Course Companion

Pearson Edexcel · International A-Level · Biology

Every topic handout in one volume

全部专题讲义合集

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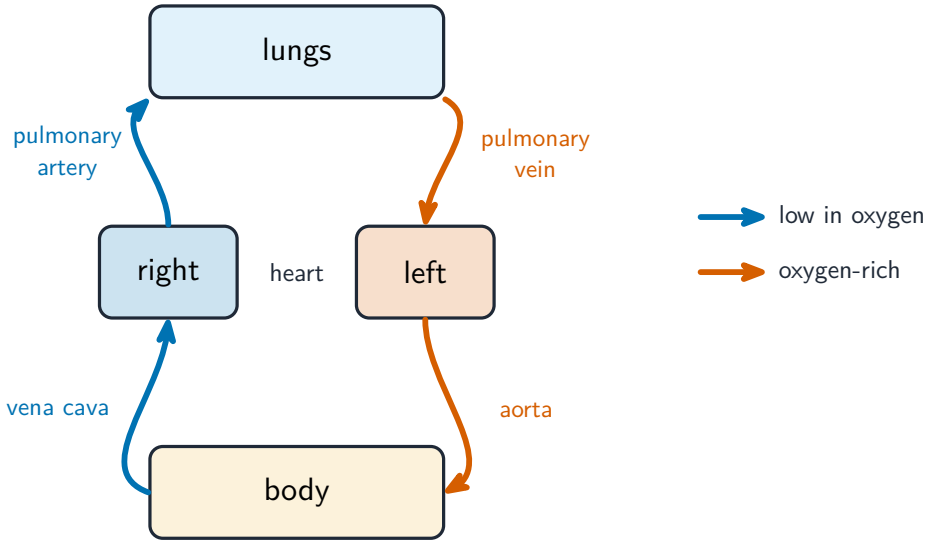
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1 · Molecules, Diet, Transport and Health

Pearson Edexcel · International A-Level · Biology

From molecules to a working circulation

A red blood cell leaving your lung carries oxygen on haemoglobin, rides an artery, squeezes through a capillary narrower than itself, releases the oxygen to a respiring cell, and returns through a vein. Every structure in that journey is built from the molecules this unit starts with, and every exam question about it asks you to connect structure to function.



Two circuits through one heart

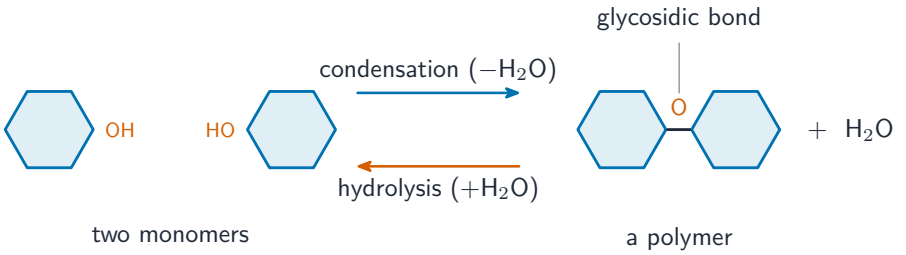
WBI11 Molecules, Diet, Transport and Health is the first IAS unit: a written paper of 1 hour 30 minutes, 80 marks, all compulsory. It assesses Topic 1 (Molecules, Transport and Health) and Topic 2 (Membranes, Proteins, DNA and Gene Expression). Expect data questions on health studies, calculations with standard form, and extended answers that name structures and explain mechanisms.

Water, carbohydrates and food tests

Water is the transport medium because it is a **polar solvent** 极性溶剂. In a water molecule, oxygen pulls the shared electrons more strongly than hydrogen: each O–H bond has a slight negative end at O and a slight positive end at H. This is the **dipole** 偶极 nature of water. Opposite charges between neighbouring molecules form **hydrogen bonds** 氢键, and polar or charged particles (glucose, sodium ions, amino acids) dissolve because water clusters around them.

Carbohydrates are joined and split by two reactions:

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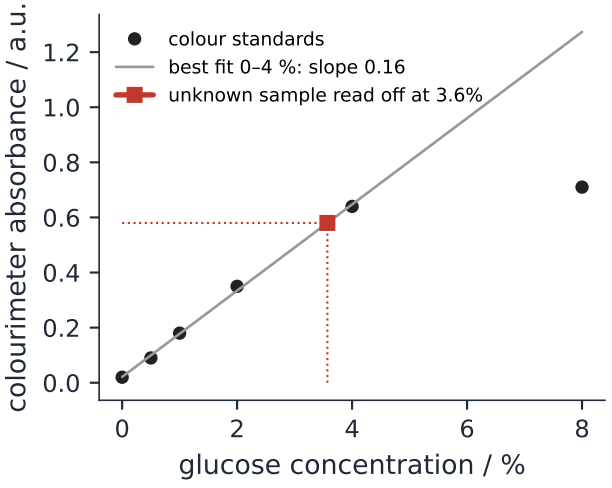
Condensation joins; hydrolysis splits

- **Condensation** 缩合 removes a water molecule as a **glycosidic bond** 糖苷键 forms between two sugars.
- **Hydrolysis** 水解 adds water back and breaks that bond.

Two glucose molecules condense to maltose; glucose plus fructose give sucrose; glucose plus galactose give lactose. Long chains make polysaccharides: **amylose** 直链淀粉 (1,4-linked, coils into a helix, compact), **amylopectin** 支链淀粉 and **glycogen** 糖原 (both 1,4-chains with 1,6-branches; glycogen is the animal store in liver and muscle). Branching means many chain ends, so glucose can be released quickly; the helix means a lot of energy fits in a small space.

■ Core Practical 1: estimating sugar and starch concentration

Reducing sugars reduce blue Benedict's reagent on heating, giving a brick-red precipitate. To estimate an unknown concentration, compare the colour against standards of known concentration, or read the solution in a colourimeter.



Calibration of Benedict's reagent: absorbance of colour standards against glucose concentration, with an unknown read off the straight part of the line.

Worked check. Standards of 0, 0.5, 1, 2 and 4 % glucose give absorbances 0.02, 0.09, 0.18, 0.35, 0.64. An unknown gives 0.58. On the straight section, each 1 % adds

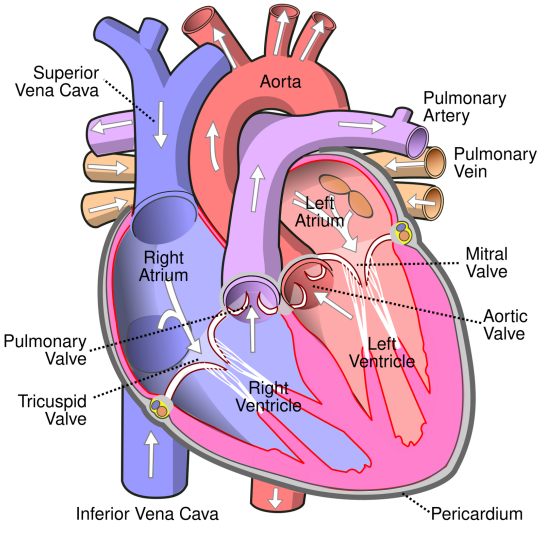
about 0.16 absorbance, so the unknown is near $0.58/0.16 \approx 3.6\%$. Reading beyond the standards (extrapolating past 4 %) is less reliable than measuring within them – a point the examiners like you to make. Iodine turns blue-black with starch; intensity of the blue-black gives the same kind of estimate for starch.

Lipids: triglycerides and ester bonds

A **triglyceride** 甘油三酯 is one glycerol plus three fatty acids, joined by three condensation reactions that form **ester bonds** 酯键. **Saturated** 饱和 fatty acids have no C=C bonds: straight chains pack closely, so animal fats are solid at room temperature. **Unsaturated** 不饱和 acids have one or more double bonds that kink the chain, packing is looser, and oils are liquid. Lipids store more energy per gram than carbohydrates because they are more reduced.

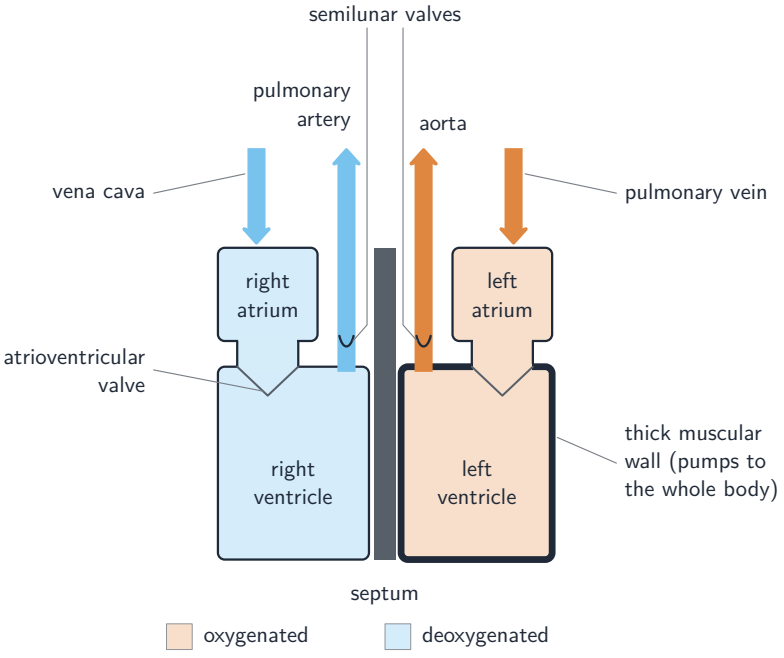
Why animals need a pump: the heart and vessels

Diffusion supplies cells only a few tenths of a millimetre thick. A big organism needs **mass transport** 大规模运输: a pump and pipes that carry every cell's supply and waste. The three vessel types match three jobs:



The heart's four chambers and valves: the thick left ventricle pumps blood round the whole body

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The four chambers of the heart with the vessels to and from lungs and body; the left ventricle has the thickest wall.

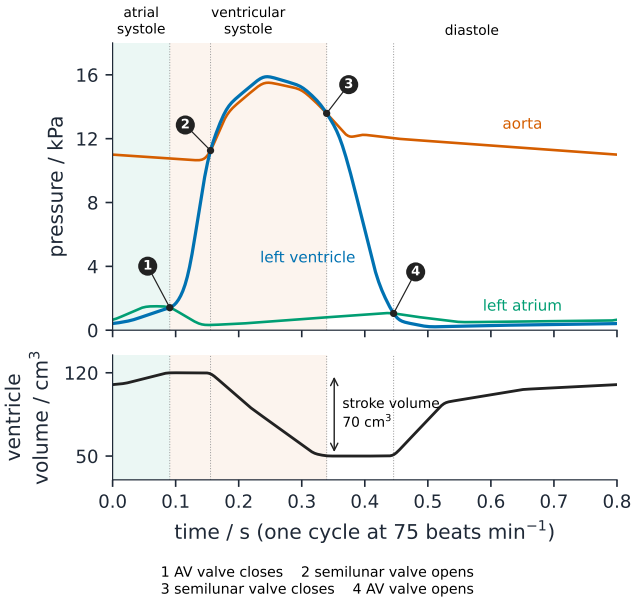
Vessel	Wall	Why
Artery	thick muscle and elastic fibres, small lumen	carries blood at high, pulsing pressure; elastin smooths the pulse
Capillary	one cell thick endothelium	short diffusion path, huge total surface area; tissue fluid leaks out at the start
Vein	thin wall, wide lumen, valves	low pressure return; valves and the surrounding muscles stop backflow

The mammalian heart is two pumps in one organ. The right side sends blood to the lungs; the left side, with the thicker ventricle wall, sends blood to the body. Atria receive; ventricles deliver. The coronary arteries feed the heart muscle itself – blockage there is a heart attack.

The cardiac cycle

One beat has three phases. **Atrial systole** 心房收缩期 squeezes the last blood into the ventricles. **Ventricular systole** 心室收缩期 raises ventricular pressure above arterial pressure, the semilunar valves open, and blood is driven out. **Diastole** 舒张期 relaxes the muscle, pressure falls, the semilunar valves slam shut (the second heart sound), and the chambers refill from the veins.

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Valves change state where two pressure curves cross; the ventricle's volume is constant whenever both valves are shut

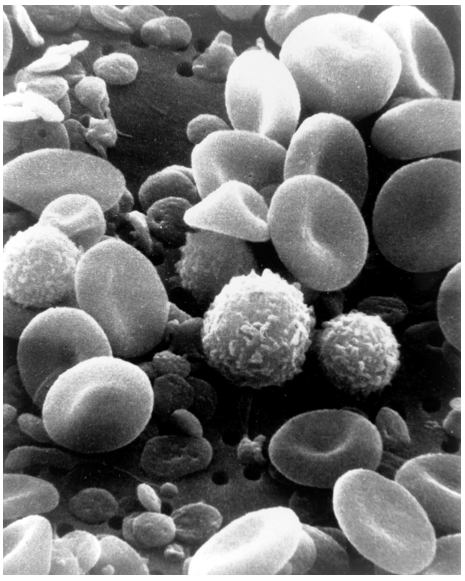
Read the figure the way an examiner wants: valve state is decided by pressure difference, never by an instruction. Atrio-ventricular valves open when atrial pressure exceeds ventricular pressure; semilunar valves open when ventricular pressure exceeds aortic pressure. Between points 1 and 2, and again between 3 and 4, both valves are shut: no blood enters or leaves, so the volume line is flat while the pressure changes fastest. Once the semilunar valve is open, ventricular and aortic pressure rise and fall almost together.

Worked check. From the figure, the ventricle holds 120 cm^3 before contracting and 50 cm^3 after, so the stroke volume is 70 cm^3. At 75 beats per minute the cardiac output is $70 \times 75 = 5250$ cm^3 per minute, about 5.3 dm^3.

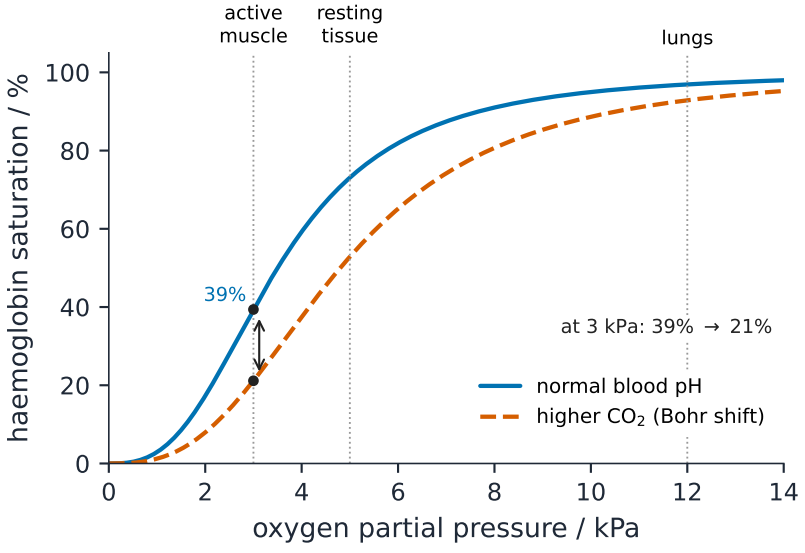
Haemoglobin and the oxygen journey

Haemoglobin is a protein of four polypeptide chains, each folded around a **haem** group carrying one Fe^{2+} ion that binds one O_2 molecule – four in total. Binding the first oxygen changes the shape of the whole molecule and makes the next bindings easier: **cooperative binding** 协同结合 gives the oxygen dissociation curve its shallow-then-steep S shape.

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Red blood cells: each is packed with haemoglobin, which loads oxygen in the lungs and unloads it in respiring tissue



The sigmoid curve for normal blood and the rightward Bohr shift when carbon dioxide rises

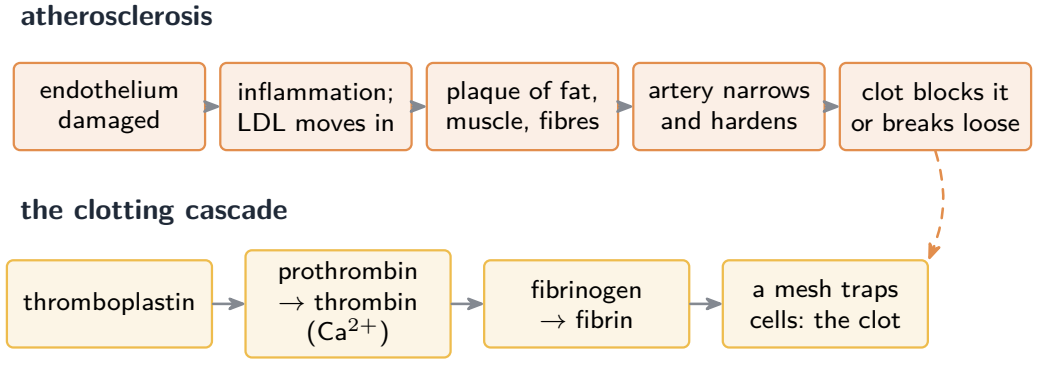
In the lungs (about 12 kPa) the curve flattens near 100 % saturation, so haemoglobin loads fully even if pO_2 there falls a little. In resting tissue (about 5 kPa) it still holds about three-quarters of its oxygen, a reserve. In active muscle (2–3 kPa) the curve is steep, so a small fall in pO_2 unloads a large amount of oxygen – exactly where it is needed. When tissue respires hard it releases more carbon dioxide; hydrogen ions attach to haemoglobin and shift the whole curve to the right (the **Bohr effect** 波尔效应), forcing even more oxygen to unload in the busiest tissue.

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Worked check. At pO_2 3 kPa the normal curve reads about 39 % saturation and the shifted curve about 21 %. Blood arriving from the lungs at 97 % gives up $97 - 39 = 58$ percentage points of its oxygen on the normal curve, but $97 - 21 = 76$ on the shifted curve, so the extra oxygen goes to the tissue that is respiring hardest.

Cardiovascular disease: a chain of events

Atherosclerosis 动脉粥样硬化 begins with damage to the **endothelium** 内皮 lining an artery. The inflammatory response grows, low-density lipoproteins invade, smooth muscle and connective tissue build a **plaque** 斑块, the artery narrows and hardens, and a clot can finally block it or break loose.



Atherosclerosis, then the clotting cascade

Clotting itself is a cascade. Damage releases **thromboplastin** 凝血酶原激酶, which (with calcium ions) converts the soluble plasma protein **prothrombin** 凝血酶原 into the enzyme **thrombin** 凝血酶; thrombin converts soluble **fibrinogen** 纤维蛋白原 into the insoluble mesh of **fibrin** 纤维蛋白 that traps platelets and cells.

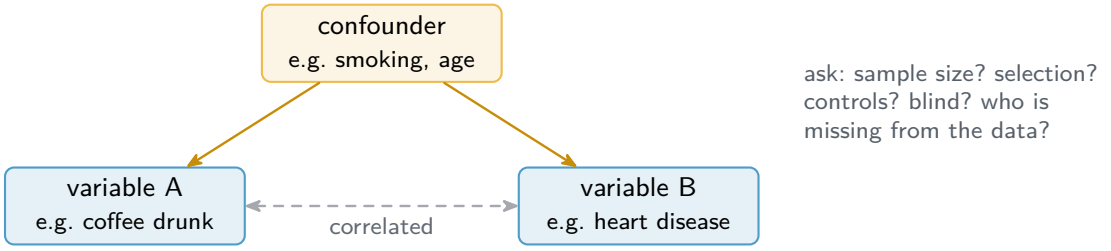
Blood pressure 血压 is reported as systolic over diastolic. Hypertension, smoking, high blood LDL-cholesterol, diet, inactivity, age, gender and genetics are **risk factors** 危险因素. Several risk factors can act together; the size of the combined risk depends on the factors and the population.

■ Reading health-risk data

Questions 8 and 9 of every paper live here. Four habits cover almost every mark:

- **Correlation is not causation.** 相关不等于因果 Two variables moving together may share a hidden cause, or the link may be chance.
- Judge the study: How large was the sample? How was it selected? What was controlled? Was it blind? Are there **confounders** 混杂变量 such as age or smoking?
- Do the arithmetic carefully: percentage change, ratios in standard form, per-capita rates.

- Ask who or what is missing: non-responders, unpublished studies, extrapolated lines.



A confounder can drive both variables

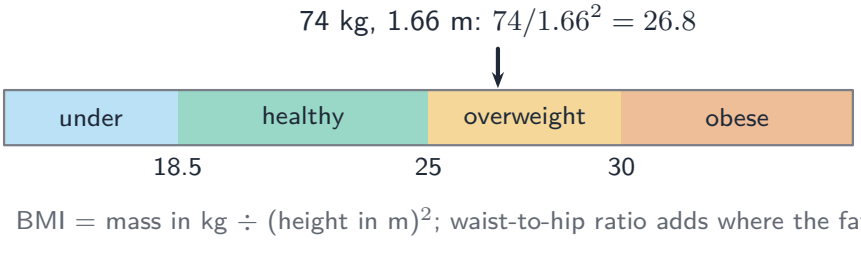
Worked check. A trial reports 6 strokes per 1 000 patient-years on a drug against 9 per 1 000 on placebo: relative risk $= 6/9 \approx 0.67$, a 33% relative reduction – but the absolute difference is 3 strokes per 1 000. "Cuts stroke risk by a third" and "3 fewer strokes per 1 000" are both true; the honest answer names both, and says which one the headline used.

Worked check. A study finds gum disease correlates with endothelial damage. Before claiming one causes the other you would want a mechanism, a dose–response pattern, and confounders (diet, smoking, age) excluded – and the question "were the groups matched for blood pressure?" is exactly a confounder question.

Diet, cholesterol and treating CVD

Energy balance decides body mass. Overweight and obesity are screened by **BMI** (mass in kg divided by height in metres squared; 18.5–24.9 is the healthy band) and **waist-to-hip ratio** (WHR). Dietary saturated fat raises blood LDL-cholesterol; unsaturated fat and soluble fibre lower it.

Worked check. A woman of mass 74 kg and height 1.66 m: BMI $= 74/1.66^2 = 74/2.76 = 26.8$ – just into the overweight band. Waist 84 cm and hips 98 cm give WHR $= 84/98 = 0.86$.



The worked BMI lands just into overweight

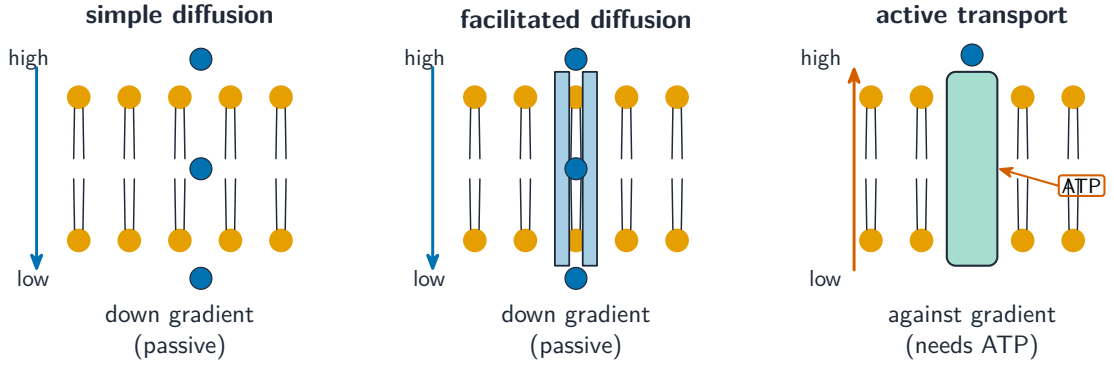
Treatments all carry risks alongside benefits:

- **Antihypertensives** 抗高血压药 (beta blockers, ACE inhibitors, diuretics) lower blood pressure.
- **Statins** 他汀类 (for example simvastatin) block a liver enzyme in cholesterol synthesis, so cells take up LDL from blood.
- **Anticoagulants** 抗凝剂 (warfarin) and **antiplatelet** drugs (aspirin) reduce clotting, so bleeding risk rises.

A question asking you to "discuss" wants both sides plus a judgement anchored in the data given.

Membranes and transport

Every exchange surface is a membrane doing controlled business. The **fluid mosaic model** 流动镶嵌模型 is the accepted picture: a phospholipid bilayer (fluid because the tails can slide), studded with intrinsic proteins that span the bilayer (channels, carriers), extrinsic proteins, cholesterol that controls fluidity, and glycoproteins and glycolipids for recognition.



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

Four transport routes:

- **Diffusion** 扩散 – net movement down a concentration gradient, no ATP.
- **Facilitated diffusion** 易化扩散 – down the gradient through a channel or carrier protein.
- **Active transport** 主动运输 – against the gradient, powered by ATP, through carrier proteins that change shape.
- **Osmosis** 渗透 – water moving from higher to lower **water potential** 水势 across a partially permeable membrane. Endocytosis and exocytosis move bulk material in vesicles.

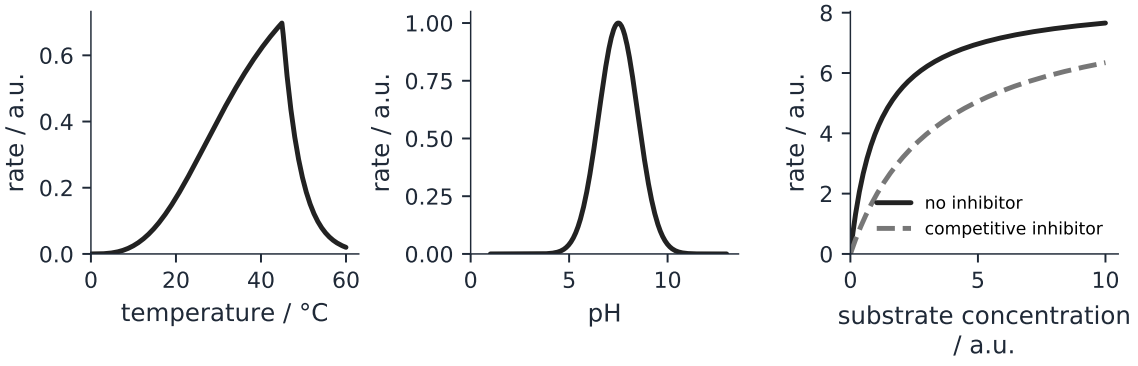
For diffusion, Fick's law: rate is proportional to (surface area × concentration difference) ÷ diffusion distance. Gas exchange surfaces answer all three: huge area,

maintained gradient, and a wall one or two cells thick. This is why alveoli, capillaries and fish gills all look the way they do.

Proteins and enzymes

An amino acid carries an amino group, a carboxyl group, a hydrogen and an R group on one central carbon; two join by a **peptide bond** 肽键 in a condensation reaction. The **primary structure** 一级结构 is the sequence; hydrogen bonds coil it into the **secondary** 二级结构; further hydrogen, ionic and disulfide bonds fold the **tertiary** 三级结构; separate chains assemble into the **quaternary** 四级结构 – haemoglobin is the classic example.

An **enzyme** 酶 is a protein whose **active site** 活性部位 fits one substrate shape. Binding is not rigid: the **induced-fit** 诱导契合 model has both molecule and site flexing until complementary. This is why temperature and pH change rate – they act on the tertiary structure – and why the active site is specific.



Enzyme rate curves: temperature rises then collapses as the protein denatures above its optimum; pH shows a sharp optimum; substrate concentration saturates, and a competitive inhibitor is out-competed at high concentration.

Competitive inhibitors 竞争性抑制剂 bind the active site and are outnumbered as substrate concentration rises; **non-competitive inhibitors** 非竞争性抑制剂 bind elsewhere and distort the site, so rate falls whatever the concentration.

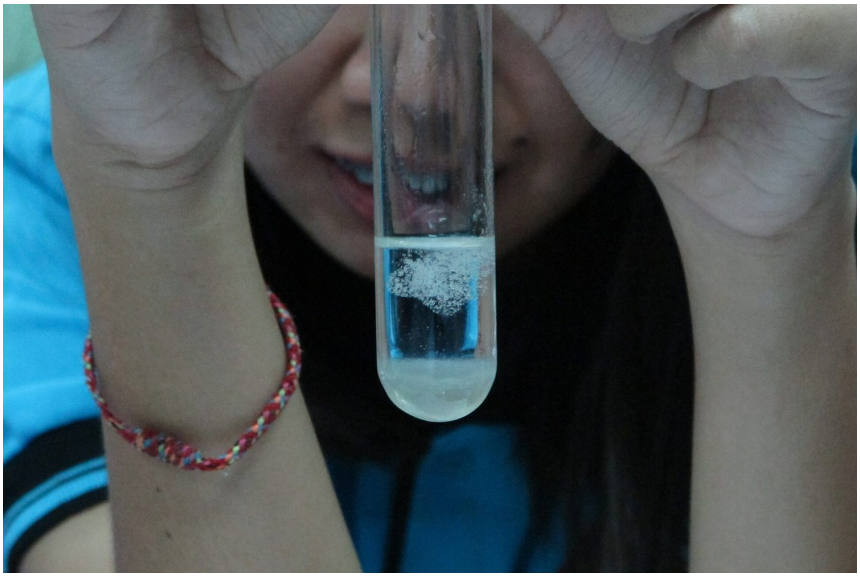
Worked check. Q10 is quoted at 2.4: between 10 °C and 20 °C the rate is 2.4 times faster; above the optimum (for example 45 °C to 55 °C) the rule no longer holds, because denaturation makes the rate fall as temperature rises. Q10 only describes; it does not explain.

DNA, replication and the code

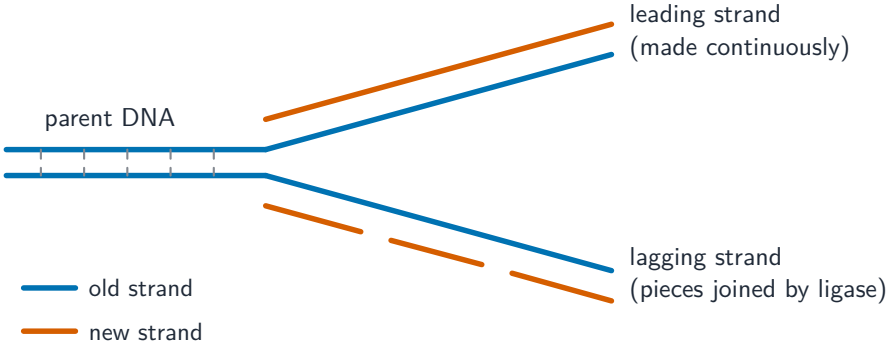
A **mononucleotide** 单核苷酸 is a pentose (deoxyribose or ribose), a phosphate and a nitrogenous base. Condensation between phosphate and sugar of neighbours makes a strand held by **phosphodiester bonds** 磷酸二酯键. DNA is two antiparallel strands:

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A pairs with T (two hydrogen bonds), G with C (three), twisted into a double helix.



DNA extracted from cells: millions of long molecules clump into visible pale strands



each new molecule = one old strand + one new strand (semi-conservative)

Semi-conservative DNA replication at a replication fork

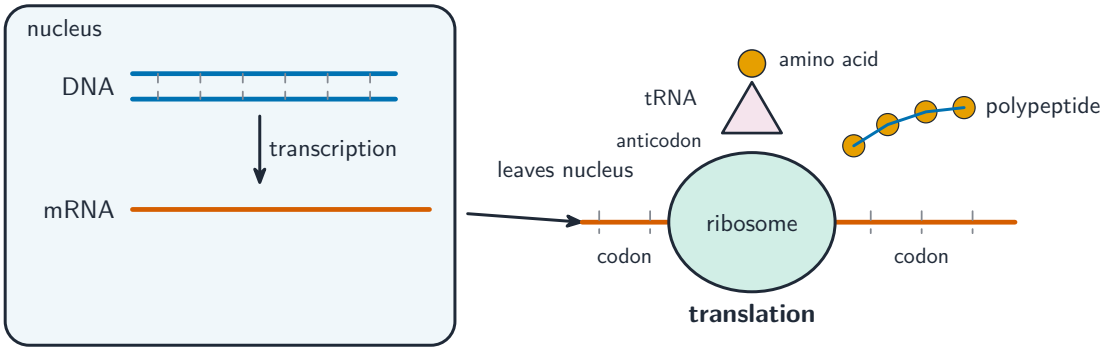
Replication is **semi-conservative** 半保留: helicase unzips the two strands, each is a template, and **DNA polymerase** DNA 聚合酶 joins free nucleotides in the 5' to 3' direction. Meselson and Stahl grew bacteria first on heavy ^{15}N then light ^{14}N nitrogen; after one round of replication all the DNA was one intermediate density, after two rounds half was light – exactly what semi-conservative predicts and the alternatives forbid.

A gene is a sequence of bases coding for a sequence of amino acids. The code is a **triplet** 三联体 code: three bases per amino acid. It is **non-overlapping** 非重叠 (read in successive groups), **degenerate** 简并 (most amino acids have several codons, so some mutations are silent), and carries start and stop codons.

Worked check. A gene of 300 base pairs coding a protein of 99 amino acids plus a stop codon: $99 \times 3 + 3 = 300$. ✓

From gene to protein – and when it goes wrong

Transcription: RNA polymerase binds the gene, uses one strand as template and builds **mRNA** 信使 RNA. Translation: in the cytoplasm, a **ribosome** 核糖体 reads the mRNA codons, and **tRNA** 转运 RNA molecules whose **anticodons** 反密码子 pair with those codons deliver amino acids in order; peptide bonds join them.



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

Mutations 突变 arise from replication errors. A **substitution** 替换 swaps one base: one amino acid changes, or nothing changes (degeneracy). An **insertion** 插入 or **deletion** 缺失 adds or removes a base and shifts every reading frame after it – a **frameshift** 移码 – usually destroying the protein.

Cystic fibrosis is the course's model: deletion of three bases removes one phenylalanine from the CFTR protein, so chloride transport fails, mucus stays thick, and airways clog. The allele is recessive: carriers are healthy. **Genetic screening** 基因筛查 can identify carriers, test embryos (pre-implantation genetic diagnosis) or foetuses (amniocentesis, chorionic villus sampling). Screening questions always carry ethics: who is tested, who is told, what happens to a positive result.

Common mistakes.

- Saying helicase breaks the phosphodiester bonds. Helicase breaks the **hydrogen bonds** between the bases; the sugar–phosphate backbones stay whole.
- Saying DNA polymerase forms the hydrogen bonds between bases. Free nucleotides pair up with the template by themselves; DNA polymerase joins neighbouring nucleotides with **phosphodiester** bonds.
- Describing semi-conservative replication as "half old and half new along each strand". Each new DNA molecule has **one whole old strand and one whole new strand**.

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- Putting the codon on the tRNA. The **codon** is on the mRNA; the tRNA carries the matching **anticodon**.
- Saying transcription happens in the cytoplasm. In eukaryotes it happens in the **nucleus**; the mRNA then leaves through a nuclear pore to the ribosomes.
- Saying atheroma builds up in the lumen of the artery. It forms **in the wall**, under the damaged endothelium, and bulges into the lumen.

Check yourself

1. Explain why amylopectin releases glucose faster than amylose, referring to bonds and ends of chains.
2. Calculate the BMI of a 91 kg man 1.83 m tall and classify him.
3. During ventricular systole, which valves are open and which are shut, and why?
4. The oxygen saturation at 4 kPa falls from about 60 % to about 34 % when CO_2 rises. Explain the molecular cause.
5. Describe the clotting cascade in order, from endothelial damage to fibrin.
6. A study reports that people who eat more yoghurt have fewer heart attacks. List three checks you would make before believing a causal claim.
7. Explain why a competitive inhibitor lowers the rate at low substrate concentration but not at very high concentration.
8. Meselson and Stahl ruled out conservative replication. Which observation, after one round, did the job?
9. A frameshift mutation is usually worse than a substitution. Explain why, using the words triplet and degenerate.
10. Name two benefits and two risks of genetic screening for cystic fibrosis carriers.

Answers: 1 many 1,6-branch points give many chain ends for enzymes to attack simultaneously; 2 $91/1.83^2 = 27.2$, overweight; 3 atrio-ventricular shut and semilunar open, because ventricular pressure is above atrial pressure (closing the atrio-ventricular valves) and above aortic pressure (opening the semilunar valves); 4 hydrogen ions from CO_2 bind haemoglobin, changing its shape and lowering oxygen affinity (Bohr effect); 5 damage exposes collagen, platelets and damaged cells release thromboplastin, thromboplastin + Ca^{2+} converts prothrombin to thrombin, thrombin converts fibrinogen to fibrin, fibrin mesh traps cells; 6 sample size and selection, confounders such as age/exercise/diet, blinded comparison, mechanism or dose–response; 7 the inhibitor competes for the active site, so at very high substrate concentration nearly every collision with the site is substrate; 8 after one round all DNA was a single intermediate band – conservative predicts one heavy and one light band; 9 a frameshift changes every triplet after the mutation, so the whole protein from that point is a different amino-acid sequence, while degeneracy lets many substitutions change nothing; 10 benefits – informed family planning, earlier treatment or lifestyle change; risks – anxiety, discrimination by insurers or employers, false positives or negatives.

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2 · Cells, Development, Biodiversity and Conservation

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From one cell to a living world

You began as one fertilised egg cell. This unit explains how that cell divided, how the copies were shuffled and halved to make gametes, how identical genes became different tissues, and how the variety that produces is counted, classified and – increasingly – defended. It is the unit of microscopes, calculations and definitions done precisely.

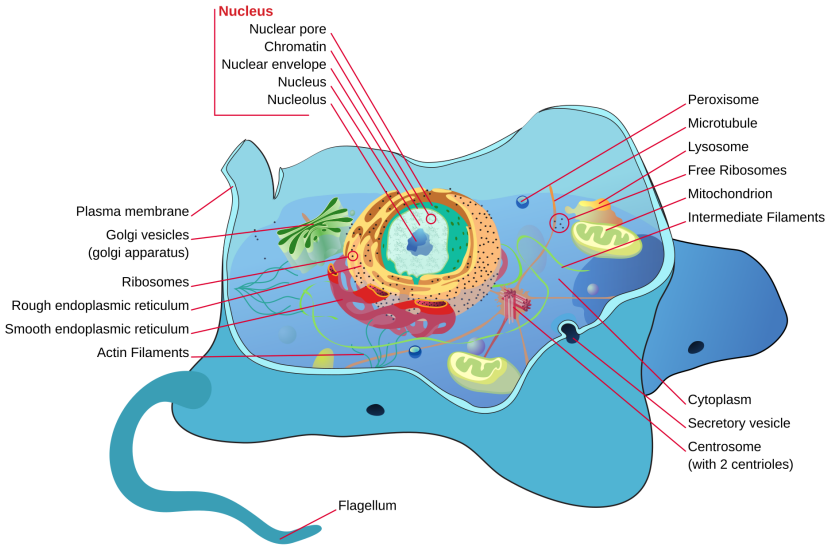
WBI12 Cells, Development, Biodiversity and Conservation is the second IAS unit: 1 hour 30 minutes, 80 marks, all compulsory. It assesses Topic 3 (Cell Structure, Reproduction and Development) and Topic 4 (Plant Structure and Function, Biodiversity and Conservation). Expect labelling diagrams, microscope and magnification calculations, the index of diversity and Hardy–Weinberg questions, and long answers on conservation evaluation.

Cell ultrastructure and the microscope

A **eukaryotic** 真核 cell is a set of specialised compartments:

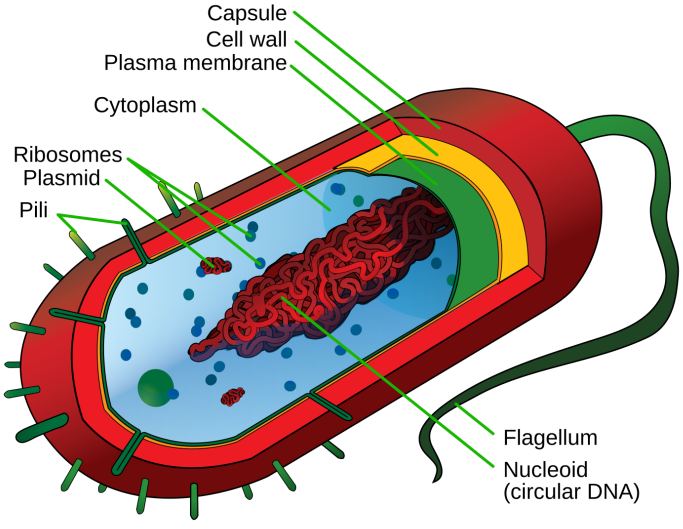
Structure	Function
Nucleus and nucleolus	DNA stored behind a double membrane; nucleolus builds ribosomes
Ribosomes (80S)	site of protein synthesis
Rough endoplasmic reticulum	folds and transports proteins made on its ribosomes
Golgi apparatus	modifies, packages and ships proteins in vesicles
Mitochondrion	site of aerobic respiration, ATP production
Chloroplast (plants)	site of photosynthesis
Lysosome	digestive enzymes for worn organelles
Cell-surface membrane	controls transport, recognition

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The compartments of an animal cell, as an electron microscope reveals them.

Cells organise into **tissues** 组织 (similar cells), **organs** 器官 (cooperating tissues) and **organ systems** 器官系统. A **prokaryotic** 原核 cell has none of the membrane-bound organelles: a cell wall, a slime **capsule** 荚膜, one circular DNA molecule plus **plasmids** 质粒, 70S ribosomes, and sometimes a **flagellum** 鞭毛.



A prokaryote: no nucleus, circular DNA and plasmids, small ribosomes.

Magnification 放大倍数 is how much bigger the image is; **resolution** 分辨率 is the smallest separation still seen as two. Light microscopes resolve about 200 nm; electron beams, far shorter in wavelength, resolve to a few nanometres – but need thin stained sections (TEM) or gold-coated surfaces (SEM). M = image size/actual size, keeping units consistent.

Worked check. A mitochondrion measures 14 mm on a photograph labelled ×20 000. Actual length = 14 000 μm/20 000 = 0.7 μm. A nucleus that must be seen with its double membrane needs an electron microscope: the two membranes lie closer than a light microscope's resolution.

Meiosis: halving and shuffling

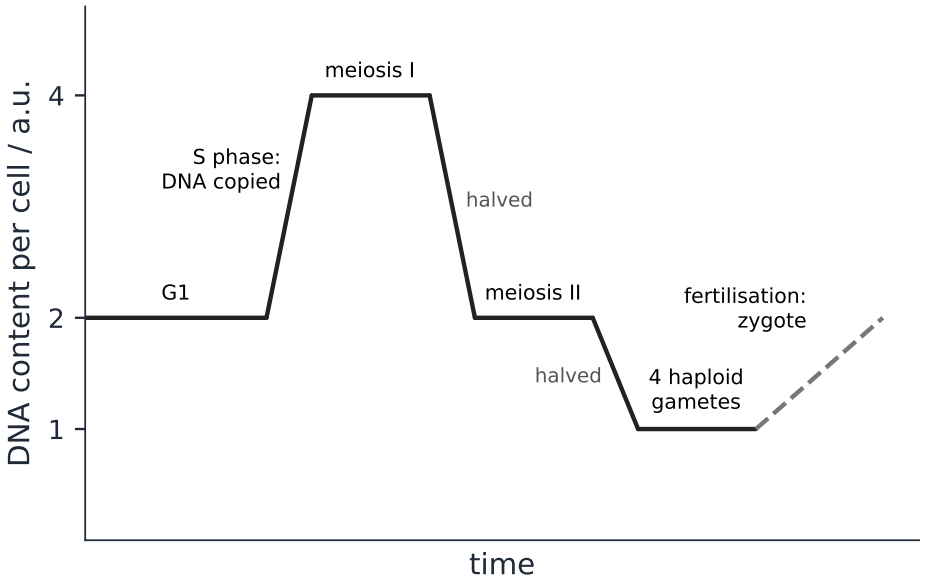
Meiosis 减数分裂 is two successive divisions after one DNA replication, producing four genetically different **haploid** 单倍体 cells from one **diploid** 二倍体 cell. Two processes create the variation:

- **Independent assortment** 独立分配 – each homologous pair lines up and separates at random in meiosis I; each gamete gets one of each pair, from either parent at random (2^n combinations).
- **Crossing over** 交叉互换 – in prophase I, non-sister chromatids of a homologous pair swap sections, mixing alleles within chromosome pairs.

Worked check. Independent assortment alone: a human ($n = 23$) makes $2^{23} \approx 8.4$ million genetically different gametes before any crossing over. And the machinery shows in one cross: $Aa \times Aa$ makes A and a gametes in equal proportion, so the Punnett square reads AA, Aa, Aa, aa – a 3:1 phenotype ratio and 1:2:1 genotypes, each outcome resting on every gamete's alleles being independent of every other's, which is exactly what meiosis I delivers.

Mammalian gametes are specialised for delivery and provisioning: the **sperm** 精子 carries an **acrosome** 顶体 (digestive enzymes), a midpiece of mitochondria and a flagellum; the **egg** 卵子 contributes nearly all cytoplasm and a **zona pellucida** 透明带 that locks out extra sperm after the **cortical reaction** 皮质反应. In flowering plants the pollen tube delivers two male nuclei: one fertilises the egg, the other the polar nuclei – **double fertilisation** 双受精.

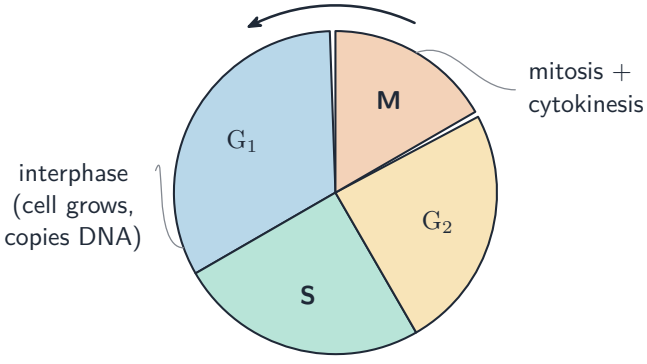
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DNA content per cell through the cell cycle, both meiotic divisions, gametes and fertilisation. Note the doubling in S phase and the two halvings.

Mitosis and the cell cycle

Mitosis 有丝分裂 gives daughter nuclei the same chromosome number as the parent nucleus. After cytokinesis, a diploid parent normally produces two diploid daughter cells for growth, repair or asexual reproduction. Interphase (G_1, **S** – DNA replication, G_2) fills most of the cycle; mitosis itself is prophase (chromosomes condense, spindle forms), metaphase (chromosomes line at the equator), anaphase (spindle fibres pull chromatids to poles), telophase (nuclear membranes reform), then **cytokinesis** 胞质分裂.



Interphase fills most of the cycle

The **mitotic index** 有丝分裂指数 = cells in mitosis ÷ total cells counted. A high

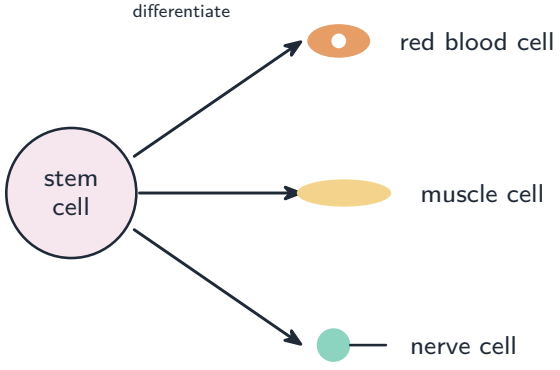
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value means a large fraction of the counted cells are dividing. Healthy growing tissues can also have high values, so this alone does not diagnose cancer.

Worked check. A root-tip squash shows 36 of 450 cells in mitosis: index $= 36/450 = 0.08 = 8\%$. If the cycle takes 20 hours, mitosis occupies $0.08 \times 20 = 1.6$ hours.

Stem cells and switching genes on

A **totipotent** 全能性 stem cell can form a whole organism (the first divisions of the zygote); a **pluripotent** 多能性 cell (inner **blastocyst** 胚泡) can form any tissue but not the whole organism. Differentiation happens by **differential gene expression** 差异基因表达: most specialised body cells retain the same genome, but each type expresses a different subset of genes. One gene can yield several proteins by **post-transcriptional modification** 转录后修饰 – RNA splicing choices of the pre-mRNA. The final phenotype also reflects the environment (height needs both genes and nutrition) and, for many traits, multiple genes acting together (**polygenic** 多基因 inheritance giving continuous variation).

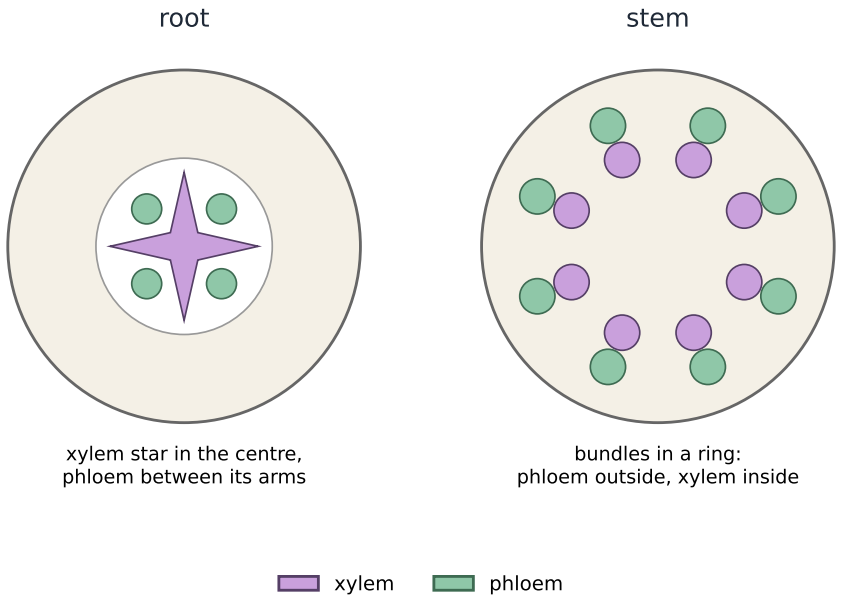


One genome, different genes switched on

Plant transport tissues

Plant cells add a cellulose **cell wall** 细胞壁 joined to neighbours by **plasmodesmata** 胞间连丝. Cellulose chains bundle into **microfibrils** 微纤维 whose criss-cross laying gives tensile strength; secondary thickening with lignin strengthens and waterproofs.

Tissue	Built from	Function
Xylem 木质部	dead hollow cells, lignified walls	water and mineral transport; support
Phloem 韧皮部	living sieve-tube elements + companion cells	translocation of sugars



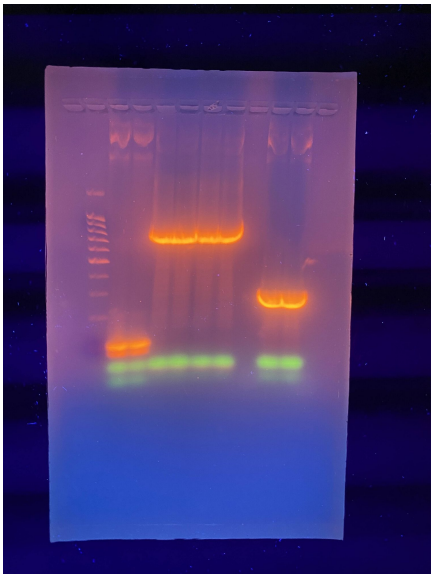
Schematic cross-sections – in the root the xylem and phloem alternate on a central star; in the stem, vascular bundles arrange phloem outside xylem in a ring.

Water and ions matter beyond drinking: **nitrate** 硝酸盐 builds amino acids, **calcium** 钙离子 cross-links pectin in walls and signals inside cells, **magnesium** 镁离子 sits at the heart of chlorophyll – a shortage yellows the leaves.

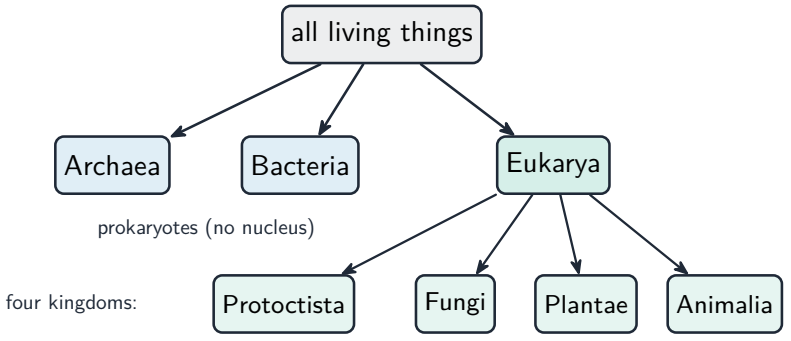
Measuring life: classification and biodiversity

Classification arranges life by shared characteristics; the **three-domain system** 三域系统 (Bacteria, Archaea, Eukarya) rests on molecular evidence – ribosomal RNA sequences – that revealed Archaea are closer to us than to bacteria. Within a habitat, diversity has two measures:

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DNA fragments separated by gel electrophoresis: comparing sequences now underpins classification



Three domains from molecular evidence

- **Species richness** 物种丰富度 – how many species.
- **Index of diversity** 多样性指数 – $D = \dfrac{N(N-1)}{\sum n(n-1)}$, where N is all individuals and n each species' count. Higher D, more diverse.

Worked check. Habitat A: 3 species with counts 40, 35, 25 ($N = 100$). $D = 100 \times 99/(40 \times 39 + 35 \times 34 + 25 \times 24) = 9900/(1560 + 1190 + 600) = 9900/3350 = 2.96$. Habitat B: 3 species, counts 90, 6, 4: $D = 9900/(8010 + 30 + 12) = 1.23$. Same richness, very different balance – D sees what richness cannot.

Within one species, the **heterozygosity index** 杂合度指数 H = (number of heterozygotes) ÷ (number of individuals) measures genetic variety. A species found nowhere else is **endemic** 特有种 – and its island home makes it both precious and fragile.

Niches, Hardy–Weinberg and conservation

A **niche** 生态位 is a species' way of life: its role, its requirements, its tolerances. Adaptations come in three registers – anatomical (thick fur), physiological (enzyme variants), behavioural (migration timing).

The **Hardy–Weinberg equation** 哈迪 – 温伯格方程 tracks allele frequencies in a large, randomly breeding population with no selection, migration or mutation:

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

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

What each Hardy-Weinberg term counts

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

q^2 = frequency of the homozygous recessive genotype. If 4 % of a population shows the recessive phenotype, $q^2 = 0.04$, so $q = 0.2$, $p = 0.8$, carriers $2pq = 0.32$.

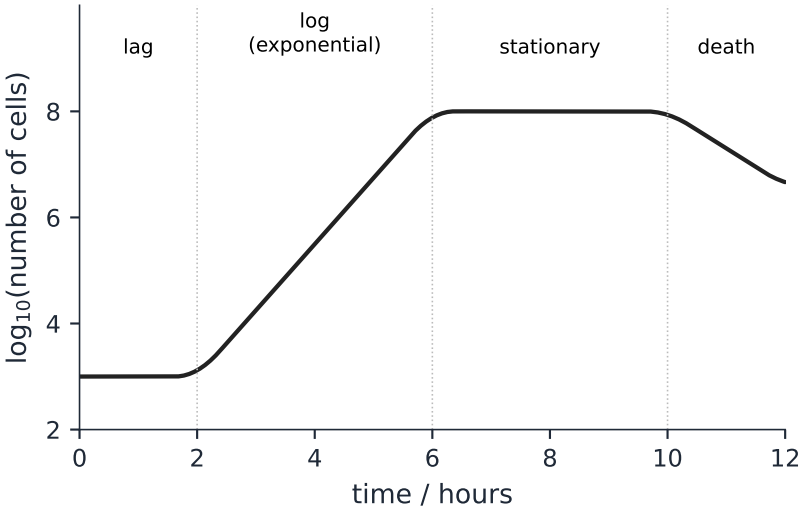
Worked check. Of 500 foxes, 45 are homozygous recessive: $q^2 = 0.09$, $q = 0.3$, $p = 0.7$. Expected carriers $= 2pq \times 500 = 0.42 \times 500 = 210$.

Conservation questions want balance. Zoos and **seed banks** 种子库 keep species against extinction and run captive breeding, but cost space, lose natural behaviour and serve few individuals; habitat protection and **corridors** 走廊 preserve ecology at scale but need land, money and political will. Credit the specific argument, not the sentiment.

Culturing and growing microbes

For the microbiology here (and Unit 4's): grow bacteria on nutrient agar or in broth, using **aseptic technique** 无菌技术 – use approved teaching cultures, sterilised equipment and the school's supervised handling, incubation and disposal procedures. Secure lids as specified by that procedure. Lower incubation temperatures reduce some risks; they do not guarantee that pathogens cannot grow. Count colonies on spread or pour

plates (each colony from one cell or a clump: **colony-forming units**), or count cells with a haemocytometer, or follow **turbidity** 浊度 in broth.



A microbial growth curve on a log scale – lag, exponential (log), stationary and death phases.

Worked check. In the exponential phase, the growth-rate constant $k = (\log_{10} N_t - \log_{10} N_0)/(0.301 \times t)$. From 1×10^4 to 4×10^7 cells in 4 hours: log difference = 3.602, so $k = 3.602/(0.301 \times 4) \approx 3.0$ divisions per hour – about a 20-minute generation time.

Common mistakes.

- Using the 4% who show a recessive phenotype as q. The 4% is q^2 (the homozygous recessive genotype); take the square root to get $q = 0.2$.
- Forgetting the 2 in $2pq$. Heterozygotes can arise in two ways (Aa and aA), so carriers are $2pq$, not pq.
- Saying the number of chromosome combinations from independent assortment is $2n$. It is 2^n, where n is the number of homologous pairs: 2^{23} in humans.
- Saying crossing over happens between sister chromatids. It happens between **non-sister** chromatids of a homologous pair; sister chromatids are identical, so swapping would change nothing.
- Using a high mitotic index alone to diagnose cancer. Growing tissues such as root tips also have high values; compare with the normal value for that tissue.

Check yourself

1. Calculate the actual width of a nucleus that appears 24 mm wide at ×4 000. Give your answer in µm.
2. Name the two processes in meiosis that create genetic variation, and state when each happens.

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3. A cell has 2 a.u. of DNA in G1. Sketch how DNA content changes through S phase, meiosis I and meiosis II.
4. Explain why all cells of a blastocyst can become any tissue, but a mature muscle cell cannot.
5. Explain two ways xylem is adapted to its function, one structural and one chemical.
6. Two habitats each contain 5 plant species. Explain why the index of diversity can still differ between them.
7. In a population of 1 000, 16 people show a recessive condition. Calculate q, p and the expected number of carriers.
8. A species of snail is endemic to one island. Explain why endemic species face higher extinction risk.
9. State three conditions a population must meet for the Hardy–Weinberg equation to hold.
10. Give one benefit and one limitation of seed banks compared with protecting habitat.

Answers: 1 $24\,000/4\,000 = 6$ μm; 2 crossing over in prophase I, independent assortment in metaphase/anaphase I (and II); 3 rises to 4 in S, halves to 2 after meiosis I, halves to 1 after meiosis II, restored to 2 at fertilisation; 4 blastocyst cells are pluripotent – all genes still switchable; a muscle cell has switched off other pathways permanently in ordinary conditions; 5 hollow, lignified dead cells form continuous water columns with no cytoplasm to resist flow; lignin waterproofs and strengthens walls against collapse; 6 D weighs the evenness of abundance, not just the species count; 7 $q^2 = 0.016$, $q \approx 0.126$, $p \approx 0.874$, carriers $2pq \approx 0.22$, about 220 people; 8 a single local event (storm, disease, introduced predator, habitat loss) removes the whole species at once; 9 large population, random mating, no selection/mutation/migration; 10 seed banks store genetic diversity cheaply and safely against habitat loss (benefit) but species exist out of their ecology – no interactions, no evolution in place, and recolonisation is uncertain (limitation).

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3 · Practical Skills in Biology I

Pearson Edexcel · International A-Level · Biology

The paper that tests your hands – without your hands

You have pipetted Benedict's onto glucose, squashed a root tip, and rinsed beetroot until the water ran clear. WBI13 asks you to write about exactly that work: why each step was done, what makes it fair, how the numbers are turned into tables and graphs, and what the result honestly shows. Nothing in the paper is new theory – it is Units 1 and 2 seen through the eyes of someone who actually did the practicals.



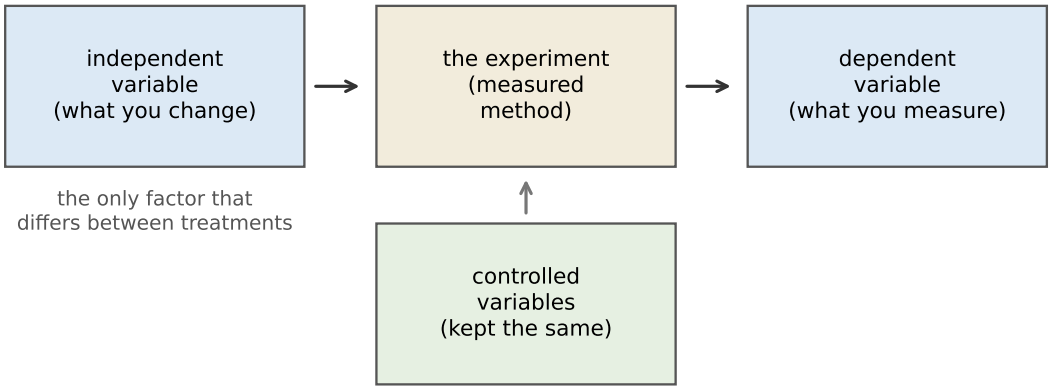
Benedict's test: blue means no sugar; orange to brick-red means reducing sugar is present

WBI13/01 Practical Skills in Biology I is the third IAS unit: 1 hour 20 minutes, 50 marks, all compulsory, usually three long questions built on core-practical contexts. Calculators and rulers are required. The specification lists what is assessed: solving problems in practical contexts, commenting on design and methods, presenting data, evaluating results with reference to **uncertainties** 不确定度 and errors, identifying variables, plotting and interpreting graphs, processing data with the mathematical skills of Appendix 6, knowing the apparatus and techniques, and planning an investigation to test a **hypothesis** 假设.

A question word to respect: *justify* – every step must be paired with the reason it makes the data valid (rinsing beetroot removes pigment from cut surfaces, so measured absorbance reflects membrane leakage, not slicing damage).

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Variables and a fair test



The three variable roles in any investigation, with a beetroot example and control treatment.

The **independent variable** 自变量 is what you deliberately change (presence or concentration of trifluralin; alcohol concentration). The **dependent variable** 因变量 is what you measure (percentage of cells in each mitotic stage; absorbance of leaked pigment). Everything else that could affect the dependent variable is a **control variable** 控制变量, kept the same with a reason: temperature, because it changes membrane fluidity and enzyme action; volume of solution, because it dilutes pigment differently. Say the variable *and* the reason – the mark scheme needs both.

A **control treatment** 对照处理 is a whole treatment left unchanged (solvent with no trifluralin; water instead of methanol) so that any difference can be attributed to the independent variable alone. Repeat readings give reliability, a mean, and a measure of spread; they do not remove a **systematic error** 系统误差 such as a balance zero error, which shifts every reading the same way.

The nine IAS core practicals

The paper's contexts come from these. Know each method, its measurements and its pitfalls.

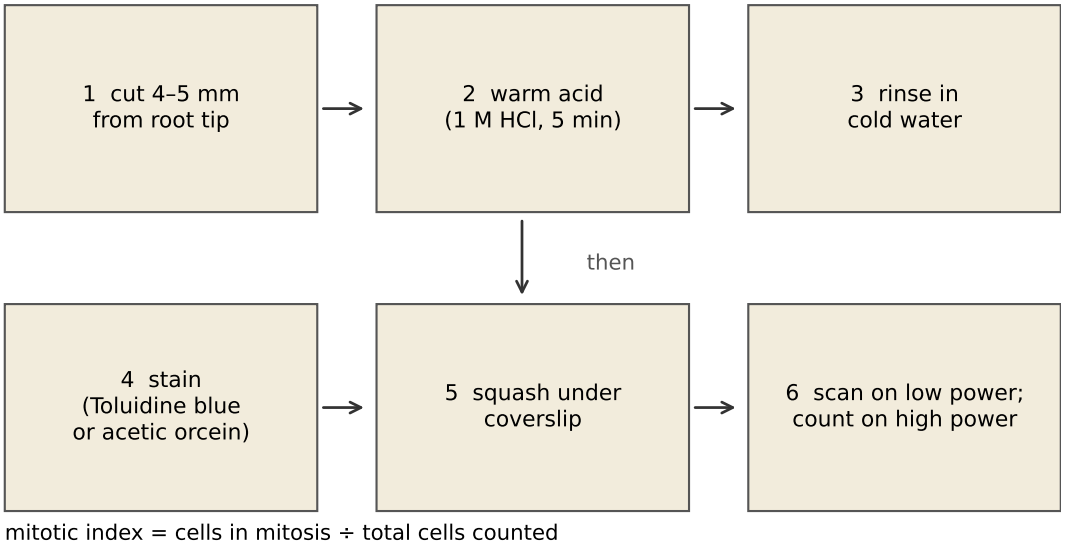
Core practical	Method core	What is measured
1 Sugar and starch concentrations	Colour standards made by serial dilution; Benedict's heated with standards and samples; iodine for starch	Colour match against standards – **semi-quantitative** 半定量

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Core practical	Method core	What is measured
2 Vitamin C content	DCPIP titration: drops (or volumes) of sample that decolourise the indicator	Volume at endpoint; compare with a known ascorbic-acid standard
3 Membrane permeability	Equal beetroot pieces, rinsed, in alcohol or temperature treatments; pigment loss into the medium	Absorbance in a **colorimeter** 色度计 (zeroed on plain solvent)
4 Enzyme rate	Substrate + enzyme at controlled pH buffer and temperature; samples tested at fixed intervals	Initial rate from time course; 1/time as a rate proxy
5 Microscopy and scale	Prepared slide, low to high power; labelled drawings; **graticule** 目镜测微尺 calibrated against a stage micrometer	Cell dimensions, magnification, scale
6 Root-tip squash	Tip cut, warm acid, rinse, stain (Toluidine blue, acetic orcein), squash, scan and count	Cells in each mitotic stage; **mitotic index** 有丝分裂指数
7 Plant sections	Plan diagrams (no cells) and cellular drawings of root, stem and leaf transverse sections	Tissue arrangement and identification
8 Fibre tensile strength	Same-length fibres hung with increasing masses until breaking	Mass at break, compared between treatments
9 Antimicrobial plants	Aseptic technique: flame loops and necks, agar plates seeded, filter-paper discs of plant extract; incubate inverted below 30 °C	Zone of inhibition around discs

For Core Practical 9, aseptic technique protects you and the culture: work near a Bunsen updraught, open plates briefly, tape (do not seal) lids, use the school-approved cultures and incubation conditions. A lower incubation temperature does not guarantee that pathogens cannot multiply.

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The root-tip squash as a numbered flow from cutting the tip to counting stages on high power.

Planning an investigation

The specification's planning list is your mark scheme. A full-credit plan names: the apparatus; the independent, dependent and controlled variables (each control with its reason); how each variable is measured with the appropriate instrument and technique; whether repeats are appropriate; the safety issues and how they are dealt with; how the data will be used (table headings planned, graph type chosen); and the sources of **uncertainty** or systematic error with how each is reduced.

Safety in biology is about the specific risk and the specific control: methanol is flammable, so keep it from flames; bacteria are cultured at low temperature so human pathogens do not grow; sharp scalpels cut away from the body.

> **Worked example (original): a CP2 plan as the marks are paid.** "Determine the vitamin C content of two fruit juices." Standardise first: count the drops of 1 % ascorbic-acid solution that decolourise 1 cm^3 of DCPIP (say 10), then the same for each juice, in repeats. Controls with reasons: same DCPIP volume and concentration (the endpoint depends on it); one dropper throughout (drop size is the unit; burette volumes remove the judgement); room temperature (rate). Safety: low hazard – avoid skin and eye contact. Processing: juice needing 5 drops where the standard needs 10 carries $10/5 \times 1\% = 2\%$ vitamin C – drops of standard ÷ drops of sample scales the concentration. A table of repeats with a mean column; the comparison in words is the answer.

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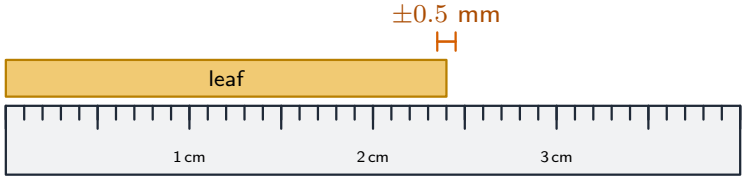
drops to decolourise 1 cm^3 DCPIP; half the drops means twice the vitamin C

juice: $\frac{10}{5} \times 1\,\% = 2\,\%$

Fewer drops means more vitamin C in each drop.

Making measurements honestly

Choose the instrument that matches the quantity: a graticule for microscope lengths, a ruler for bench lengths, a colorimeter for colour intensity, a stopwatch for time, a syringe or graduated pipette for small volumes. Quote only the figures the instrument supports: a ruler graduated in millimetres gives a length to the nearest millimetre, with an **absolute uncertainty** 绝对不确定度 of ± half a division (± 0.5 mm) or ± one division by the conservative course convention – state which you use.



reading: 24 mm ±0.5 mm, percentage uncertainty $= \frac{0.5}{24} \times 100\% = 2.1\%$

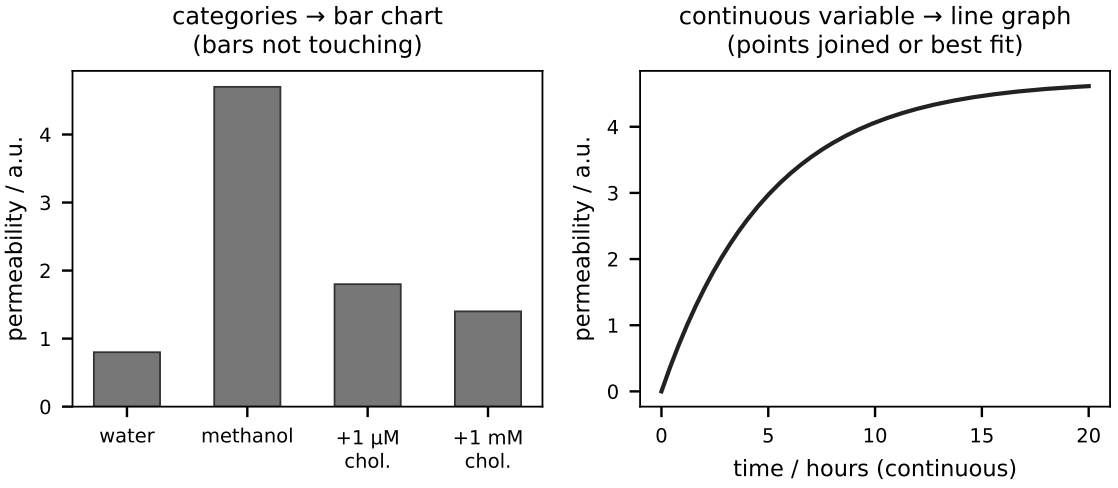
An illustration: half a division on a millimetre ruler is ±0.5 mm, 2.1% of 24 mm

Percentage uncertainty 百分比不确定度 = (absolute uncertainty ÷ measurement) ×100%. For the maximum-uncertainty model used here, add percentage uncertainties for products or quotients, and absolute uncertainties for sums or differences. **Significant figures** 有效数字 must be justified by the measured inputs and the stated uncertainty. Both 12.67 and 12.70 have four significant figures; a trailing zero can be significant. Whether either value is correct depends on the calculation, not on the zero alone.

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Presenting data: tables and graphs

A table earns its marks by rule: each column headed with quantity *and* unit (permeability / a.u.), units never written inside cells, all data entered exactly, and no units or units-symbols invented for arbitrary instrument readings – the paper supplies a.u. (arbitrary units). Draw the table before entering values so nothing is squeezed in.



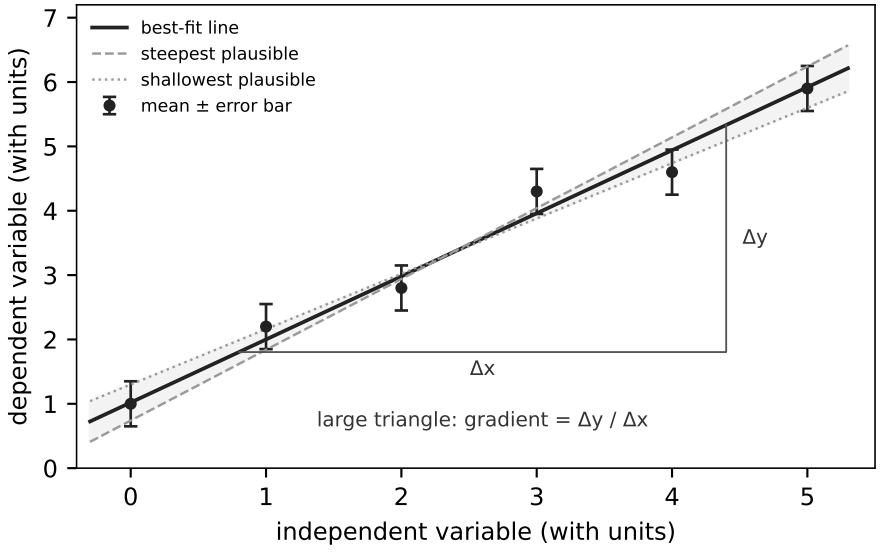
Choosing the graph form - bar chart for categoric treatments, line graph for a continuous variable.

Graph rules earn marks the same way: axes labelled with quantity and unit, the independent variable on the x-axis, a scale that uses most of the grid without awkward fractions, no broken axis, points plotted with a sharp cross, and the right form – a **bar chart** 柱状图 for categoric treatments (bars not touching), a **line graph** 折线图 for a continuous variable. A best-fit line or curve shows the trend; joining every dot claims a pattern the data may not have.

Analysing: gradients and percentages

A **gradient** 梯度 comes from a large triangle drawn on the best-fit line, at least half the line's length: gradient $= \Delta y/\Delta x$, with the y-unit and x-unit divided out in the answer. Read values off the line (not a data point) when interpolating.

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Error bars with best-fit, steepest and shallowest plausible lines and a large-triangle gradient.

The percentage family recurs every year. **Percentage change**: $\dfrac{\text{final} - \text{initial}}{\text{initial}} \times 100\%$. **Percentage difference** (the 2025 formula): difference ÷ mean of the two values ×100%. From a bar chart, percentage of cells in a stage × total cells = cells in that stage – 80 % of 98 cells is 78.4, which reports as **78 cells**, because 0.4 of a cell does not exist.

Worked check. Highest cassava region 33.65, lowest 29.64 g per 100 g. Difference $= 33.65 - 29.64 = 4.01$. Mean $= (33.65 + 29.64)/2 = 31.645$. Percentage difference $= 4.01 \div 31.645 \times 100 = 12.67\%$ (13 % at 2 s.f., 12.7 % at 3 s.f.; 12.70 % is not the correct 4 s.f. rounding of this calculation).

Evaluating and extending

An **anomalous result** 异常值 is a reading inconsistent with the others – a point far from the line – checked by repeating that treatment, not silently deleted. Improvements must be realistic and named: a colorimeter instead of colour matching (quantitative, removes judgement); zeroing on plain solvent (removes a systematic offset); more concentrations within the range tested (narrows interpolation); repeating to compute a mean and **standard deviation** 标准差 (SD), standard error or range, then drawing **error bars** 误差线. To extend a study to variability between organisms, repeat on *different* individuals under the same conditions – not more measurements on the same one – then report a mean and a named measure of spread.

State the conclusion inside the measured range: a graph is evidence for the model between the first and last data points, and a zero intercept or an unexpected offset is information about the method or the model, not a nuisance.

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What written practice cannot do

This unit examines written practical skills. A full-mark answer here does not show that you carried out aseptic technique cleanly, focused a microscope patiently, or squashed a root tip without smearing it – the practical experience itself is developed in class while studying Units 1 and 2, and only written evidence is assessed here. Practise the real practicals; then describe them.

Check yourself

1. In a trifluralin investigation, state the independent variable and explain why some seedlings were placed in solvent without trifluralin.
2. List, in order, the steps for preparing and examining a root-tip squash, naming one acceptable stain.
3. 98 cells are seen; 80 % are in metaphase. How many cells is that? Why is your answer a whole number?
4. Highest region 33.65 and lowest 29.64 g per 100 g of tissue. Calculate the percentage difference using the mean of the two values.
5. A student's beetroot method reads: "cut pieces, put in alcohol, measure colour." Add the three justifications the mark scheme most needs.
6. Which graph type for: (a) permeability of four named liquids; (b) permeability against time over 20 hours?
7. Explain the difference between a quantitative and a semi-quantitative result, with one example of each from the core practicals.
8. State two things repeat readings improve and one thing they cannot remove.
9. Describe how to extend a starch-variability study from one cassava root to many, naming a statistic you would report.
10. Why is 12.70 % rejected when 12.67 % is accepted, in a percentage-difference answer?

Answers: 1 presence (or concentration) of trifluralin; the solvent-only treatment is a control, so any change can be attributed to trifluralin rather than the solvent; 2 cut 4–5 mm of tip, warm dilute acid, rinse, stain (Toluidine blue or acetic orcein), squash, scan then count on high power; 3 $0.80 \times 98 = 78.4 \approx 78$ cells, because a fraction of a cell cannot be observed; 4 difference 4.01, mean 31.645, $4.01/31.645 \times 100 = 12.67\%$; 5 equal pieces (surface area would change pigment loss); rinse first (leakage, not cut damage); a named control with reason (e.g. temperature – permeability); 6 (a) bar chart, (b) line graph; 7 quantitative = objective measured value (DCPIP volume; absorbance); semi-quantitative = judgement against standards (Benedict's colour match); 8 reliability and an estimate of spread (mean, SD); a systematic error such as a zero offset; 9 same-condition roots, measurements across different roots, report mean with SD (or SEM/range/error bars); 10 the value is $\approx 12.6718\ \% \rightarrow 12.67\ \%$ at 4 s.f.; 12.70 % has 4 s.f. but is wrongly rounded – the final zero is not itself the error.

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4 · Energy, Environment, Microbiology and Immunity

Pearson Edexcel · International A-Level · Biology

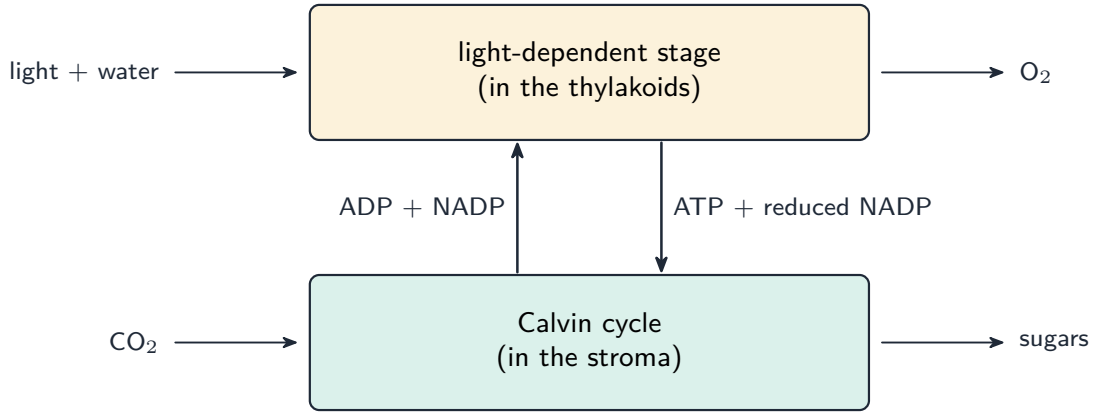
Energy in, energy through, energy lost

A wheat field intercepts sunlight, fixes carbon, feeds a food chain – and loses energy at every step. This unit follows the energy from photon to ecosystem, then turns to the smallest participants: the microbes that recycle, the pathogens that take, and the immune system that defends. WBI14 is also the most calculation-heavy paper after Unit 1: expect NPP, growth constants, diversity indices and time-of-death arithmetic.

WBI14 Energy, Environment, Microbiology and Immunity is the first IA2 unit: 1 hour 30 minutes, 90 marks, all compulsory. It assesses Topic 5 (Energy Flow, Ecosystems and the Environment) and Topic 6 (Microbiology, Immunity and Forensics).

Photosynthesis: two stages, two places

The overall reaction: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$, driven by light energy. In the **thylakoid** 类囊体 membranes, the **light-dependent reactions** 光反应 photolyse water (releasing O_2 and H^+), **photophosphorylate** 光合磷酸化 ADP and reduce NADP. In the **stroma** 基质, the **light-independent reactions** 暗反应 (Calvin cycle) fix carbon dioxide onto ribulose bisphosphate with rubisco, reduce the products using the ATP and reduced NADP from stage one, and make **GALP** – some to glucose, most to regenerate RuBP.

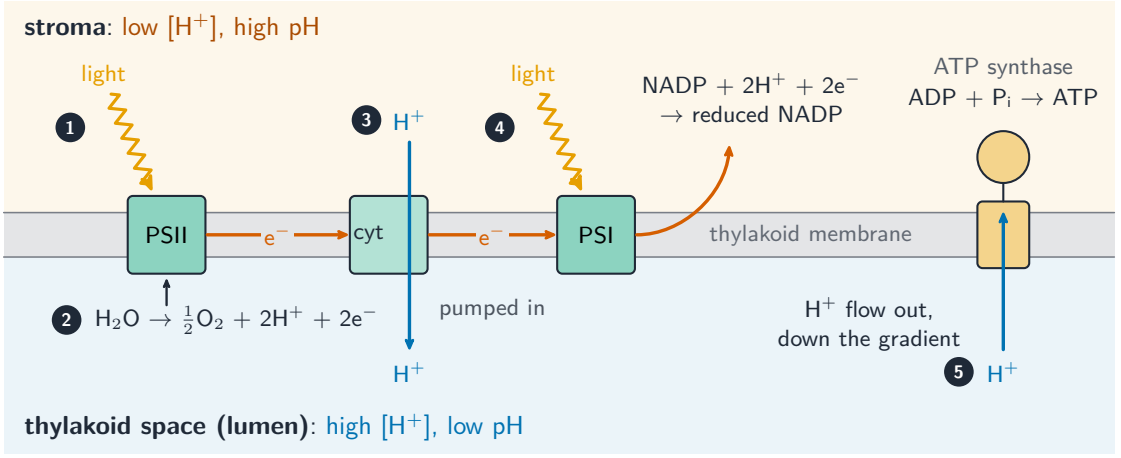


Thylakoids feed the stroma

Structure matches function: thylakoids stacked for absorbing surface; stroma packed with enzymes for the cycle.

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The light-dependent stage, step by step

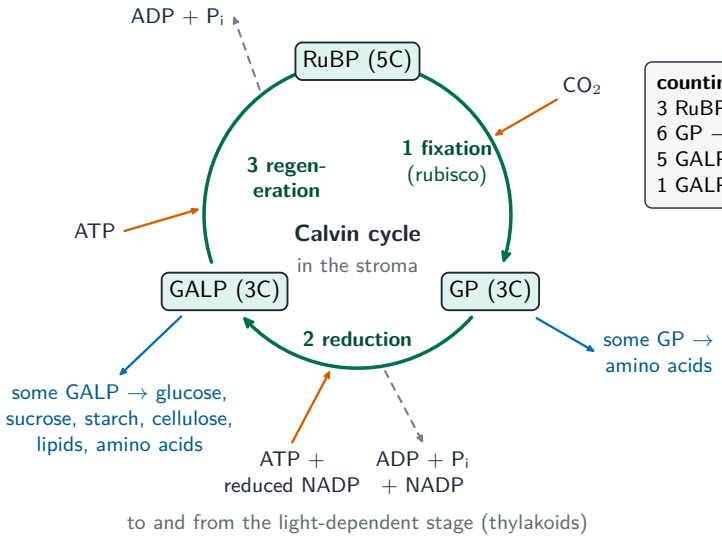


Light excites electrons; their energy pumps H^+ into the thylakoid space, and H^+ flowing back through ATP synthase makes ATP

1. Light excites electrons in the chlorophyll of **photosystem II** 光系统 II, and they leave it.
2. **Photolysis** 光解: water is split to replace those electrons, $H_2O \rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$. The oxygen is a waste product.
3. The electrons pass along **electron carriers** 电子载体. The energy they lose pumps H^+ into the thylakoid space.
4. Light excites the electrons again in **photosystem I** 光系统 I. They reduce NADP, together with H^+: NADP + $2H^+$ + $2e^-$ → reduced NADP.
5. H^+ diffuses back to the stroma through **ATP synthase** ATP 合酶 (**chemiosmosis** 化学渗透). The flow drives ADP + P_i → ATP.

In **cyclic photophosphorylation** 循环光合磷酸化, electrons from photosystem I go back to the carriers instead of to NADP. Only ATP is made: no reduced NADP and no oxygen.

The Calvin cycle, step by step



counting carbons over 3 turns
3 RuBP + 3 CO_2 → 6 GP (15C + 3C = 18C)
6 GP → 6 GALP
5 GALP → 3 RuBP (15C, back into the cycle)
1 GALP left over: the **gain** of the cycle

Three turns fix three CO_2: five of the six GALP rebuild RuBP, and one is the gain

1. **Carbon fixation** 碳固定: **rubisco** 核酮糖二磷酸羧化酶 joins CO_2 to **RuBP** (5C). The 6C product splits at once into two **GP** (3C).
2. **Reduction**: GP is reduced to **GALP** (3C), using ATP and reduced NADP from the light-dependent stage.
3. **Regeneration**: most GALP is used to make RuBP again, using more ATP.

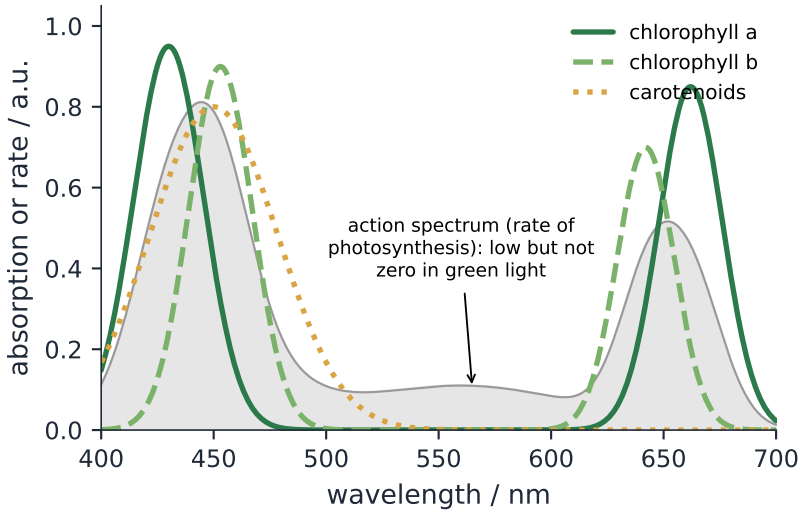
Count the carbons to see why. Six turns fix six CO_2 and give 12 GALP. Ten of them rebuild six RuBP ($10 \times 3 = 6 \times 5 = 30$ carbons), and the other two GALP make one glucose.

Common mistakes.

- Calling the Calvin cycle the "dark reaction" that happens at night. It needs ATP and reduced NADP from the light, so it stops soon after dark.
- Saying the oxygen comes from CO_2. It comes from the **photolysis of water**.
- Saying rubisco "makes glucose". It only fixes CO_2 onto RuBP.
- Saying light makes ATP directly. Light excites electrons; ATP is made by H^+ flowing through ATP synthase.

■ Pigments and spectra

Chlorophyll a and b absorb red and blue light; carotenoids widen the range and protect. The **absorption spectrum** 吸收光谱 shows what each pigment takes up; the **action spectrum** 作用光谱 shows what rate of photosynthesis each wavelength drives – their agreement is evidence that these pigments do the work. Chromatography separates pigments by solubility; Rf = distance moved by pigment/distance moved by solvent.



Absorption spectra of the chloroplast pigments, with the shaded action spectrum tracking their combined absorption.

Limiting factors 限制因素: light intensity, CO_2 concentration, temperature. A greenhouse raises the weakest of the three – and exam answers say which and why.

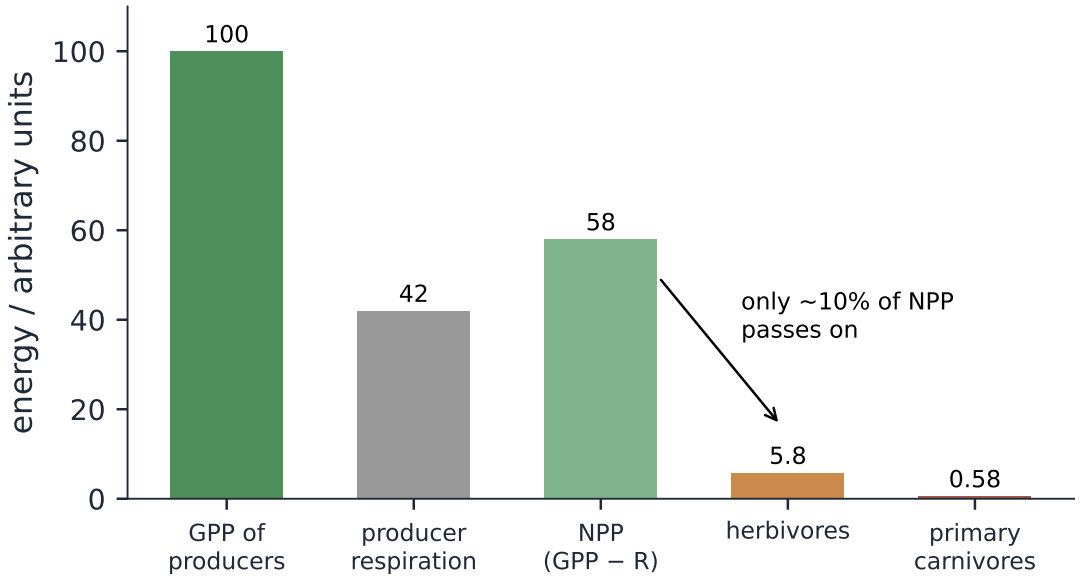
Productivity and the short food chain

Gross primary productivity 总初级生产力 (GPP) is the energy fixed by photosynthesis per area per time (kJ m^{-2} yr^{-1}). Plants spend much of it on their own respiration; what remains is **net primary productivity** 净初级生产力:

$$\text{NPP} = \text{GPP} - R$$

Only about 10 % of the energy at each trophic level passes upward – lost to respiration as heat, egestion, excretion and parts never eaten. That is why chains rarely exceed four or five levels and why top predators are rare.

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Energy leaving a food chain – GPP split by plant respiration, then roughly a tenth passing at each step upward.

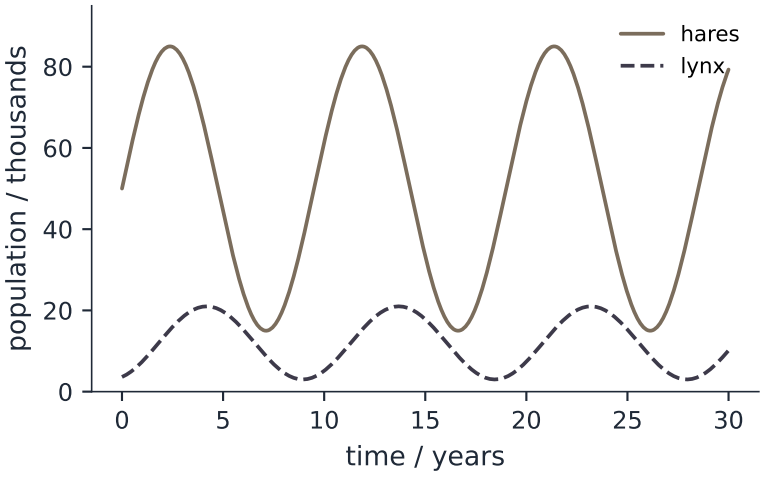
Worked check. A grassland fixes 45 000 kJ m^{-2} yr^{-1} and respirers 19 000. NPP = 26 000 kJ m^{-2} yr^{-1}. Cattle eating that grass keep about 10 %: 2 600 kJ m^{-2} yr^{-1}. Humans eating the cattle keep 260 – the energy arithmetic behind "eating lower on the chain feeds more people".

Ecosystems, populations and succession

Four definitions, precisely: **habitat** 栖息地 (where), **population** 种群 (one species' individuals), **community** 群落 (all populations), **ecosystem** 生态系统 (community + environment). Abiotic factors (light, water, temperature, pH) and biotic factors (competition, predation, disease) set who lives where and how abundantly – together, the **niche** 生态位.

Predator and prey cycle with a delay: hares rise, lynx follow, hares fall, lynx starve – a lag of about a quarter cycle.

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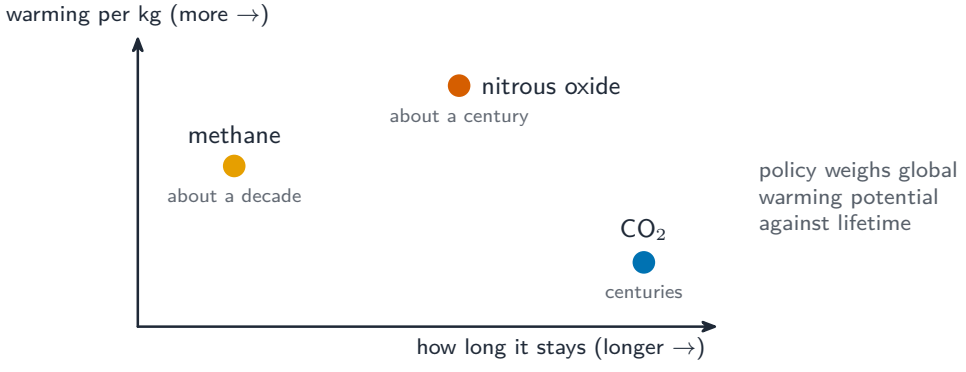


A classic predator-prey cycle – the lynx population tracks the hare population with a delay.

Succession 演替 begins when pioneer species colonise bare ground; each stage changes the soil and microclimate, enabling the next, until the **climax community** 顶极群落 stabilises. Measuring abundance uses quadrats and transects (random sampling for estimates, systematic along a gradient) and capture-mark-recapture for animals ($N \approx$ first catch $\times$ second catch/marked recaptures).

Climate change: evidence, causes, effects

Evidence comes from direct temperature records, ice cores (trapped air giving ancient CO_2), tree rings (**dendrochronology** 树轮年代学) and pollen layers in peat. The **enhanced greenhouse effect** 温室效应: outgoing long-wave radiation is absorbed by CO_2, methane and nitrous oxide and re-emitted downward. The gases differ – methane is potent but short-lived; CO_2 lasts centuries; nitrous oxide combines both – so policy weighs **global warming potential** 全球增温潜势 against lifetime.



Potency and lifetime differ between gases

Extrapolating a trend beyond its data is a judgement, not a fact: state the assumption (the trend continues) and its weakness. Effects already examined: shifting rainfall and species ranges, and – close to this course – temperature's effect on enzyme rates in cold-blooded organisms and whole ecosystems.

Worked check. Methane's global warming potential is about 28× CO_2's per kg averaged over 100 years, and over 80× over the first 20 years, because it lasts only ~12 years against CO_2's centuries. A one-tonne methane leak warms far more than a one-tonne CO_2 leak in the first decades, but fades while the CO_2 persists – the arithmetic of "warming potential vs cumulative load".

Evolution and speciation

Evolution is a change in **allele frequency** 等位基因频率. It needs variation (mutation, meiosis) and a filter: **directional selection** 定向选择 shifts the mean when the environment moves; **stabilising selection** 稳定选择 trims the extremes in a stable one. Drift changes frequencies by chance in small populations; gene flow (migration) mixes them back.

Speciation 物种形成 needs isolation: **allopatric** 异域的 (a physical barrier – allopatric = different homeland) or **sympatric** 同域的 (reproductive isolation in the same place – behavioural, temporal or genetic). Isolated populations diverge until they can no longer interbreed.

Culturing microorganisms

Aseptic technique protects you and the culture: flame the loop to red heat, flame bottle necks, lift lids briefly, secure plates and use approved teaching cultures under the school's incubation and disposal procedures. Lower incubation temperatures reduce some risks but do not guarantee that pathogens cannot multiply. Measure growth by direct cell count (haemocytometer), **turbidity** 浊度 in broth, or viable counts by **dilution plating** 稀释涂布 (colony count × dilution factor ÷ volume plated, giving colony-forming units per unit volume).

The growth curve: **lag** 延迟期 (enzymes synthesising), **log** 对数期 (exponential doubling), **stationary** 稳定期 (deaths = divisions), **death** 衰亡期. The exponential constant:

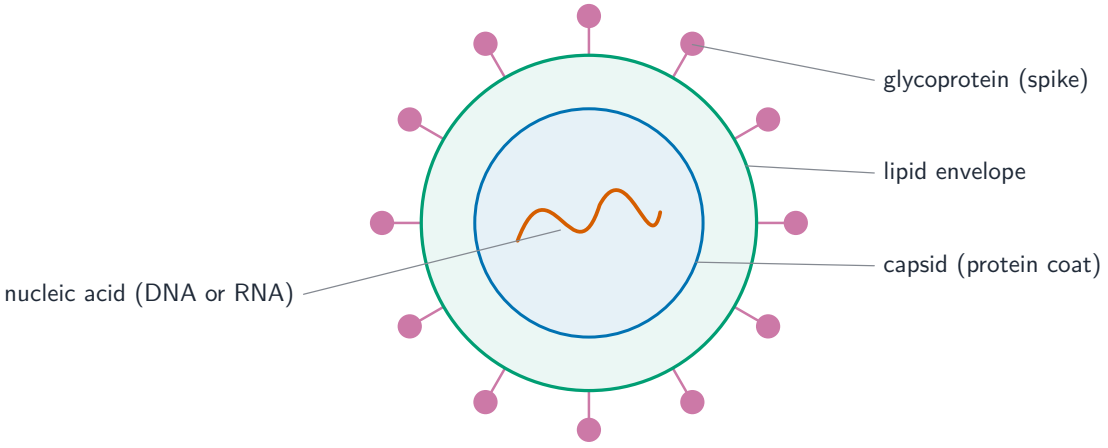
$$k = \frac{\log_{10} N_t - \log_{10} N_0}{0.301 \times t}$$

Worked check. From 2×10^4 to 1.6×10^7 cells in 5 hours: log difference = 2.903; $k = 2.903/(0.301 \times 5) = 1.93$ generations per hour – a doubling time of about 31 minutes.

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Pathogens and the body's barriers

Bacteria: cell wall, plasmids, ribosomes, circular DNA, some with capsule and flagellum. Viruses: nucleic acid (DNA or RNA) in a **capsid** 衣壳, some with an envelope – no organelles, no metabolism of their own; they hijack host cells. **Mycobacterium tuberculosis** 结核分枝杆菌 infects lungs, surviving inside macrophages; **HIV** 人类免疫缺陷病毒 infects T helper cells and can weaken immune defence. Untreated HIV increases the risk of active TB, including reactivation of an existing infection; reactivation is not inevitable.

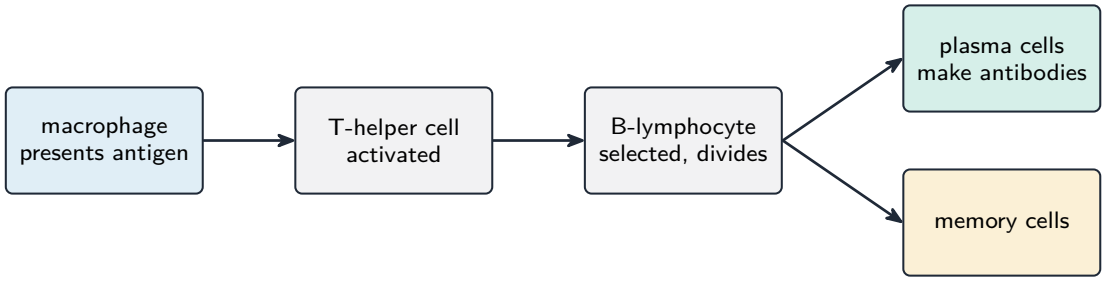


No organelles, no metabolism of its own

Barriers come first: skin, mucus and cilia, stomach acid, lysozyme in tears, and the clotting cascade sealing wounds.

The immune response

Non-specific: inflammation (vasodilation and fluid leak bringing phagocytes), phagocytosis, interferon. Specific – **antigens** 抗原 trigger it:



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

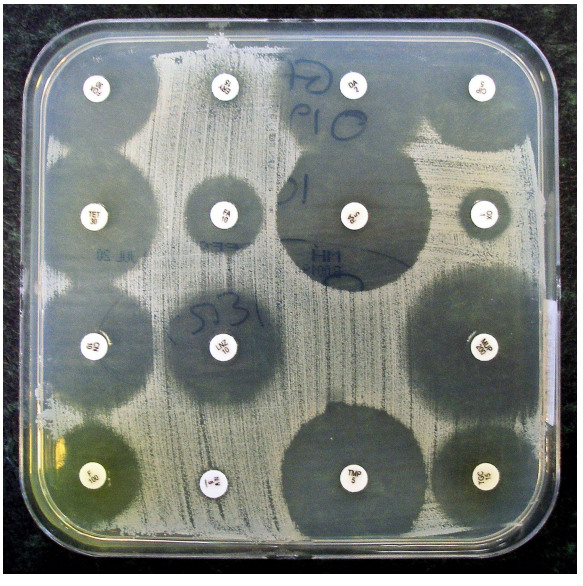
- **Humoral** 体液: B effector cells → plasma cells → **antibodies** 抗体; **B memory cells** B 记忆细胞 remain for the faster, stronger secondary response.
- **Cellular** 细胞: T helper cells coordinate, **T killer cells** T 杀伤细胞 destroy infected cells, T memory cells persist.

The standard Y-shaped antibody has four polypeptide chains (two heavy, two light) and two matching antigen-binding sites. Each site includes a **variable region** 可变区 whose shape helps determine antigen specificity. Immunity splits two ways: **active** 主动 (your own antibodies – natural infection or vaccination) vs **passive** 被动 (given antibodies – mother to baby, antiserum); natural vs artificial in each. Vaccination works at the scale of populations too (**herd immunity** 群体免疫) – but pathogens evolve back: the evolutionary race.

Worked check. A vaccine's second dose produces antibody levels ten times the first and within days rather than weeks: clonal selection finds the memory B cells, which divide rapidly into plasma cells – the secondary response the primary response built.

Antibiotics and hospital-acquired infections

Bacteriostatic 抑菌的 antibiotics stop bacterial growth; **bactericidal** 杀菌的 ones kill. Resistance arises by mutation and spreads by selection whenever exposure kills the susceptible and spares the resistant – unnecessary antibiotic exposure favours selection, so antibiotics should be used only when clinically indicated and as prescribed. Hospital-acquired infections thrive where vulnerable patients, invasive devices and resistant strains meet; hand hygiene, sterile procedure and isolating carriers break the chain.

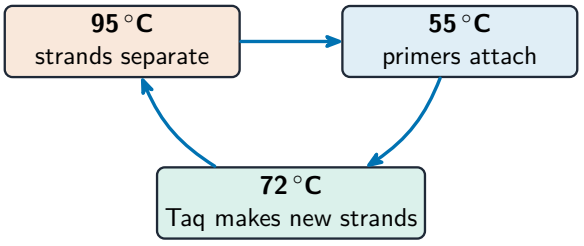


Antibiotic discs on a bacterial lawn: a clear zone shows the bacteria are sensitive to that antibiotic

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Decomposition, PCR, profiling and time of death

Decomposers recycle carbon and nitrogen – the ecosystem's waste system. The **polymerase chain reaction** 聚合酶链式反应 cycles denaturation (95 °C), primer annealing (50–60 °C) and extension (72 °C), ideally doubling the target DNA each cycle: in this simplified model, one starting copy gives 2^n copies after n cycles. Actual amplification efficiency can be lower. **Gel electrophoresis** 凝胶电泳 drags negatively charged DNA fragments through gel – short fragments run furthest. The **profile** 电泳图谱 of band positions supports comparisons between samples and investigation of family relationships.



Each cycle doubles the target DNA

Time of death narrows by four clocks: body temperature (falls ~1 °C per hour, modified by size, clothing, air), **rigor mortis** 尸僵 (sets then passes), decomposition degree, and insect succession on the body – each stage's arrivals time-stamp the interval.

Worked check. A body found at 22 °C core temperature in a 15 °C room: $(37 - 22)/(1\ ^\circ\text{C per hour}) \approx 15$ hours – but state the assumptions (still air, average build) before trusting it.

Check yourself

1. Name the products of the light-dependent reactions used by the Calvin cycle.
2. A crop fixes 60 000 kJ m^{-2} yr^{-1} and respirers 20 000. Calculate NPP and the energy reaching a third trophic level at 10 % transfer each step.
3. Explain why the action spectrum is evidence that chlorophyll carries out photosynthesis.
4. Distinguish directional and stabilising selection with one example of each.
5. Give two reasons a food chain rarely exceeds five trophic levels.
6. A culture grows from 5×10^3 to 4×10^6 in 6 hours. Calculate k and the doubling time.
7. Explain why a second vaccine dose raises antibody titre far faster than the first.
8. State the difference between bacteriostatic and bactericidal, and why the distinction matters for a patient with a weak immune system.

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9. Three PCR cycles from one double-stranded template: how many copies?
10. A body's core is 30 °C. Estimate the time since death under standard assumptions and name one factor that would extend the true interval.

Answers: 1 ATP and reduced NADP; 2 NPP = 40 000; third level = 400 (10 % per step of 4 000); 3 wavelengths chlorophyll absorbs best are the wavelengths that drive photosynthesis best; 4 directional – antibiotic resistance shifting the mean; stabilising – human birth weights; 5 energy lost at each step (respiration, heat, egestion) leaves too little to support another level; 6 $k = 2.903/(0.301 \times 6) = 1.61$ h^{-1}; doubling $\approx$ 37 min; 7 memory B cells persist and divide rapidly into plasma cells – the secondary response; 8 bacteriostatic stops growth (host immunity must clear it), bactericidal kills – weak immunity needs bactericidal; 9 $2^3 = 8$ copies; 10 $(37 - 30)/1 = 7$ hours; heavy clothing or a warm room slows cooling, so true time is longer.

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5 · Respiration, Internal Environment, Coordination and Gene Technology

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Inside the body: energy, balance and control

Sprint for a bus and your body performs a symphony: muscles burn glucose faster, the heart doubles its output, ventilation deepens, sweat starts, and the kidney re-tunes its water recovery – all controlled without a conscious thought. This unit follows that machinery: respiration at molecular scale, muscle and heart at tissue scale, nerves and hormones as the controllers, and gene technology as the modern window onto it.

WBI15 Respiration, Internal Environment, Coordination and Gene Technology is the second IA2 unit: 1 hour 45 minutes, 90 marks. It assesses Topic 7 (Respiration, Muscles and the Internal Environment) and Topic 8 (Coordination, Response and Gene Technology), and one 20-mark question is built on a **pre-released scientific article** – you will have studied it in advance.

Respiration: four stages, one purpose

Respiration releases energy in steps, each catalysed by a specific enzyme. Aerobic respiration's summary:

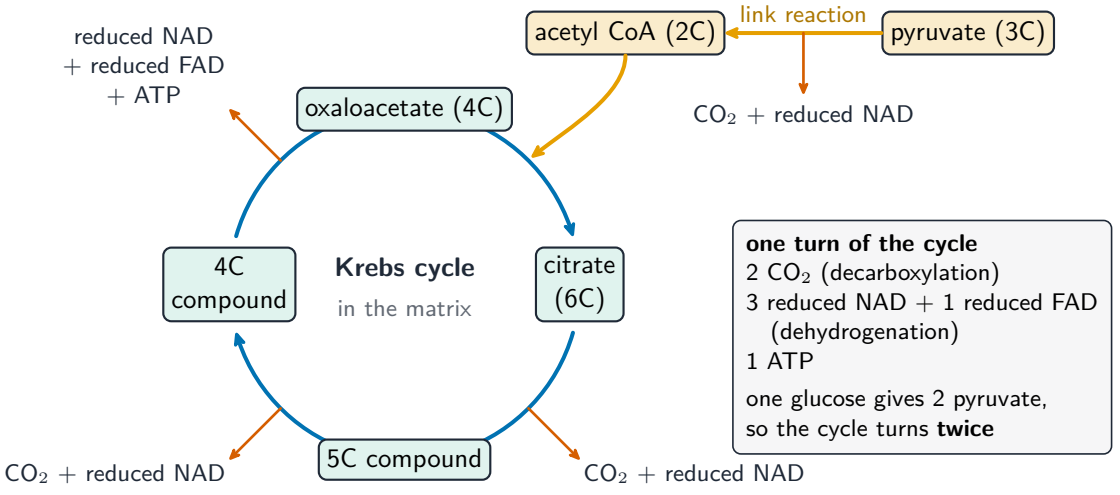


A sprint outruns the oxygen supply, so muscles add anaerobic respiration and build up lactate

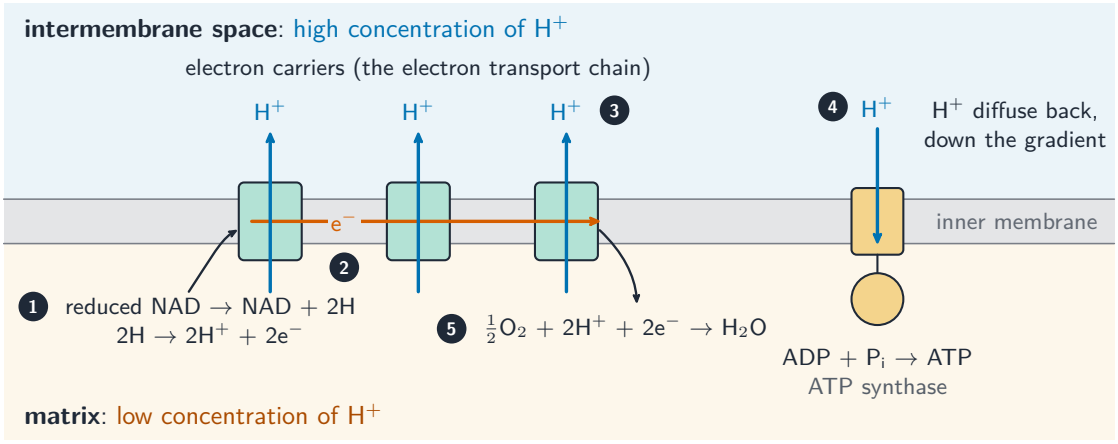
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \ (+ \text{ ATP})$$

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Stage	Where	What happens	Net yield
Glycolysis 糖酵解	cytoplasm	hexose phosphorylated then split; pyruvate formed	2 ATP, 2 reduced NAD
Link reaction 丙酮酸氧化脱羧	mitochondrial matrix	pyruvate oxidised and decarboxylated to acetyl	1 CO_2, 1 reduced NAD per pyruvate
Krebs cycle 三羧酸循环	matrix	acetyl fully oxidised; substrates regenerate	CO_2, ATP, reduced NAD, reduced FAD
Oxidative phosphorylation 氧化磷酸化	cristae	electron transport chain pumps H^+; chemiosmosis through ATP synthase; O_2 the final acceptor	most ATP



Each turn removes two carbons as CO_2 and loads the coenzymes with hydrogen; oxaloacetate is rebuilt to start the next turn



Electrons flow along the carriers and pump H^+ out; H^+ flowing back through ATP synthase makes ATP; oxygen accepts the electrons at the end

The same machine as in the chloroplast. In both organelles an electron transport chain pumps H^+ across a membrane, and H^+ flows back through ATP synthase (chemiosmosis). The differences: in the mitochondrion the electrons come from reduced NAD and FAD, and **oxygen** is the final electron acceptor; in the chloroplast they come from water, and NADP is the final acceptor.

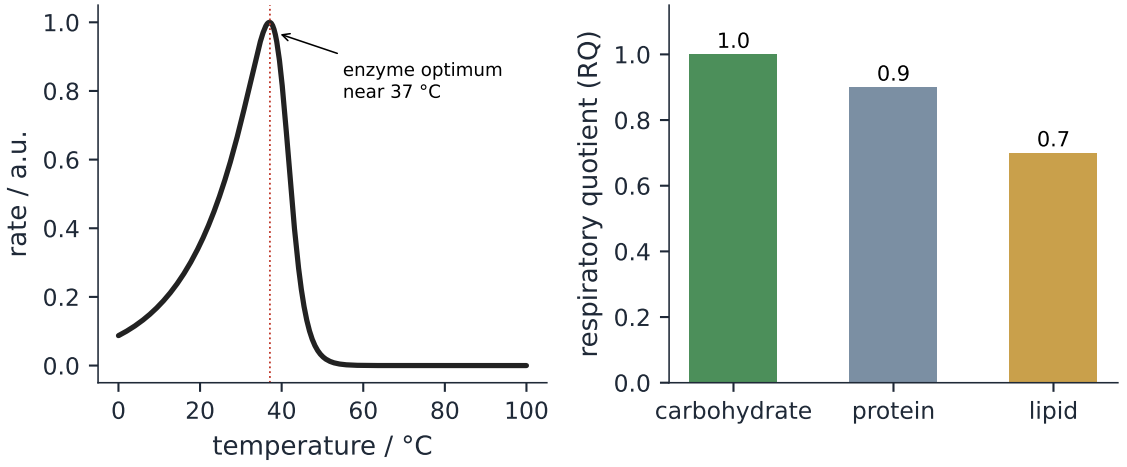
Common mistakes.

- Saying the Krebs cycle makes most of the ATP. It makes only 2 per glucose directly; its job is to load NAD and FAD, which feed the chain.
- Saying oxygen is needed "to make CO_2". The CO_2 comes from decarboxylation in the link reaction and Krebs cycle. Oxygen accepts electrons at the end of the chain.
- Saying glycolysis happens in the mitochondrion. It happens in the cytoplasm.
- Forgetting that the cycle turns **twice** per glucose, so every figure for one turn doubles.

Worked check. The books per glucose: glycolysis nets 2 ATP (4 made, 2 spent) and 2 reduced NAD; the link reaction runs TWICE (one per pyruvate), adding 2 reduced NAD; Krebs turns twice, adding 2 ATP, 6 reduced NAD and 2 reduced FAD. Totals: 4 ATP made directly, 10 reduced NAD and 2 reduced FAD feeding the cristae – roughly 30 ATP per glucose all told. The exam wants the bookkeeping (which stage sent each coenzyme) more than the final number; anaerobic collapses the account to glycolysis's net 2, because the stalled chain stops recycling the NAD.

Anaerobic conditions stop the chain – reduced NAD cannot be recycled – so pyruvate accepts its hydrogen and becomes **lactate** 乳酸 in muscle. After exercise, lactate is carried to the liver and rebuilt into glucose (needing oxygen: the **oxygen debt** 氧债).

Respiratory quotient 呼吸商: RQ = CO_2 produced/O_2 consumed. Carbohydrate 1.0, protein 0.9, lipid ≈ 0.7 – an organism's RQ reveals what it is burning.

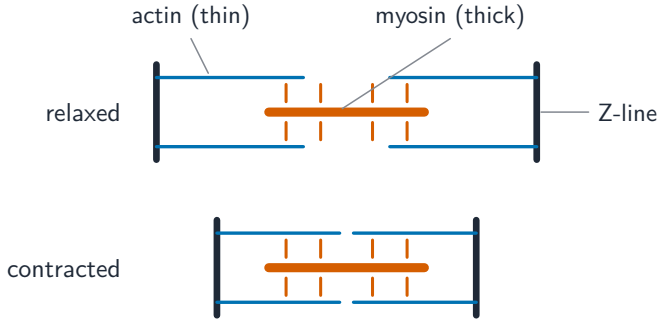


Left, respiration rate peaks at the enzyme optimum near body temperature and collapses as proteins denature. Right, respiratory quotient by substrate.

Worked check. A respirometer shows 60 cm^3 CO_2 produced and 60 cm^3 O_2 consumed in the same interval: RQ = 1.0 – carbohydrate. A germinating seed with RQ 0.7 is burning lipid reserves.

Muscles: the sliding filament

A **tendon** 肌腱 joins muscle to bone; a **ligament** 韧带 joins bone to bone across a joint; muscles work in antagonistic pairs. A skeletal muscle fibre is a fused, multinucleate cell packed with **myofibrils** 肌原纤维 of **actin** 肌动蛋白 and **myosin** 肌球蛋白.



the filaments slide over each other, so the sarcomere shortens

The filaments slide; they do not shorten

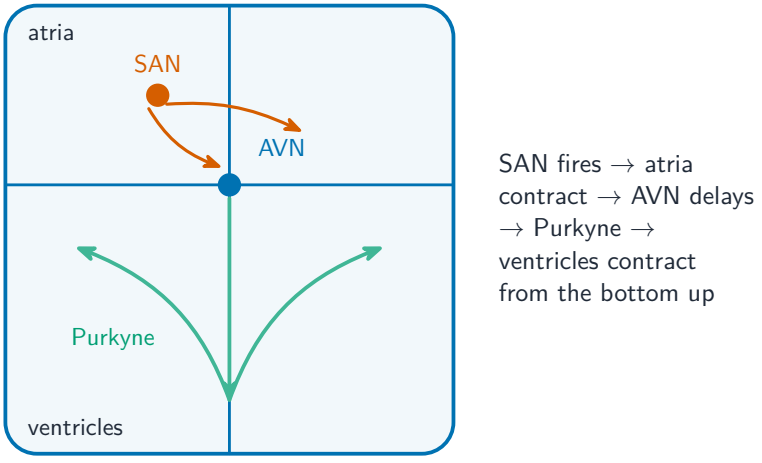
Contraction is the sliding filament cycle: an action potential releases Ca^{2+}; calcium exposes actin's binding sites; the energised myosin head (its ATP split) attaches, pulls

the actin, then detaches when new ATP binds – thousands of heads per second, each stroke a few nanometres.

Fast-twitch fibres: thick, few mitochondria, quick and powerful, fatigue fast (sprinting). Slow-twitch: many mitochondria, rich blood supply, myoglobin – endurance.

The heart's own clock and the medulla's override

Cardiac muscle is **myogenic** 自主性的: it beats without nerve input. The **sino-atrial node** 窦房结 sets the pace; the wave spreads over the atria to the **atrio-ventricular node**, then along Purkyne fibres to the ventricles – atria contract first, ventricles a fraction later.



SAN, AVN, then Purkyne fibres

The cardiovascular control centre and the ventilation centre in the **medulla oblongata** 延髓 adjust both systems to demand: chemical receptors sense CO_2 and pH, baroreceptors pressure.

$$\text{cardiac output} = \text{stroke volume} \times \text{heart rate}$$

Worked check. At rest: $70\ \text{cm}^3 \times 72\ \text{min}^{-1} \approx 5.0\ \text{dm}^3\ \text{min}^{-1}$. During exercise: $120\ \text{cm}^3 \times 150\ \text{min}^{-1} = 18\ \text{dm}^3\ \text{min}^{-1}$ – the table the exam loves. Ventilation rises in step, read from spirometer traces (tidal volume × breathing rate = **minute ventilation** 每分钟通气量).

Homeostasis and feedback

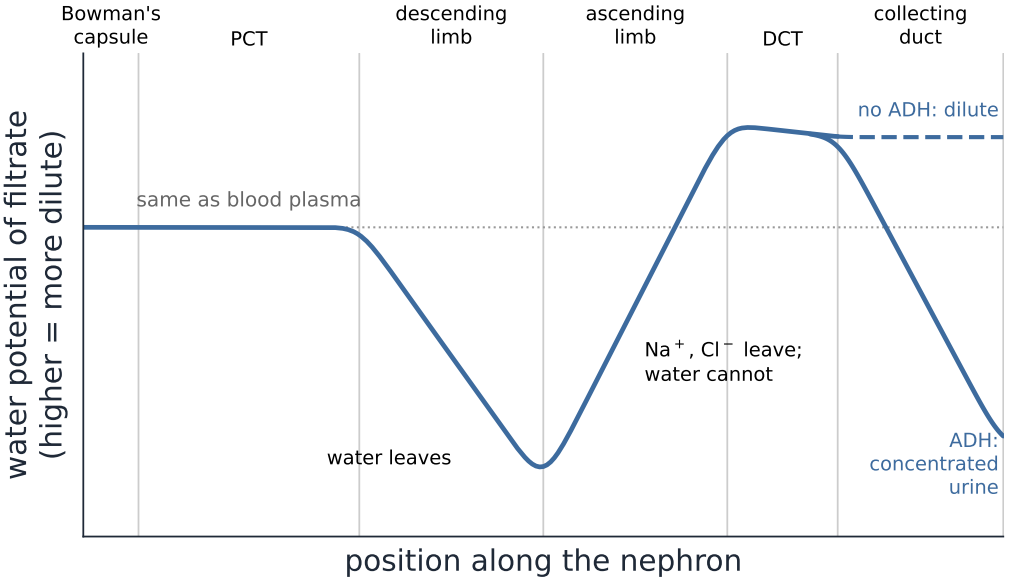
Homeostasis 稳态 holds the internal environment in dynamic equilibrium – not stillness, but variables oscillating inside narrow limits. **Negative feedback** 负反馈 corrects deviations in either direction (the thermostat pattern); **positive feedback**

正反馈 amplifies them (a self-reinforcing loop, as voltage-gated sodium channels open during an action potential).

Thermoregulation runs through the **hypothalamus** 下丘脑: heat loss by vasodilation and sweating; heat conservation by vasoconstriction, shivering and hair erection. **Adrenaline** 肾上腺素 prepares the fight-or-flight response – heart rate, blood glucose and airways all respond together.

The kidney: filter, reabsorb, fine-tune

Blood enters the **nephron** 肾单位's glomerulus at high pressure – the afferent arteriole is wider than the efferent – and small molecules are forced through podocytes and the basement membrane into **Bowman's capsule** 肾小囊 (ultrafiltration: everything except cells and large proteins). The **proximal convoluted tubule** 近曲小管 reabsorbs all glucose and amino acids plus most salts and water (active transport then osmosis). The **loop of Henle** 亨勒环 builds a water-potential gradient down the medulla by countercurrent multiplication. The **collecting duct** 集合管 makes the final decision: **ADH** 抗利尿激素 is made in the hypothalamus and released by the posterior pituitary; it promotes aquaporin insertion so more water is reabsorbed – concentrated urine when dehydrated, dilute when not.



The filtrate is concentrated down the descending limb and diluted up the ascending limb; only in the collecting duct, and only with ADH, does it lose water to give concentrated urine

Read the graph in order. In the PCT the filtrate's water potential does not change, because water follows the reabsorbed solutes by osmosis. The descending limb is permeable to water, so water leaves into the salty medulla. The ascending limb pumps out Na^+ and Cl^- but is impermeable to water, so by the DCT the filtrate is **more**

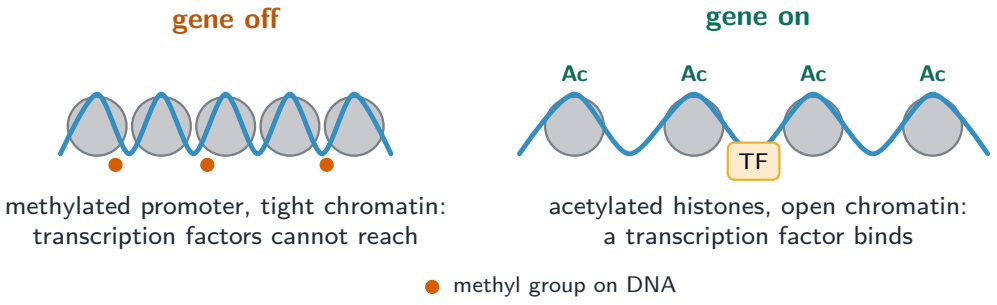
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dilute than plasma. Whether it stays dilute depends on ADH in the collecting duct. Excess amino acids are **deaminated** 脱氨 in the liver; the toxic ammonia becomes **urea** 尿素 for excretion.

Worked check. ADH present → collecting duct walls permeable → water leaves down the gradient into the medullary blood → small volume, concentrated urine. Alcohol suppresses ADH – large volume, dilute.

Switching genes: transcription factors and epigenetics

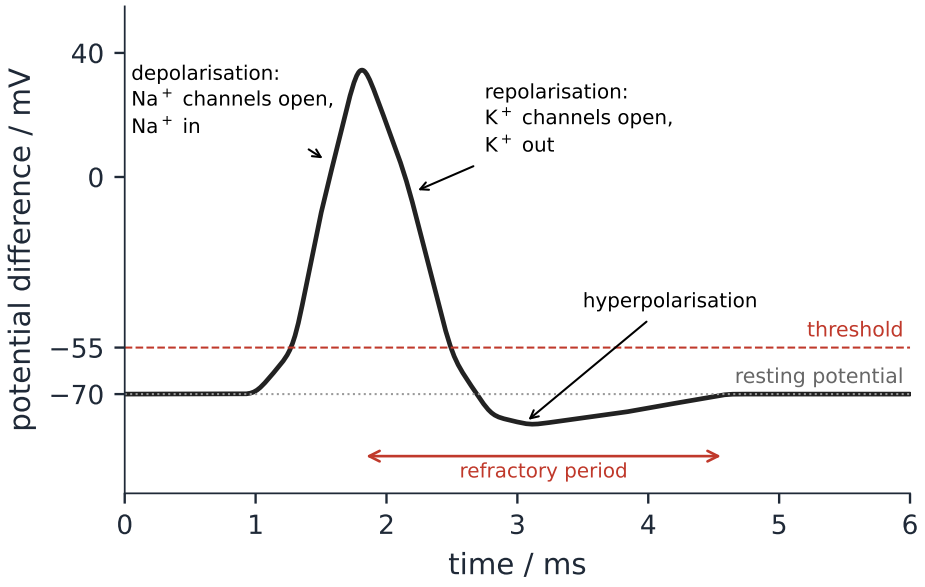
A **transcription factor** 转录因子 binds a gene's promoter and switches transcription on or off. Steroid hormones enter target cells and bind intracellular receptor proteins. The activated receptors can act as transcription factors; the hormone molecule itself does not bind DNA as a transcription factor. **Epigenetics** 表观遗传学 concerns changes in gene activity without changing the DNA base sequence. Promoter DNA **methylation** 甲基化 can reduce transcription. Histone acetylation usually makes chromatin more accessible, whereas deacetylation can make it less accessible. Methylation at a tumour-suppressor promoter can reduce protective gene expression. Imprinting errors can disrupt development, including some cases of Prader–Willi syndrome.



Methylation closes a gene; acetylation opens it

Nerve impulses and synapses

The resting neurone pumps Na^+ out and K^+ in (the **sodium-potassium pump** 钠钾泵), holding an interior at about −70 mV. A stimulus past **threshold** 阈值 (about −55 mV) opens sodium channels: an **all-or-nothing** 全或无 action potential spikes to +30 mV, then potassium channels repolarise; the **refractory period** 不应期 prevents backward travel and sets a maximum frequency.



The action potential – depolarisation as sodium enters, repolarisation as potassium leaves, then the refractory period.

In **myelinated** 有髓 neurones the impulse jumps node to node (**saltatory conduction** 跳跃传导) – far faster. At the **synapse** 突触, calcium entry triggers vesicles of neurotransmitter to fuse with the presynaptic membrane; the transmitter diffuses and binds postsynaptic receptors; enzymes then clear the gap. Drugs act here: SSRIs block serotonin re-uptake, so the signal persists; lidocaine blocks sodium channels; ecstasy (MDMA) floods the cleft with serotonin then depletes it.

The nervous system divides: CNS (brain, spinal cord) and PNS – **somatic** (voluntary) and **autonomic** (involuntary; sympathetic accelerates, parasympathetic calms). Receptors are transducers: rods (dim light, many per bipolar cell – sensitivity), cones (colour, one-to-one – acuity), plus thermoreceptors, chemoreceptors, baroreceptors, **nociceptors** 伤害感受器 (pain). The spinal **reflex arc** 反射弧 passes sensory → relay → motor neurone in the cord's grey matter – fast, involuntary, protective. **Habituation** 习惯化 is a decreasing response to a repeated harmless stimulus.

Plants: light and growth switches

Phytochrome 光敏色素 flips between Pr (absorbs red) and Pfr (absorbs far-red); sunlight's red bias leaves Pfr dominant, controlling germination and flowering by day length. **Auxin** 生长素 elongates cells by acidifying walls; **gibberellins** 赤霉素 induce enzymes (amylase in the aleurone layer) that mobilise starch in germination.

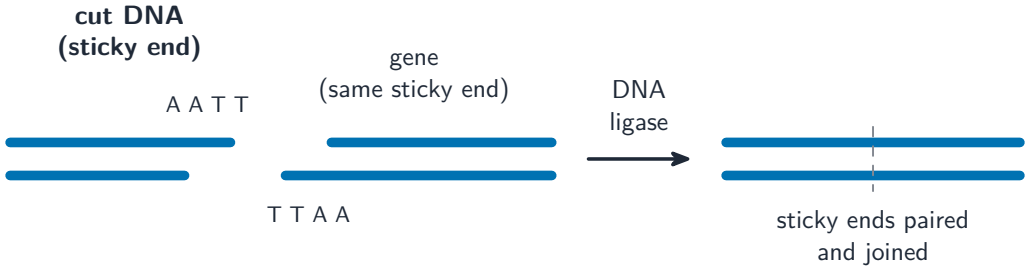
The brain and its chemistry

Landmarks and jobs: **cerebral hemispheres** 大脑半球 (voluntary, thought), **cerebellum** 小脑 (coordination, balance), **hypothalamus** and **pituitary** 垂体 below them (homeostasis, hormones), **medulla oblongata** (heart, breathing). **MRI** shows structure; **fMRI** shows activity via oxygenated-blood flow; **CT** fast structural scans; **PET** metabolism with radioactive tracers.

Chemistry first: Parkinson's is a **dopamine** 多巴胺 deficit – treated with **L-Dopa**, which crosses the blood-brain barrier and is converted to dopamine in the brain. Low serotonin links to depression – the target of SSRIs.

Gene technology

Recombinant DNA 重组 DNA: a **restriction enzyme** 限制性内切酶 cuts DNA at its recognition sequence, leaving **sticky ends** 黏性末端; the human gene (made without introns from mRNA) is spliced into a **plasmid** 质粒 with DNA **ligase** 连接酶; the plasmid transforms host bacteria; **marker genes** (antibiotic resistance or fluorescence) select the cells that took it up. Scale up in a fermenter and the bacteria secrete human **insulin** 胰岛素 – cleaner and safer than extracting from pigs. GM animals make human proteins in milk; risks and benefits of GM crops (resistance, yields versus gene flow to wild relatives) are the standard evaluation.



Matching sticky ends, sealed by ligase

Microarrays 微阵列 identify active genes: sample mRNA hybridises to complementary probes on the chip; spots that fluoresce mark genes being transcribed. **Bioinformatics** 生物信息学 compares sequences across species and individuals – how relatedness is now measured.

Check yourself

1. Name the stage of respiration occurring in the mitochondrial matrix and one of its inputs.
2. A runner's muscles produce lactate. Explain why, and what happens to the lactate afterwards.

3. Myosin heads cannot detach without ATP. Explain what this means for muscles after death.
4. Calculate cardiac output for stroke volume 85 cm^3 and heart rate 140 min^{-1}.
5. Explain why the afferent arteriole is wider than the efferent arteriole.
6. State two differences between negative and positive feedback, with one example of each.
7. Why does myelination increase conduction speed?
8. An axon's threshold is −55 mV. A stimulus moves it to −60 mV. What happens, and why?
9. Red light converts phytochrome to which form?
10. Explain why L-Dopa is given instead of dopamine itself.
11. A microarray spot fluoresces strongly. What does that show?
12. Why must the human insulin gene be made from mRNA rather than from genomic DNA when inserting into bacteria?

Answers: 1 the link reaction (or Krebs cycle) – input pyruvate (or acetyl); 2 oxygen is short so reduced NAD is recycled by reducing pyruvate to lactate; afterwards lactate goes to the liver and is converted back to glucose, using oxygen; 3 without ATP the myosin stays bound to actin – rigor mortis; 4 $85 \times 140 = 11\,900\ cm^3\,min^{-1} = 11.9\ dm^3\,min^{-1}$; 5 the pressure difference drives ultrafiltration of plasma into Bowman's capsule; 6 negative returns a variable toward its set point (thermoregulation); positive pushes it further away (sodium channels opening during an action potential); 7 the impulse jumps between nodes of Ranvier instead of depolarising the whole membrane – fewer, bigger steps; 8 nothing – threshold is not reached, so no action potential (all-or-nothing); 9 Pfr; 10 dopamine cannot cross the blood-brain barrier but L-Dopa can, and is converted to dopamine inside the brain; 11 that gene was being actively transcribed – its mRNA was present and hybridised; 12 bacteria cannot splice introns, so the gene must come from mature mRNA that already lacks them.

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6 · Practical Skills in Biology II

Pearson Edexcel · International A-Level · Biology

Planning like a scientist, writing like an examiner

WBI16 is the last Biology paper you will sit, and it looks like no other: one question may hand you a half-complete statistics table, another asks you to design a whole **investigation** 探究 from a **hypothesis** 假设 you did not choose. Everything comes from the practical work of Units 4 and 5 – **respirometers** 呼吸计, **spirometers** 肺活量计, **quadrats** 样方, dilution plates – but now you must plan, measure, present, test and conclude at IA2 depth.

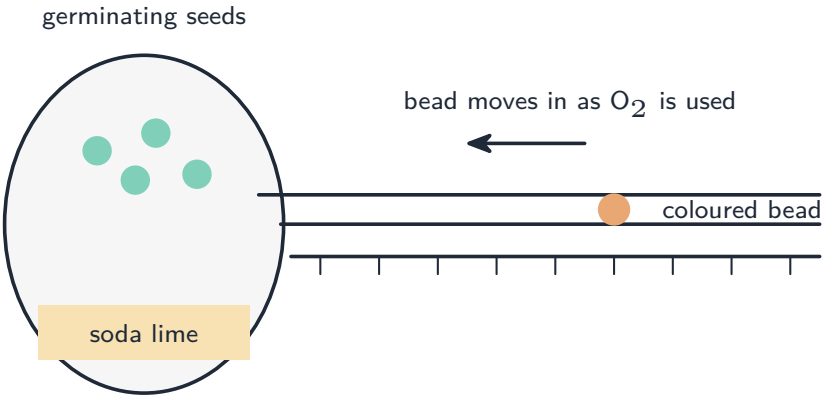
WBI16/01 Practical Skills in Biology II is 1 hour 20 minutes, 50 marks, all compulsory. The specification's assessed list matches Unit 3's, with one difference in emphasis: *plan whole investigations, analyse data and evaluate results and methodology* – a 16-mark plan question closes the paper, and statistics enter: standard deviations, null hypotheses and a correlation coefficient with critical values.

The IA2 core practicals (Topics 5–8)

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Core practical	Method core	What is measured
10 Photosynthesis rate	Aquatic plant under light of varied intensity/wavelength, temperature, CO_2 supply; gas collected over time	Gas volume per time; rate and limiting-factor plateaus
11 Ecology of a habitat	Quadrats and **transects** 样带; **abiotic** 非生物 factors measured at each site	Distribution and **abundance** 丰度; means with spread
12 Development rate	Seedling growth or brine-shrimp hatching at different temperatures, ethical use of organisms	Growth/hatch rate per temperature
13 Liquid-culture growth	Microorganism grown in broth; samples over time, safe and ethical use	Growth curve by cell count, mass or **turbidity** 浊度
14 Antibiotics on bacteria	**Aseptic** 无菌 plating; antibiotic discs or plant extracts on a seeded lawn; incubate inverted below 30 °C	**Zones of inhibition** 抑菌圈
15 Respiration in yeast	Artificial hydrogen carrier – **redox indicator** 氧化还原指示剂 (TTC, methylene blue, DCPIP) – changes colour as yeast respires; the direction depends on the indicator	Time to colour change at each condition
16 Respirometer and RQ	Organism in a sealed chamber; CO_2 absorbent (soda lime) draws the fluid marker as O_2 is used; with and without the absorber gives RQ	O_2 uptake per time; RQ = CO_2 produced ÷ O_2 used
17 Exercise and ventilation	Spirometer trace: **tidal volume** 潮气量, breathing rate, **minute ventilation** 每分钟通气量, O_2 uptake before and after exercise	Recovery time to resting values
18 Amylase in germinating grain	Extracts from grains at different germination times tested on starch	Appearance/effect of amylase with germination

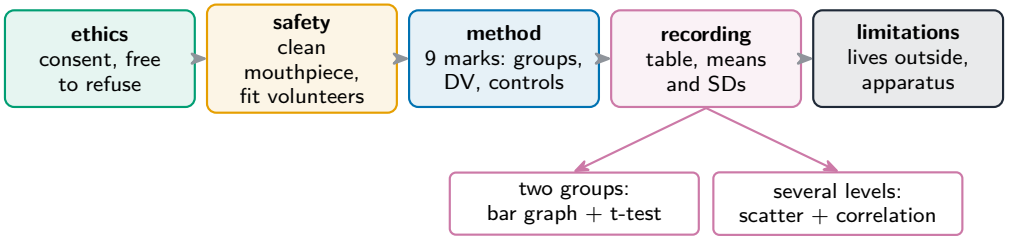
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CP16: soda lime takes up carbon dioxide, so the bead tracks oxygen use.

The 16-mark plan, taken apart

The closing question (2025: fitness programmes and recovery time) pays out in named blocks – answer in the same order. **Ethics** 伦理: **informed consent** 知情同意 of volunteers; no one is forced to participate. **Safety**: sterilise or replace the mouthpiece between students (infection); check volunteers are healthy enough for the exercise. **Method, nine marks**: two groups (with and without the fitness programme); the **dependent variable** 因变量 stated as *the time for the breathing rate and tidal volume to return to resting values*; apparatus used in detail – soda lime in the canister, nose clip, practise breaths first; find the resting values first; the same standardised exercise for everyone; two **control variables** 控制变量 **and** the method of control for one; repeats giving means **and standard deviations** 标准差. **Recording and analysis**: a table of raw times with headings and units from which means are calculated; a bar graph of mean recovery time per group (two groups) tested with a **t-test** t 检验, or a line/scatter graph (several fitness levels) tested with a **correlation** 相关 test. **Limitations** 局限性: volunteers' lives outside the experiment cannot be fully controlled; apparatus difficulties (leaks, soda lime exhausted, abnormal breathing through a mouthpiece).



Answer in the blocks the marks are paid in.

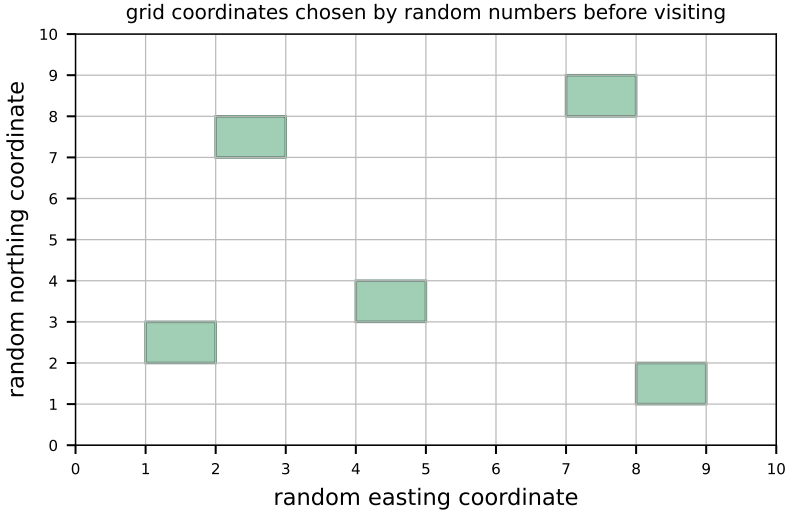
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Sampling a habitat fairly

Random sampling 随机取样 has a method: lay a grid over the area, generate random **coordinate** 坐标 pairs (random numbers, or numbers drawn from a bag), and only then visit those points with the quadrat. Saying "sample at random" earns nothing. Record the abiotic variables that matter – soil pH, moisture, minerals, light intensity, season – and control what you can by choosing matched sites. A photograph's **magnification** 放大倍数 is image ÷ actual: an earthworm 5.0 cm in a photograph and 13.5 cm real gives ×0.37 – photographs can be smaller than life.



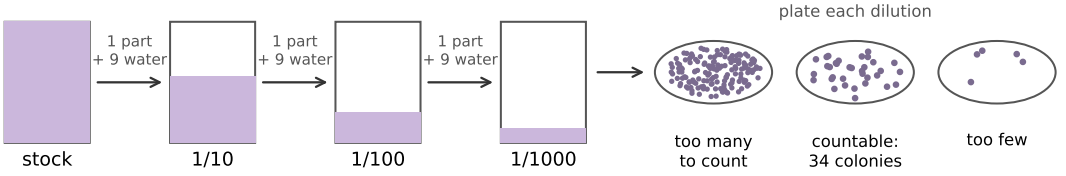
A quadrat with a ruler for scale: random coordinates decide where each one goes



A sampling grid with coordinates chosen by random numbers before visiting, five quadrat squares marked.

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Counting the uncountable



spread a known volume of each dilution on agar, incubate at a fixed temperature for a fixed time, count the plate with 30–300 separate colonies, then multiply back by the dilution factor

Serial dilution from stock to 1/1000: too many to count, a countable 34-colony plate, too few.

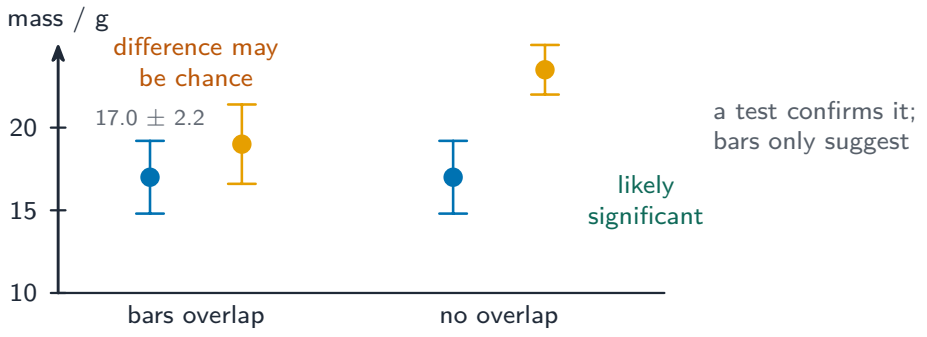
A drop of soil suspension holds too many bacteria to count, so **dilution plating** 稀释涂布 justifies each step: **serially dilute** 连续稀释 the culture (1 part + 9 parts water, repeated) *because* raw samples are too numerous to count; plate a known volume of a suitable dilution *so that* separate **colonies** 菌落 can be counted; incubate for a fixed time and temperature *so that* colonies become visible; work aseptically *to avoid* **contamination** 污染 and counting errors. Use a countable plate and the method's accepted count range. Colony count × **dilution factor** 稀释倍数 ÷ plated volume estimates colony-forming units per unit volume; one colony can come from one cell or a clump. Use approved teaching cultures and supervised school procedures.

Statistics I: standard deviation

The formula is supplied; the skill is completing the table. For five sites with masses 18.1, 19.7, 16.2, 13.8, 17.1 g (mean 16.98 ≈ 17.0): each deviation $(X - \bar{X})$ is squared – 1.21, 7.29, 0.64, 10.24, 0.01 – summed $\sum(X - \bar{X})^2 = 19.39$, divided by $n - 1 = 4$:

$$s = \sqrt{\frac{\sum(X - \bar{X})^2}{n - 1}} = \sqrt{\frac{19.39}{4}} = \sqrt{4.8475} = 2.2 \text{ g}$$

To compare two groups, plot **mean ± SD** (**error bars** 误差线): if the bars do not overlap, the difference is likely **significant** 显著的 – properly, a t-test decides.



Overlapping bars warn; a test decides

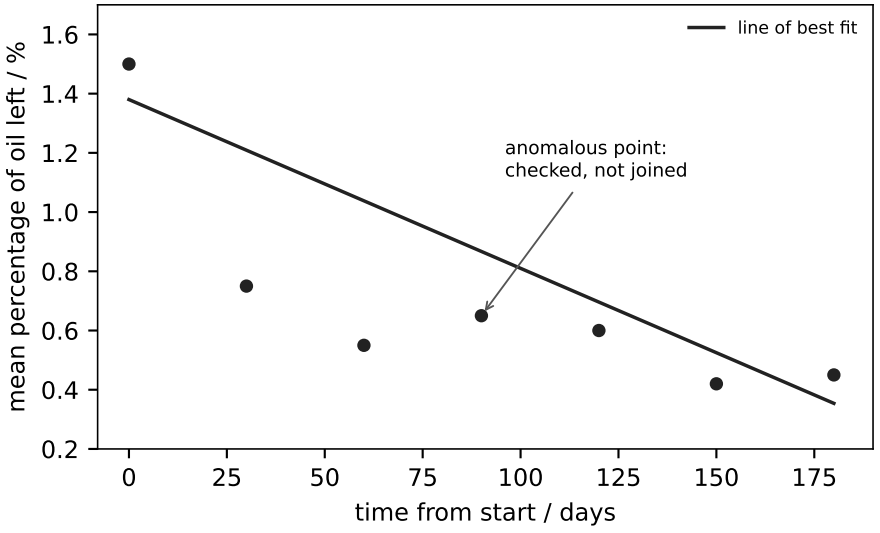
Worked example (original). Recovery times after standard exercise: trained group mean 94 s ($s = 11$, $n = 8$), untrained 126 s ($s = 14$, $n = 8$). The t-test gives $t = 32 \div \sqrt{11^2/8 + 14^2/8} = 5.08$ at $n_1 + n_2 - 2 = 14$ **degrees of freedom** 自由度; the **critical value** 临界值 at $p = 0.05$ is 2.145. Calculated exceeds critical, so reject the **null hypothesis** 零假设: the programme significantly shortens recovery. Write the same three sentences as for Spearman below – compare, reject, conclude – and quote the degrees of freedom, which examiners check.

Statistics II: Spearman's rank and the null hypothesis

Null hypothesis: "there is no correlation between the percentage of oil remaining and the time stored." Rank both variables (largest = 1), find each difference d and square it, then:

$$r_s = 1 - \frac{6\sum d^2}{n(n^2-1)} = 1 - \frac{6 \times 104}{7 \times 48} = 1 - 1.857 = -0.857$$

Compare the magnitude (0.857, ignore the sign for the comparison) with the critical value at $p = 0.05$ for $n = 7$ (0.786). Calculated exceeds critical, so **reject the null hypothesis**: there is a significant **negative correlation** 负相关 between oil remaining and time. Write all three sentences – comparison, reject, conclusion.



A negative-correlation scatter with a line of best fit that ignores one anomalous point.

Choosing the test: difference between two group means → **t-test** (bar chart); association between two measured variables → **correlation** (scatter or line graph). Never a t-test on a correlation question.

Graphs that decide marks

The oil-decay graph is a **line graph** 折线图 – time is **continuous** 连续的 – with labelled **axes** 坐标轴 and units (days; mean % oil left), linear **scales** 刻度, points plotted exactly, and a single best-fit line. The 90-day reading (0.65 %) sits above every neighbour: it is **anomalous** 异常的. The best fit ignores it; you check it by repeating that sampling, never delete it silently.

What written practice cannot do

As with Unit 3: a perfect written plan does not demonstrate that you performed aseptic technique, read a spirometer trace live, or handled organisms ethically in the room. Those competences are built in class while studying Units 4 and 5; this paper examines the thinking around them.

Check yourself

1. Name two artificial hydrogen carriers usable in CP15, and state what happens to their colour as yeast respires.
2. Write a null hypothesis for: "the number of bacteria in soil increases as crude oil is broken down."
3. Masses 21.4, 19.8, 18.6, 22.1, 20.6 g. Compute the sum of squared deviations and the standard deviation.

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4. Ranks give $\sum d^2 = 104$ with $n = 7$. Calculate r_s and state the conclusion against the 0.05 critical value 0.786.
5. In the oil-decay table, which reading is anomalous, and what two things do you do about it?
6. State two abiotic variables (not temperature) affecting an earthworm study and one method of control.
7. A plan compares two groups' recovery times. Which graph and which test? And with five fitness levels?
8. Give the two ethical/safety points the spirometer plan must include before any practical work.
9. Justify "serially dilute the culture" and "spread on agar to make a lawn" in dilution plating.
10. An earthworm is 13.5 cm long and appears 5.4 cm in a photograph. Calculate the magnification.

Answers: 1 any two of TTC, methylene blue or DCPIP; as they accept hydrogen from respiration, methylene blue and DCPIP lose their blue colour, while TTC turns from colourless to red; 2 no correlation between bacterial number and oil broken down (correlation coefficient zero); 3 mean 20.5; squared deviations total 7.48; $s = \sqrt{7.48/4} = 1.4$ g; 4 $r_s = 1 - 624/336 = -0.857$; $0.857 > 0.786$, reject the null hypothesis: significant negative correlation; 5 the 90-day value (0.65 %): ignore it on the best fit, check it by repeating that sampling; 6 two of soil pH, moisture, minerals, light, season; control e.g. compare only matched soil-moisture sites; 7 bar graph of means and a t-test; five levels: scatter/line graph and a correlation test; 8 informed consent (no compulsion); sterilise or replace the mouthpiece (infection); 9 dilution brings numbers down to countable; the lawn separates individuals so each forms a countable colony; 10 $5.4/13.5 = 0.40$ ($\times 0.4$).

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