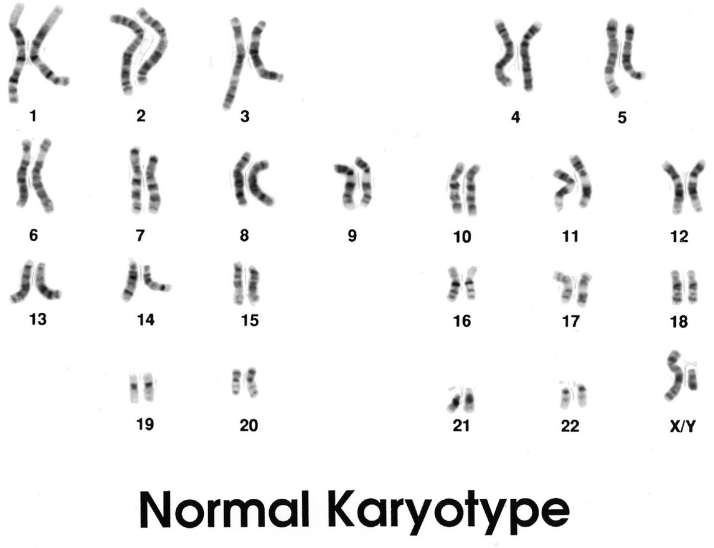
Exam tips

- In signal transduction name the three stages: **reception → transduction → response**.
- **Negative** feedback reverses a change to keep conditions steady (homeostasis); **positive** feedback amplifies a change to completion (childbirth, clotting).
- Order the **cell cycle**: interphase (grow, copy DNA in S phase) then mitosis → two **identical** daughter cells.
- The DNA is copied **once**, in S phase, so each daughter gets a full copy.
- Failed **checkpoints** allow uncontrolled division → cancer.

Heredity

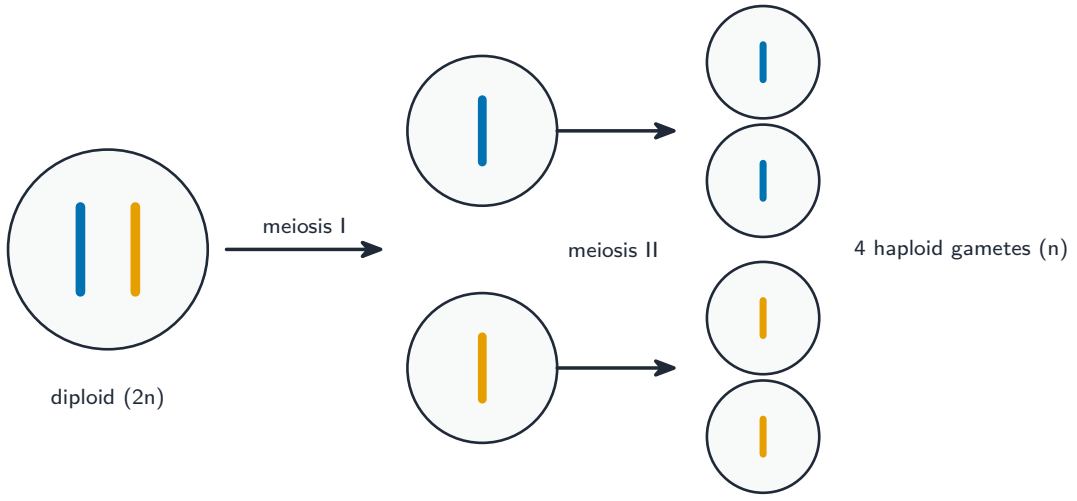
AP Biology

Meiosis



A human karyotype: 22 pairs of autosomes plus the sex chromosomes

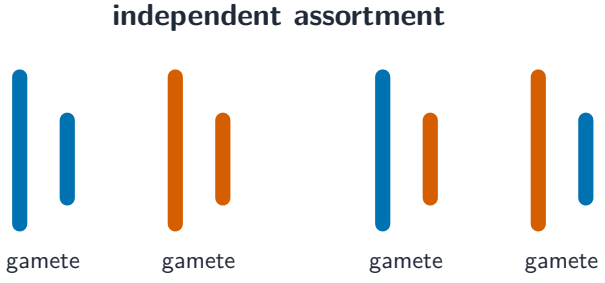
Meiosis 减数分裂 makes **gametes** 配子 (eggs and sperm) with **half** the chromosome number, so fertilization restores the full set. One diploid cell divides **twice** to give four haploid cells. Meiosis I separates **homologous chromosomes** 同源染色体 (reducing the number); meiosis II separates sister chromatids (like mitosis).



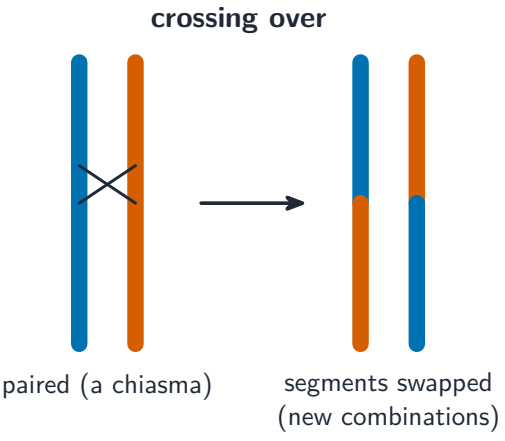
Meiosis halves the chromosome number in two divisions

Meiosis and Genetic Diversity

Meiosis shuffles genes three ways, so offspring differ from parents and each other:



Independent assortment produces many gamete combinations



Crossing over swaps segments between homologous chromosomes

- **Crossing over** 交叉互换: homologous chromosomes swap segments in meiosis I.
- **Independent assortment** 自由组合: each homologous pair lines up and separates randomly.
- **Random fertilization**: any sperm can meet any egg.

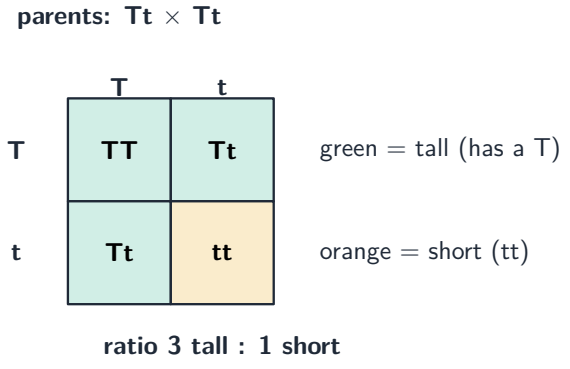
Together these create enormous variation – the raw material for evolution.

Mendelian Genetics

Natural variation in snail shell banding — heritable differences selection can act on

A gene's alternative versions are **alleles** 等位基因. An organism's **genotype** 基因型

(its alleles) produces its **phenotype** 表型 (its traits). Mendel's rules: a **dominant** 显性 allele masks a **recessive** 隐性 one; the two alleles **segregate** into different gametes (law of segregation); genes for different traits assort **independently**. A **Punnett square** 庞纳特方格 predicts offspring ratios (a heterozygous cross gives 3:1). **Homozygous** 纯合 means two identical alleles; **heterozygous** 杂合 means two different.

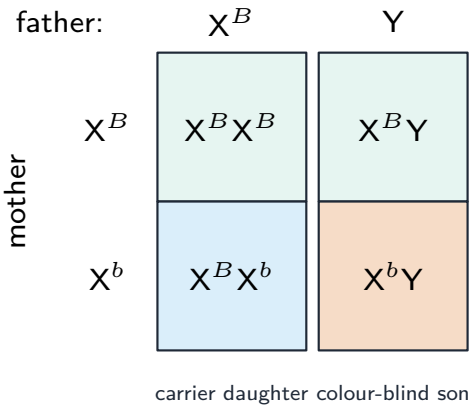


A monohybrid Punnett square giving a 3:1 ratio

Worked example. For a **dihybrid** cross of two independent genes, $AaBb \times AaBb$, use the multiplication rule instead of a 16-box square. Each gene alone gives $\frac{3}{4}$ dominant, so the chance an offspring shows **both** dominant traits is $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$, and the chance of the fully recessive *aabb* is $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$. Multiplying two independent 3:1 ratios is what produces the classic 9:3:3:1 pattern.

Non-Mendelian Genetics

Many traits do not follow simple dominance:



Sex linkage gives different results for sons and daughters

- **Incomplete dominance** 不完全显性: heterozygotes are a blend (red × white → pink).
- **Codominance** 共显性: both alleles show fully (AB blood type).
- **Multiple alleles**, **polygenic** 多基因 traits (many genes, like height), **pleiotropy** (one gene, many effects), and **sex-linked** 伴性 genes (on the X chromosome) all give more complex ratios.

Worked example (chi-square test). To check whether real data fit a predicted ratio, use $\chi^2 = \sum \frac{(o-e)^2}{e}$. A monohybrid cross predicts 3:1, so of 80 offspring you expect 60 dominant and 20 recessive, but you observe 55 and 25. Then $\chi^2 = \frac{(55-60)^2}{60} + \frac{(25-20)^2}{20} = \frac{25}{60} + \frac{25}{20} = 0.42 + 1.25 = 1.67$. With 1 degree of freedom the critical value at $p = 0.05$ is 3.84; since $1.67 < 3.84$, we **fail to reject** the null hypothesis – the deviation is within chance.

Environmental Effects on Phenotype

Phenotype is not set by genes alone – the **environment** also matters. Temperature, nutrition, and other factors can change how genes are expressed (a Himalayan rabbit's dark fur where it is cold, a plant's height with more sunlight). So identical genotypes can give different phenotypes in different conditions.

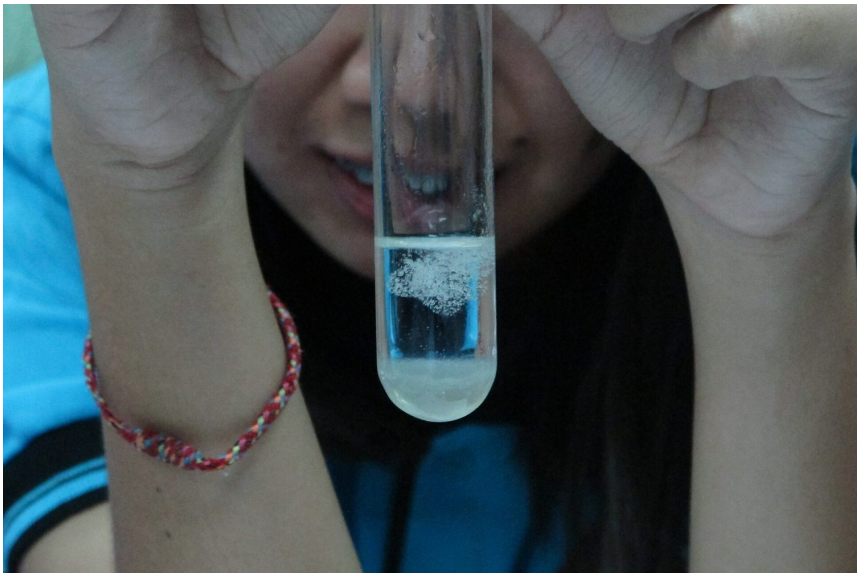
Exam tips

- Contrast mitosis (2 identical, full chromosome number) with **meiosis** (4 non-identical gametes, half the number).
- Explain variation from **crossing over, independent assortment, and random fertilisation**.
- Use the multiplication rule for dihybrid crosses (each gene's 3:1 multiplied), and a **chi-square** test ($\chi^2 = \sum \frac{(o-e)^2}{e}$) to judge observed vs expected ratios.
- Keep **genotype** (the alleles) separate from **phenotype** (what you see) — AA and Aa can look the same.
- Recognise non-Mendelian patterns: incomplete dominance, codominance, and sex linkage.

Gene Expression and Regulation

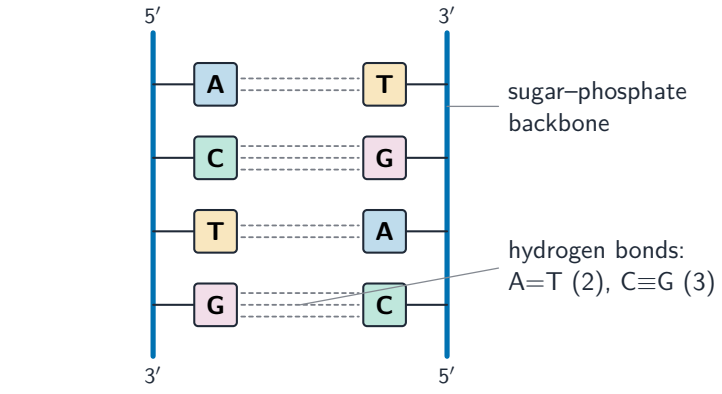
AP Biology

DNA and RNA Structure



Spooling precipitated DNA from a cell extract — DNA is a real, visible molecule

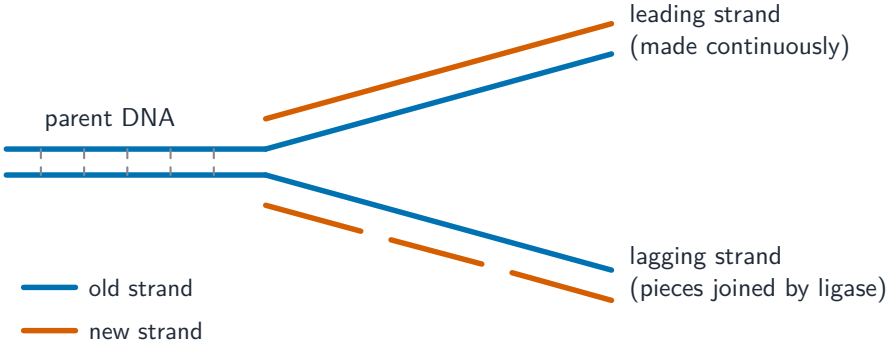
DNA carries genetic information as a **double helix** 双螺旋 of two strands. Its **nucleotides** 核苷酸 pair by rule – A with T, G with C (**complementary base pairing** 互补配对) – so one strand specifies the other. The strands run **antiparallel** 反平行. **RNA** is single-stranded, uses **uracil** (U) instead of thymine, and has ribose sugar.



DNA: two antiparallel strands held by complementary base pairs

DNA Replication

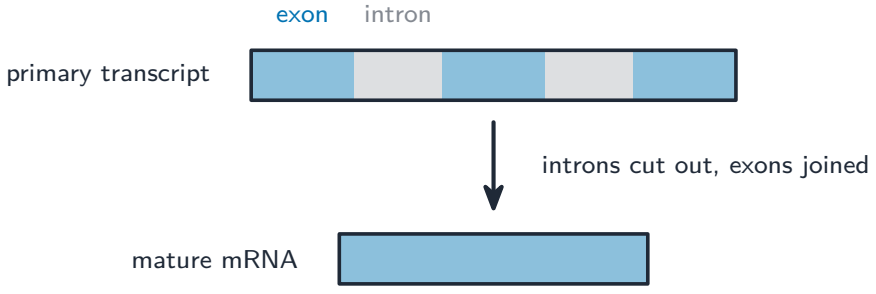
Before a cell divides, DNA is copied **semiconservatively** 半保留复制: the helix unwinds and each old strand templates a new one, so each daughter helix has one old and one new strand. **DNA polymerase** 聚合酶 adds nucleotides following base-pairing rules, building the new strand and proofreading as it goes.



Semi-conservative DNA replication at a replication fork

Transcription and RNA Processing

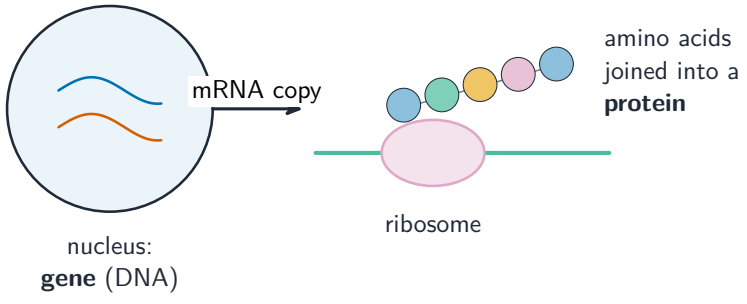
Transcription 转录 copies a gene's DNA into **messenger RNA** 信使 RNA (mRNA). **RNA polymerase** reads the template strand and builds a complementary RNA. In eukaryotes the mRNA is then **processed**: a cap and tail are added, and **introns** 内含子 (non-coding parts) are spliced out, leaving the **exons** 外显子.



Introns are removed and exons joined to make mature mRNA

Translation

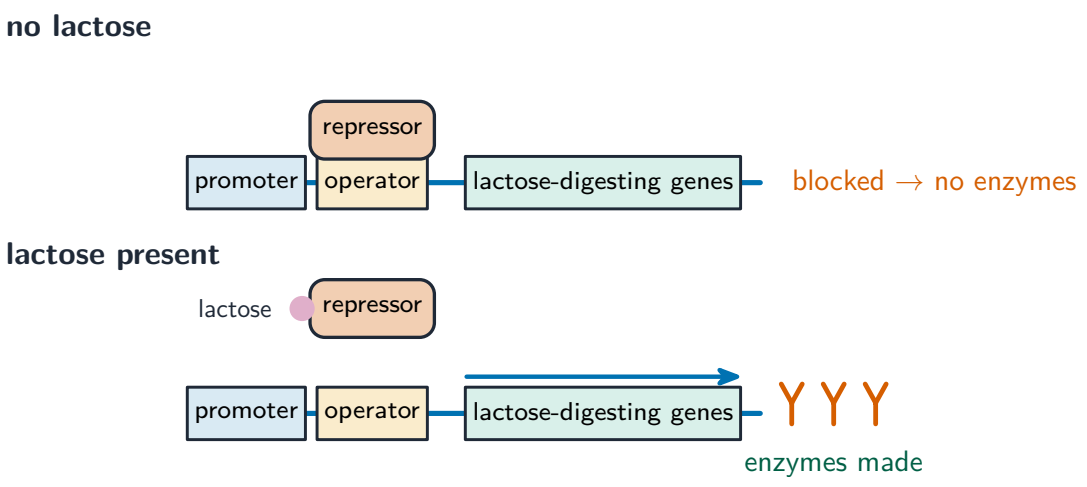
Translation 翻译 builds a protein from the mRNA at the **ribosome** 核糖体. The mRNA is read in three-base **codons** 密码子, each specifying one amino acid (the genetic code). **Transfer RNA** 转运 RNA brings the matching amino acid, and the ribosome links them into a polypeptide until a stop codon ends it. This is the "central dogma": DNA → RNA → protein.



mRNA is read by a ribosome to build a protein from amino acids

Regulation of Gene Expression

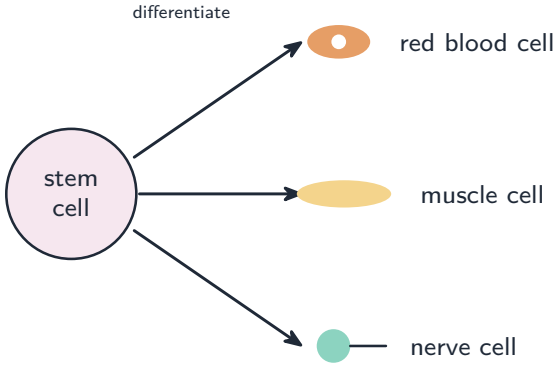
Cells control **which** genes are expressed and **when**. In prokaryotes, **operons** 操纵子 switch groups of genes on or off. In eukaryotes, regulation happens at many levels – which genes are transcribed (transcription factors, promoters, enhancers), RNA processing, and after translation. This lets a cell respond to its environment without changing its DNA.



The lac operon switches genes on only when lactose is present

Gene Expression and Cell Specialization

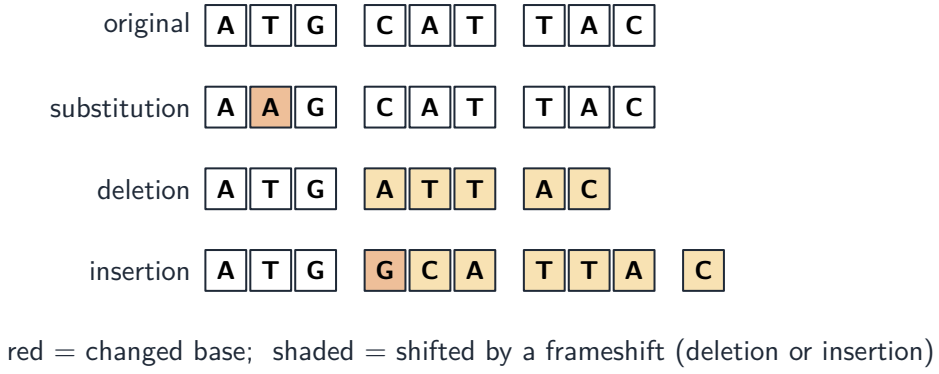
Every cell in a body has the **same** DNA, yet cells differ because they express **different** genes – **differential gene expression** 差异表达. This is how one fertilized egg produces many specialized cell types (muscle, nerve, skin); signals during development turn specific genes on and off.



A stem cell differentiates into specialised cell types

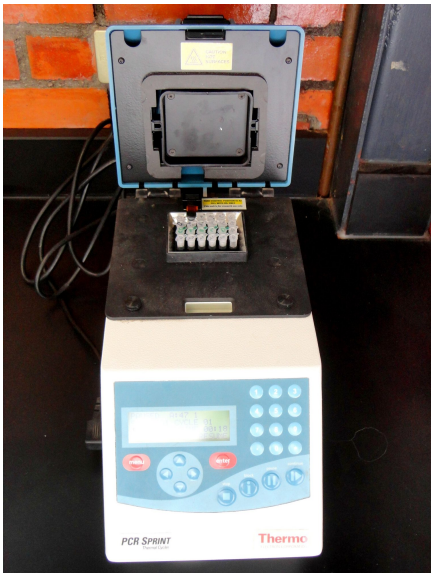
Mutations

A **mutation** 突变 is a change in the DNA sequence. **Point mutations** change one base (silent, missense, or nonsense); **insertions/deletions** can cause a **frameshift** 移码 that garbles everything downstream. Mutations in gametes are heritable; they may be harmful, neutral, or beneficial – and beneficial ones supply the variation for natural selection.

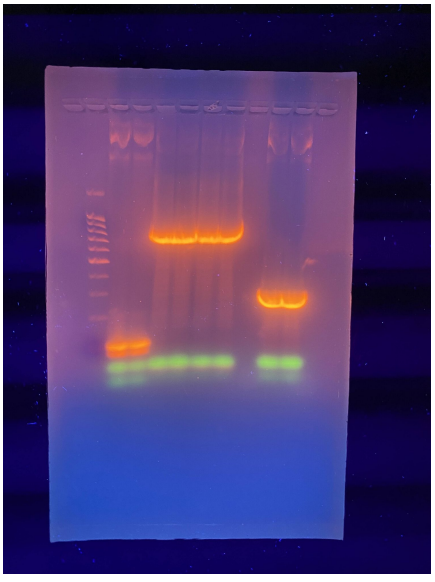


Substitution, deletion, and insertion mutations

Biotechnology

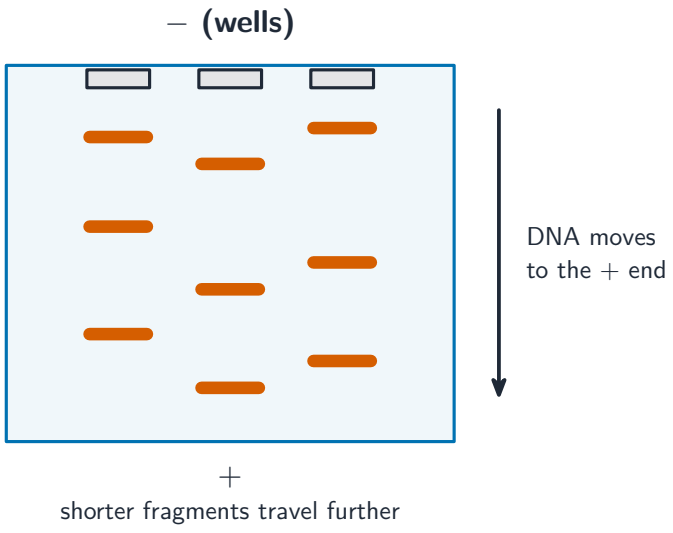


A thermal cycler repeatedly heats and cools samples to amplify DNA (PCR)

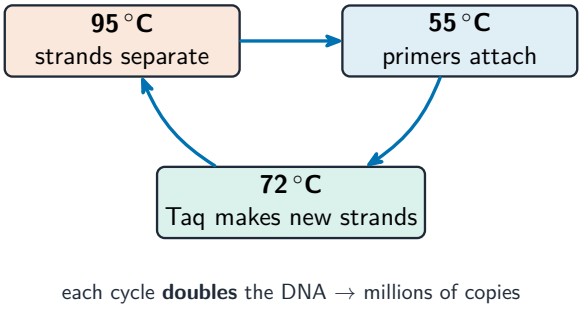


Agarose gel under UV light: DNA fragments separate by size as bright bands

Biotechnology 生物技术 tools manipulate genetic material: **PCR** 聚合酶链反应 copies DNA, **gel electrophoresis** 凝胶电泳 separates DNA fragments by size, **restriction enzymes** and cloning move genes between organisms, and **CRISPR** edits sequences. These techniques enable genetic testing, engineered organisms, and medical treatments.



Gel electrophoresis separates DNA fragments by length



The polymerase chain reaction doubles the DNA each cycle

Worked example. A template DNA strand `3'-TAC GGA TTC-5'` is transcribed into mRNA `5'-AUG CCU AAG-3'`. A ribosome reads three codons: AUG = Met (start), CCU = Pro, AAG = Lys — coding for **Met–Pro–Lys**. Changing the third base of a codon often gives the same amino acid, because the genetic code is **degenerate**, which softens the effect of many mutations.

Exam tips

- Know the **central dogma** DNA → RNA → protein: transcription makes mRNA, translation reads it in three-base **codons** at the ribosome.
- Remember RNA is single-stranded and uses **U** instead of T; replication is **semi-conservative**.

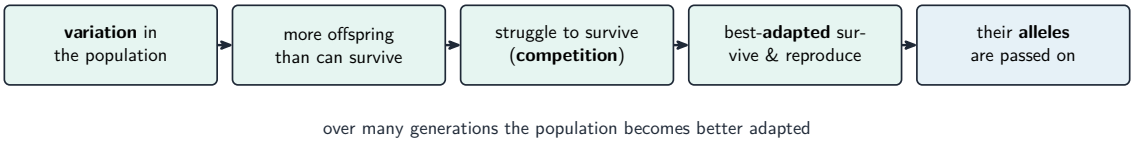
- Every cell has the **same DNA** — cells differ because they express **different genes** (differential gene expression).
- A **mutation** is a change in the DNA sequence and may be harmful, neutral, or beneficial (the raw material for selection).
- Link biotech tools to their jobs: PCR copies DNA; gel electrophoresis separates fragments by size.

Natural Selection

AP Biology

Introduction to Natural Selection

Evolution 进化 is a change in the heritable traits of a population over generations. **Natural selection** 自然选择 is its main driver: individuals vary, some variations are heritable, more offspring are produced than survive, and those with traits better suited to the environment survive and reproduce more. Over time, helpful traits become more common.



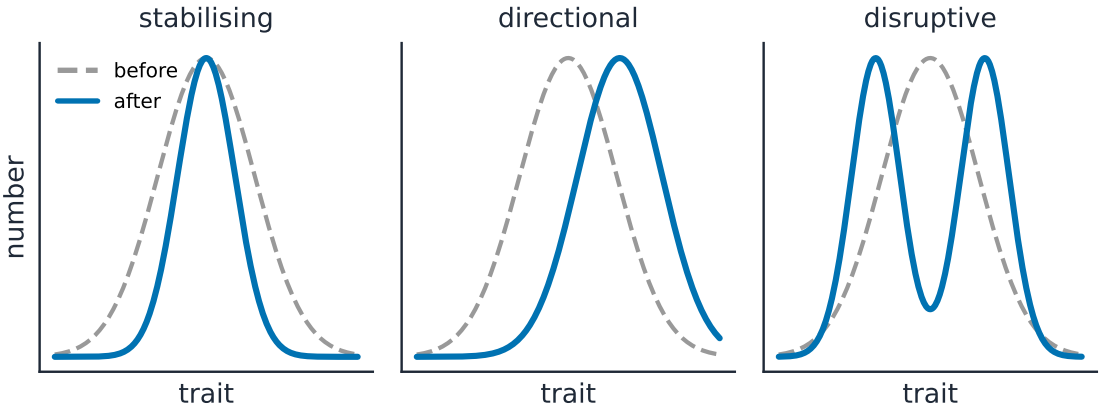
Natural selection: the best-adapted survive, reproduce, and pass on their alleles

Natural Selection

Peppered moth dark form (carbonaria) — industrial melanism is a classic natural-selection case study

Selection acts on **variation** 变异. **Fitness** 适合度 means reproductive success, not strength. Selection comes in modes: **directional** (favors one extreme), **stabilizing**

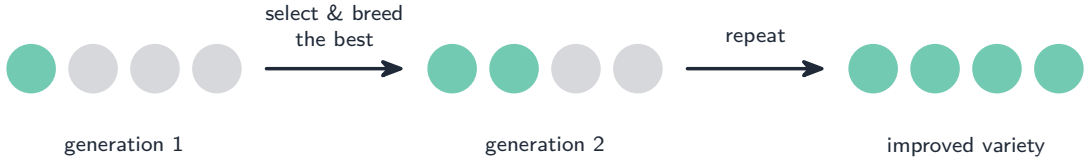
(favors the average), and **disruptive** (favors both extremes). The environment does the "selecting," so a trait that helps in one setting may not in another. Well-suited traits are **adaptations** 适应.



Stabilising, directional, and disruptive selection

Artificial Selection

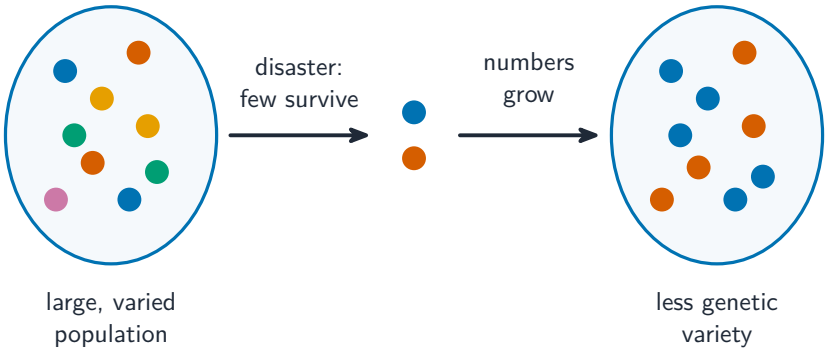
In **artificial selection** 人工选择, humans – not nature – choose which individuals breed, selecting for desired traits (crops, livestock, dogs). It works the same way as natural selection and, being fast and visible, is strong evidence that selection can reshape populations.



Selective breeding makes a wanted feature more common over generations

Population Genetics

Population genetics 群体遗传学 studies the pool of alleles in a population. Evolution is a change in **allele frequencies** 等位基因频率 over time. Besides natural selection, allele frequencies change through **mutation** (new alleles), **gene flow** 基因流 (migration), and **genetic drift** 遗传漂变 (random change, strongest in small populations – the bottleneck and founder effects).



A population bottleneck reduces genetic variety

Hardy-Weinberg Equilibrium

The **Hardy–Weinberg** 哈迪-温伯格 model gives the allele and genotype frequencies expected when a population is **not** evolving. With allele frequencies p and q ($p+q=1$):

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

where p^2 and q^2 are the homozygotes and $2pq$ the heterozygotes. It holds only under five conditions (no selection, no mutation, no migration, random mating, large population); when real data differ from the prediction, the population **is** evolving.

Worked example. In a population, 16% of individuals show the recessive phenotype, so $q^2 = 0.16$ and $q = \sqrt{0.16} = 0.4$. Then $p = 1 - q = 0.6$. The predicted **carrier** frequency (heterozygotes) is $2pq = 2(0.6)(0.4) = 0.48$, i.e. 48%, and the homozygous dominants are $p^2 = 0.6^2 = 0.36$, i.e. 36%. As a check, $0.36 + 0.48 + 0.16 = 1$. This is the standard route: recessive phenotype $\rightarrow q^2 \rightarrow q \rightarrow p \rightarrow$ everything else.

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

p	frequency of allele *A*
q	frequency of allele *a*
p^2	frequency of genotype *AA*
$2pq$	frequency of genotype *Aa*
q^2	frequency of genotype *aa*

H–W equilibrium: no selection, mutation, migration, drift, or non-random mating

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

Evidence of Evolution

Archaeopteryx fossil: feathers plus reptilian features — evidence of common ancestry

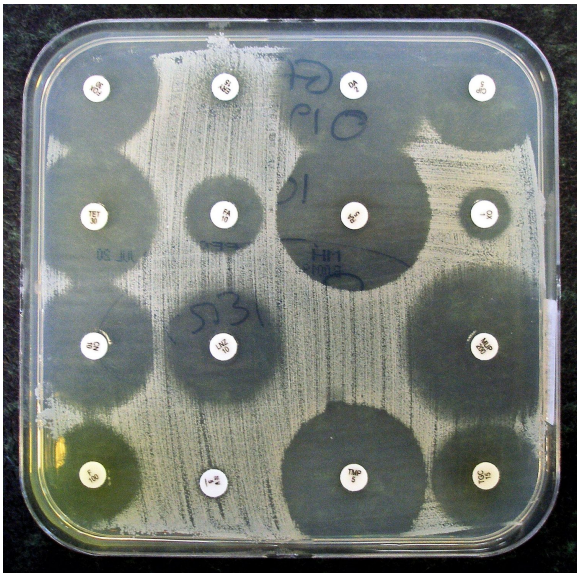
Multiple independent lines support evolution: the **fossil record** 化石记录, **homologous structures** 同源结构 (shared anatomy from common ancestry), **vestigial structures** 痕迹器官, shared **embryology**, and molecular evidence – the near-universal genetic code and matching DNA/protein sequences.

Common Ancestry

All life shares a **common ancestor** 共同祖先, shown by universal features: the same DNA/RNA machinery, the same genetic code, ribosomes, and core metabolic pathways in all organisms. The more features and sequences two species share, the more recently they diverged.

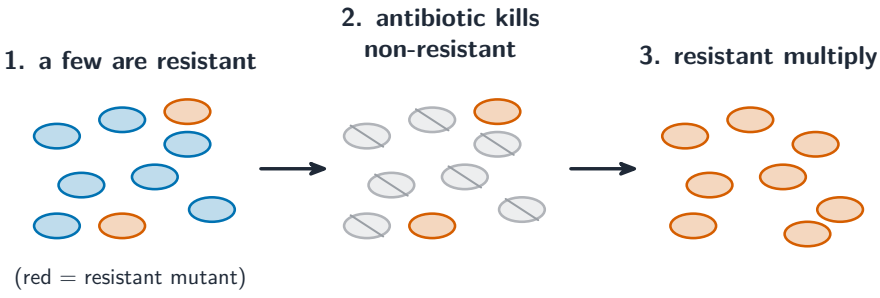
Archaeopteryx: transitional fossils link major groups and support common ancestry

Continuing Evolution



Antibiotic sensitivity plate: clear zones show which antibiotics kill the bacteria

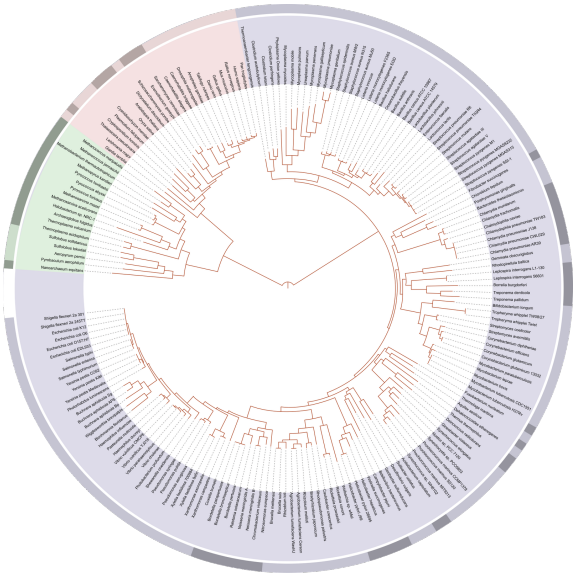
Evolution is ongoing and observable: antibiotic-resistant bacteria, pesticide-resistant insects, and rapid changes in fast-breeding species. Because environments keep changing, selection keeps acting – evolution has no endpoint.



How antibiotic resistance spreads through a population by natural selection

Phylogeny

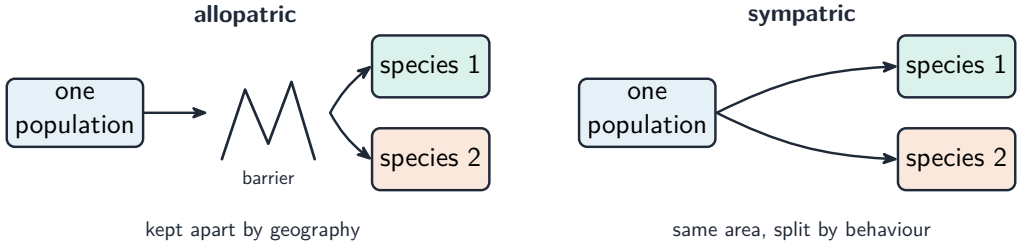
A **phylogenetic tree** 系统发育树 (cladogram) diagrams evolutionary relationships, with branch points marking common ancestors and shared derived traits grouping related species. Trees are hypotheses, revised as new (especially molecular) data arrive.



The tree of life: phylogeny groups organisms by shared ancestry from a common origin

Speciation

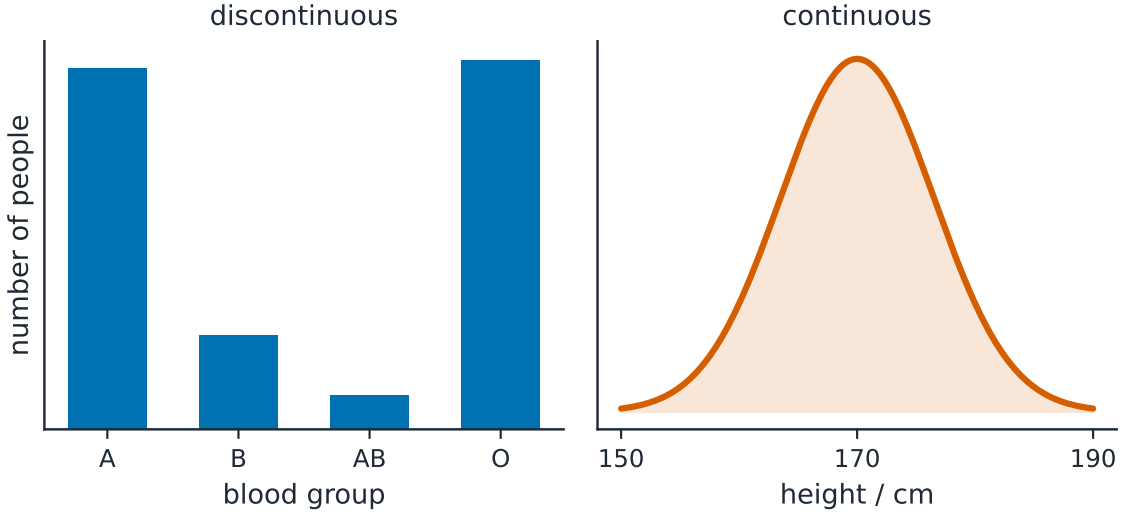
Speciation 物种形成 is the origin of new species, usually when populations become **reproductively isolated** 生殖隔离 and diverge. **Allopatric** speciation follows a geographic split; **sympatric** speciation happens without one. Once populations can no longer interbreed, they are separate species.



Allopatric and sympatric speciation

Variations in Populations

Genetic **diversity** 多样性 helps a population survive change – if conditions shift, some variants may already be suited to them. Low diversity (as in an endangered species) leaves a population vulnerable. Variation arises from mutation and the reshuffling of meiosis and sexual reproduction.



Discontinuous and continuous variation

Origins of Life on Earth

Evidence suggests early Earth's conditions could form simple organic molecules (the Miller–Urey type experiments), which assembled into polymers, then self-replicating **RNA** (the "RNA world"), and eventually membrane-bound cells. The first cells were prokaryotes; eukaryotes arose later through **endosymbiosis** 内共生.

Stromatolites: layered microbial mats are among the oldest evidence of life on Earth

A hydrothermal vent: hot chemical-rich water may have powered early metabolism at life's origin

Exam tips

- State natural selection cleanly: **variation → differential survival and reproduction → helpful traits become common**.
- **Fitness = reproductive success**, not strength or health.
- Evolution is a change in **allele frequencies** in a **population** — individuals do not evolve.
- Use **Hardy–Weinberg** ($p^2 + 2pq + q^2 = 1$): start from the recessive phenotype $q^2 \to q \to p$.
- Cite independent **evidence** (fossils, homologous structures, DNA) and explain speciation via reproductive isolation.

Ecology

AP Biology

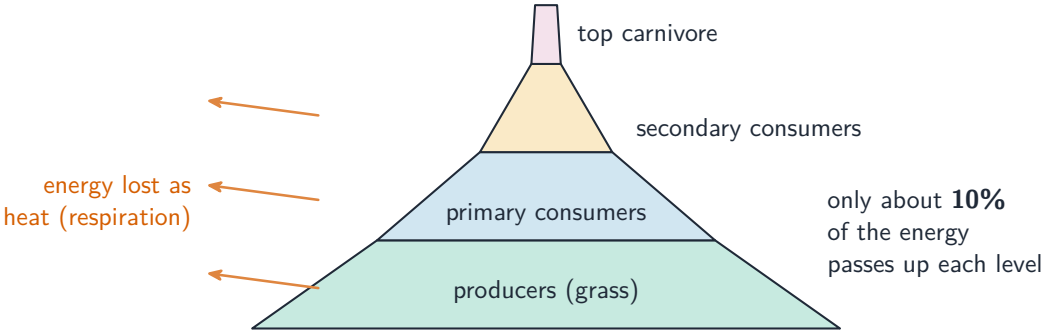
Responses to the Environment

Organisms sense and respond to their surroundings in ways that aid survival and reproduction. **Behaviors** may be **innate** (inherited, like reflexes and instincts) or **learned**. Responses such as migration, hibernation, and phototropism, and signals between organisms, are shaped by natural selection because they improve fitness.

Sunflowers face the light: organisms detect and respond to environmental stimuli

Energy Flow Through Ecosystems

Energy enters most **ecosystems** 生态系统 as sunlight, is captured by **producers** 生产者 (photosynthesizers), and passes to **consumers** 消费者 along a **food chain** 食物链. Each level is a **trophic level** 营养级. Only about **10%** of energy transfers up each level (the rest is lost as heat), so food chains are short and producers are the most abundant. Energy **flows** through and is lost, while matter (carbon, nitrogen) **cycles**.

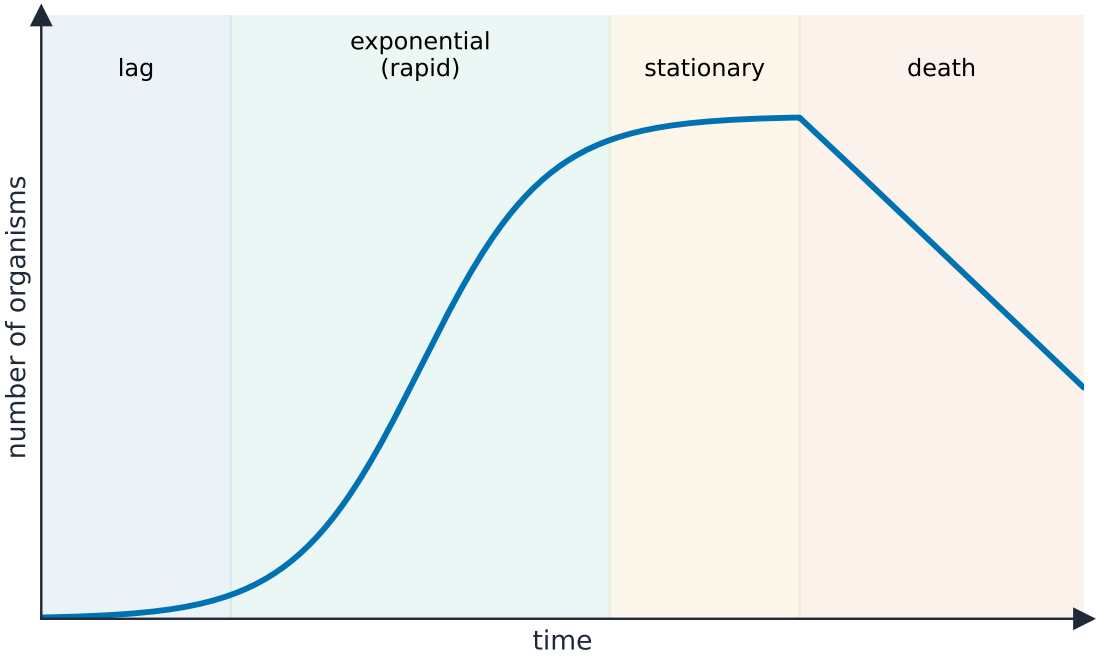


Only about 10% of the energy passes to the next trophic level

Worked example. Suppose producers capture 10,000 kcal. Applying the 10% rule, primary consumers receive about 1,000 kcal, secondary consumers 100 kcal, and tertiary consumers only 10 kcal. Losing 90% as heat at every step is exactly why food chains rarely exceed four or five levels – there is too little energy left to support another.

Population Ecology

A **population** 种群 is the individuals of one species in an area. Its growth depends on birth, death, immigration, and emigration. **Exponential growth** 指数增长 (J-shaped) happens with unlimited resources; **logistic growth** 逻辑斯蒂增长 (S-shaped) levels off at the **carrying capacity** 环境容纳量 K – the maximum the environment can sustain – following $\dfrac{dN}{dt} = r_{\max} N \dfrac{K - N}{K}$.



Population growth: lag, exponential, then levelling off at the carrying capacity

Worked example. A population has $r_{\max} = 0.5$ yr^{-1}, carrying capacity $K = 1000$, and current size $N = 400$. Then $\dfrac{dN}{dt} = 0.5 \times 400 \times \dfrac{1000 - 400}{1000} = 0.5 \times 400 \times 0.6 = 120$ individuals per year. The $\frac{K-N}{K}$ term is why growth is fastest near $N = K/2$ and slows toward zero as N approaches K.

Effect of Density on Populations

Some factors depend on crowding, others do not:

- **Density-dependent** 密度制约 factors intensify as a population grows – competition, predation, disease.
- **Density-independent** 非密度制约 factors act regardless of density – weather, natural disasters.

These factors regulate population size around the carrying capacity.

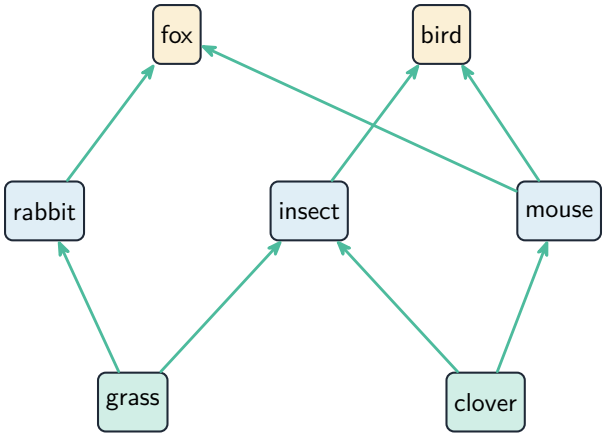
A dense deer herd: density-dependent factors such as disease and food competition intensify as numbers rise

Community Ecology

Clownfish among sea-anemone tentacles — a textbook mutualism

A **community** 群落 is all the interacting populations in an area. Key interactions: **competition** 竞争 (for shared resources), **predation** 捕食, **symbiosis** 共生 – **mu-**

tualism (both benefit), **commensalism** (one benefits, other unaffected), and **parasitism** (one benefits, other harmed). These relationships shape which species coexist.



A food web links several food chains together

Biodiversity

Coral reef outcrop: high biodiversity in a productive marine ecosystem

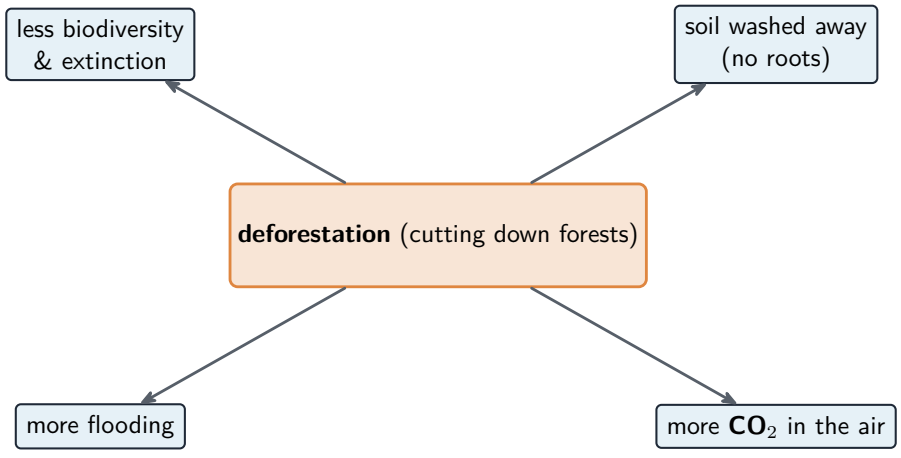
Biodiversity 生物多样性 is the variety of life – genes, species, and ecosystems. Higher diversity generally makes a community more **resilient** 有韧性, better able to withstand and recover from disturbance. A **keystone species** 关键种 has an outsized effect, so losing it can collapse the community.

Biodiversity at three levels: genetic, species, and habitat

Disruptions in Ecosystems

Deforested landscape — habitat loss is a major disruption to ecosystems

Ecosystems change from natural and human causes – climate shifts, invasive species, habitat loss, and pollution. A disturbance can trigger **ecological succession** 生态演替 (the community rebuilds over time). Because species are interconnected, a change to one – especially a keystone or a trophic level – can ripple through the whole ecosystem.



Deforestation lowers biodiversity and causes erosion, flooding, and higher CO2

Exam tips

- Apply the **10% rule**: about 90% of energy is lost at each trophic level, so food chains are short.
- Distinguish **exponential** (J) from **logistic** (S) growth; the latter levels off at the **carrying capacity** ($\frac{dN}{dt} = r_{\max} N \frac{K-N}{K}$).
- Separate **density-dependent** (competition, disease, predation) from **density-independent** (weather) limiting factors.
- Name community interactions (competition, predation, symbiosis) and the effect of a **keystone species**.
- Explain how disturbing one species — especially a keystone or a whole trophic level — ripples through the ecosystem.