

Course Companion

# Pearson Edexcel • International A-Level • Biology

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Every topic handout in one volume

exercises.lol

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# 1 • Molecules, Diet, Transport and Health

Pearson Edexcel • International A-Level • Biology

## From molecules to a working circulation

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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.

**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

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Water is the transport medium because it is a **polar solvent**. 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** nature of water. Opposite charges between neighbouring molecules form **hydrogen bonds**, and polar or charged particles (glucose, sodium ions, amino acids) dissolve because water clusters around them.

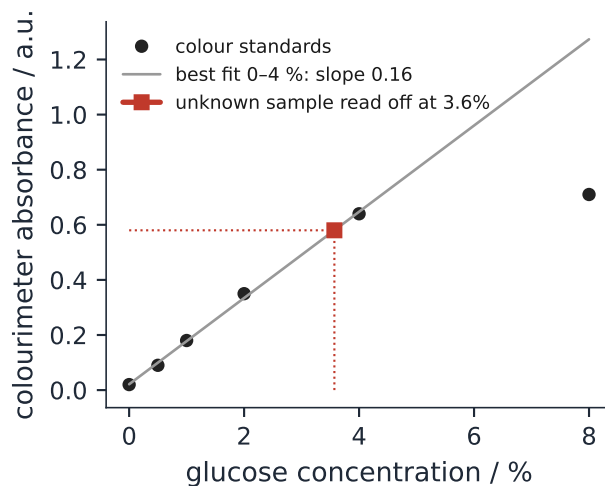
Carbohydrates are joined and split by two reactions:

- **Condensation** removes a water molecule as a **glycosidic bond** forms between two sugars.
- **Hydrolysis** 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** (1,4-linked, coils into a helix, compact), **amylopectin** and **glycogen** (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.



**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** is one glycerol plus three fatty acids, joined by three condensation reactions that form **ester bonds**. **Saturated** fatty acids have no C=C bonds: straight chains pack closely, so animal fats are solid at room temperature. **Unsaturated** 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

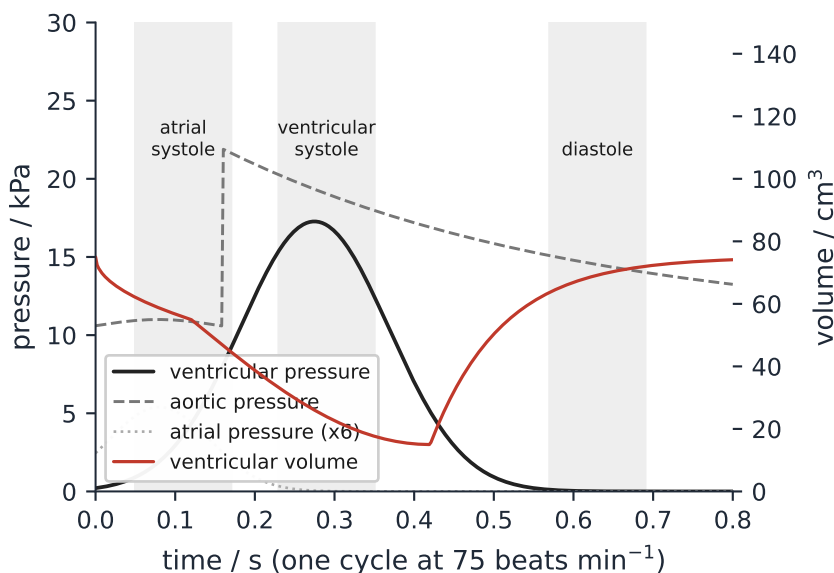
Diffusion supplies cells only a few tenths of a millimetre thick. A big organism needs **mass transport**: a pump and pipes that carry every cell's supply and waste. The three vessel types match three jobs:

| 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

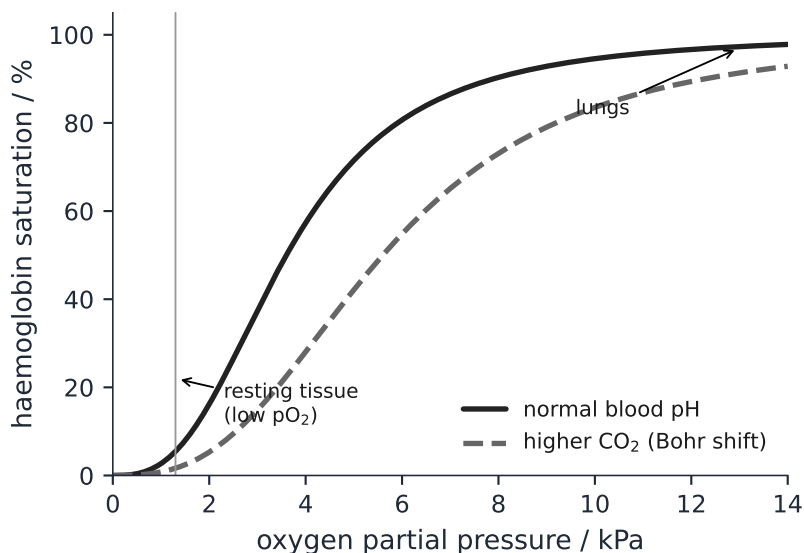
One beat has three phases. **Atrial systole** squeezes the last blood into the ventricles. **Ventricular systole** raises ventricular pressure above arterial pressure, the semilunar valves open, and blood is driven out. **Diastole** relaxes the muscle, pressure falls, the semilunar valves slam shut (the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



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.

## Haemoglobin and the oxygen journey

Haemoglobin is a protein of four polypeptide chains, each folded around a **haem** group carrying one  $\text{Fe}^{2+}$  ion that binds one  $\text{O}_2$  molecule – four in total. Binding the first oxygen changes the shape of the whole molecule and makes the next bindings easier: **cooperative binding** gives the oxygen dissociation curve its shallow-then-steep S shape.



In the lungs (high  $pO_2$ ) the curve flattens near 100 % saturation. In resting tissue near 1–2 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 respire hard it releases more carbon dioxide; hydrogen ions attach to haemoglobin and shift the whole curve to the right (the **Bohr effect**), forcing even more oxygen to unload in the busiest tissue.

**Worked check.** At  $pO_2$  2 kPa the normal curve reads about 30 % saturation and the shifted curve about 15 % – haemoglobin holds only about a third as much oxygen at that partial pressure, so most of its four sites are released to the tissue sooner.

## Cardiovascular disease: a chain of events

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

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

**Blood pressure** is reported as systolic over diastolic. Hypertension, smoking, high blood LDL-cholesterol, diet, inactivity, age, gender and genetics are **risk factors**. 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.** 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** 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.

**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  $WHR = 84/98 = 0.86$ .

Treatments all carry risks alongside benefits:

- **Antihypertensives** (beta blockers, ACE inhibitors, diuretics) lower blood pressure.
- **Statins** (for example simvastatin) block a liver enzyme in cholesterol synthesis, so cells take up LDL from blood.
- **Anticoagulants** (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** 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.

Four transport routes:

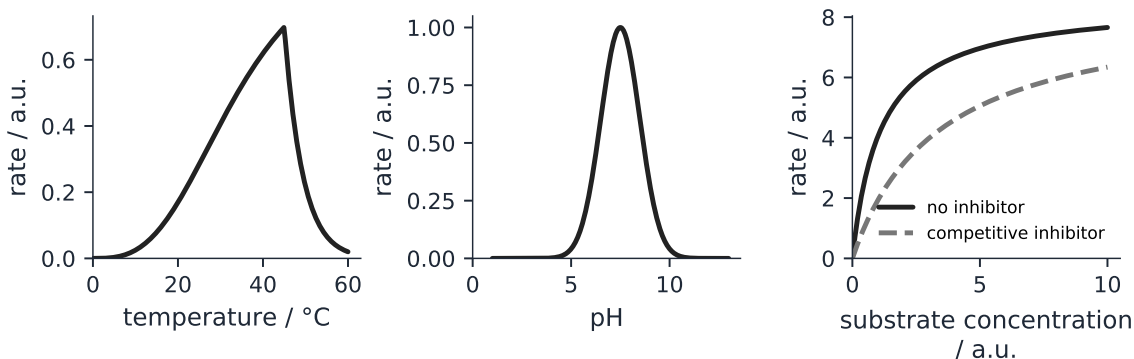
- **Diffusion** – net movement down a concentration gradient, no ATP.
- **Facilitated diffusion** – down the gradient through a channel or carrier protein.
- **Active transport** – against the gradient, powered by ATP, through carrier proteins that change shape.
- **Osmosis** – water moving from higher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

For diffusion, Fick's law: rate is proportional to (surface area  $\times$  concentration difference)  $\div$  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** in a condensation reaction. The **primary structure** is the sequence; hydrogen bonds coil it into the **secondary**; further hydrogen, ionic and disulfide bonds fold the **tertiary**; separate chains assemble into the **quaternary** – haemoglobin is the classic example.

An **enzyme** is a protein whose **active site** fits one substrate shape. Binding is not rigid: the **induced-fit** 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.



**Competitive inhibitors** bind the active site and are outnumbered as substrate concentration rises; **non-competitive inhibitors** 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; between 45 °C and 55 °C the same factor means the denatured enzyme is collapsing at an increasing rate. Q10 only describes; it does not explain.

## DNA, replication and the code

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A **mononucleotide** 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**. DNA is two antiparallel strands: A pairs with T (two hydrogen bonds), G with C (three), twisted into a double helix.

Replication is **semi-conservative**: helicase unzips the two strands, each is a template, and **DNA polymerase** joins free nucleotides in the 5' to 3' direction. Meselson and Stahl grew bacteria first on heavy  $^{15}\text{N}$  then light  $^{14}\text{N}$  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** code: three bases per amino acid. It is **non-overlapping** (read in successive groups), **degenerate** (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

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

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

## 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<sub>2</sub> 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, semilunar open, because ventricular pressure exceeds aortic but not atrial-from-above pressure; 4 hydrogen ions from CO<sub>2</sub> bind haemoglobin, changing its shape and lowering oxygen affinity (Bohr effect); 5 damage exposes collagen, platelets and damaged cells release thromboplastin, thromboplastin + Ca<sup>2+</sup> 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.

# 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** 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                                 |

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

**Magnification** is how much bigger the image is; **resolution** 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).  $M = \text{image size/actual size}$ , keeping units consistent.

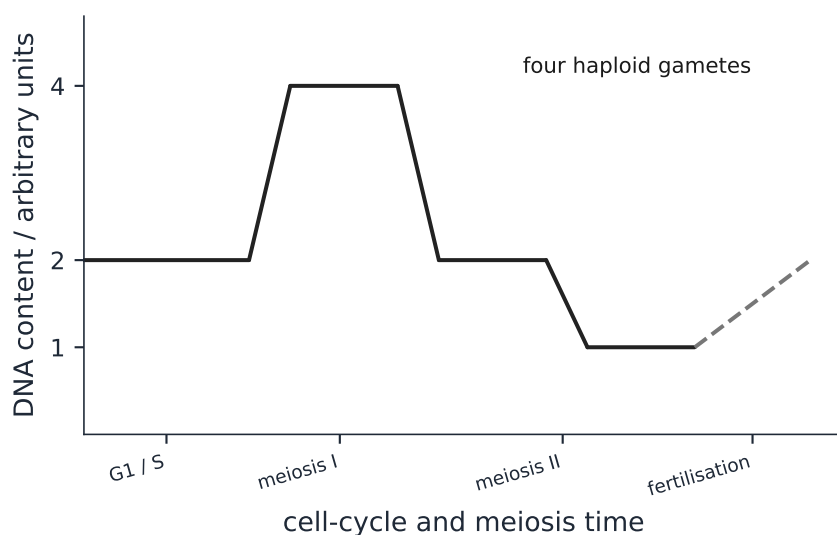
**Worked check.** A mitochondrion measures 14 mm on a photograph labelled  $\times 20\,000$ . Actual length =  $14\,000\ \mu\text{m}/20\,000 = 0.7\ \mu\text{m}$ . A nucleus that must be seen with its double membrane needs an electron microscope: the two membranes lie closer than a light microscope's resolution.

## Meiosis: halving and shuffling

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

- **Independent assortment** – 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** – in prophase I, homologous chromatids swap sections, mixing alleles within chromosome pairs.

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



# Mitosis and the cell cycle

**Mitosis** 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**

The **mitotic index** = cells in mitosis ÷ total cells counted. A high 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.

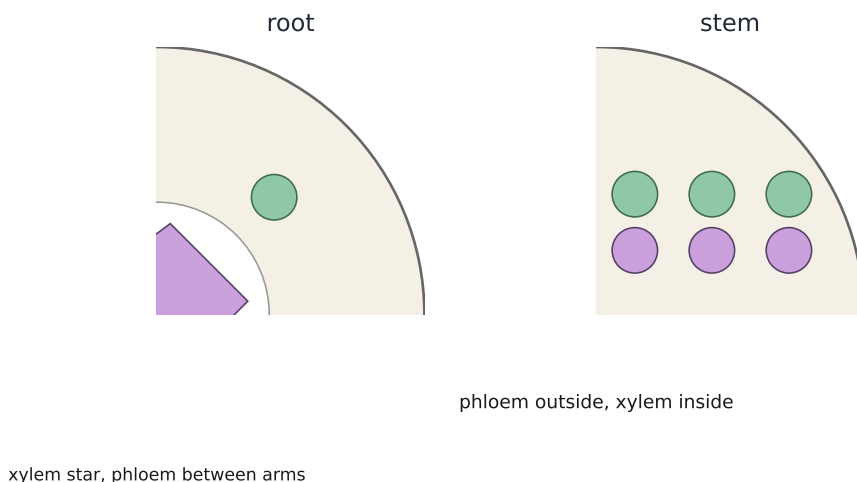
# Stem cells and switching genes on

A **totipotent** stem cell can form a whole organism (the first divisions of the zygote); a **pluripotent** cell (inner **blastocyst**) can form any tissue but not the whole organism. Differentiation happens by **differential gene expression**: 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** – 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** inheritance giving continuous variation).

# Plant transport tissues

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

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



Water and ions matter beyond drinking: **nitrate** builds amino acids, **calcium** cross-links pectin in walls and signals inside cells, **magnesium** 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** (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:

- **Species richness** – how many species.
- **Index of diversity** –  $D = \frac{N(N-1)}{\sum n(n-1)}$ , 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**  $H = (\text{number of heterozygotes}) \div (\text{number of individuals})$  measures genetic variety. A species found nowhere else is **endemic** – and its island home makes it both precious and fragile.

## Niches, Hardy–Weinberg and conservation

A **niche** 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** – tracks allele frequencies in a

large, randomly breeding population with no selection, migration or mutation:

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

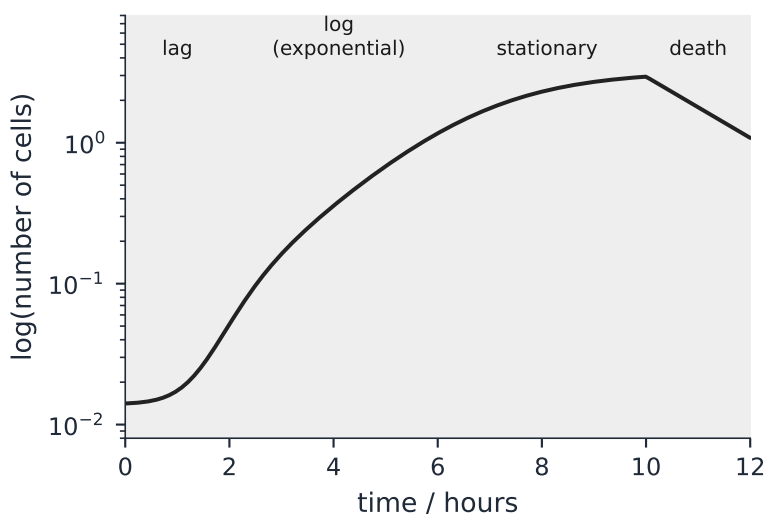
$q^2$  = frequency of the homozygous recessive genotype. If 4 % of a population shows the recessive phenotype,  $q^2 = 0.04$ , so  $q = 0.2$ ,  $p = 0.8$ , carriers  $2pq = 0.32$ .

**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** keep species against extinction and run captive breeding, but cost space, lose natural behaviour and serve few individuals; habitat protection and **corridors** 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** – 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** in broth.



**Worked check.** In the exponential phase, the growth-rate constant  $k = (\log_{10} N_t - \log_{10} N_0) / (0.301 \times t)$ . From  $1 \times 10^4$  to  $4 \times 10^7$  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.

## Check yourself

1. Calculate the actual width of a nucleus that appears 24 mm wide at  $\times 4\,000$ . Give your answer in  $\mu\text{m}$ .
2. Name the two processes in meiosis that create genetic variation, and state when each happens.
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  $24\,000/4\,000 = 6\ \mu\text{m}$ ; 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).

# 3 · Practical Skills in Biology I

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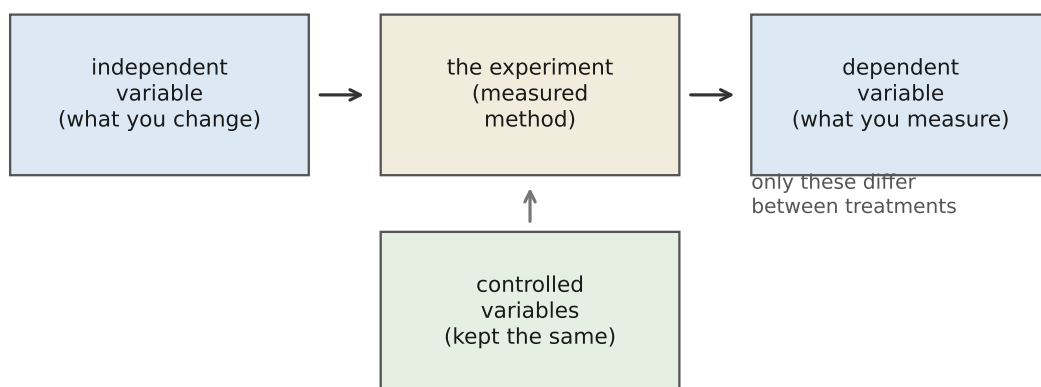
## The paper that tests your hands – without your hands

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.

**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** 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**.

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).

## Variables and a fair test



Beetroot example: alcohol changed, pigment lost measured; temperature, size, volume, time fixed; a water-only treatment is the control.

The **independent variable** is what you deliberately change (presence or concentration of trifluralin; alcohol concentration). The **dependent variable** 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** , 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** 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** such as a balance zero error, which shifts every reading the same way.

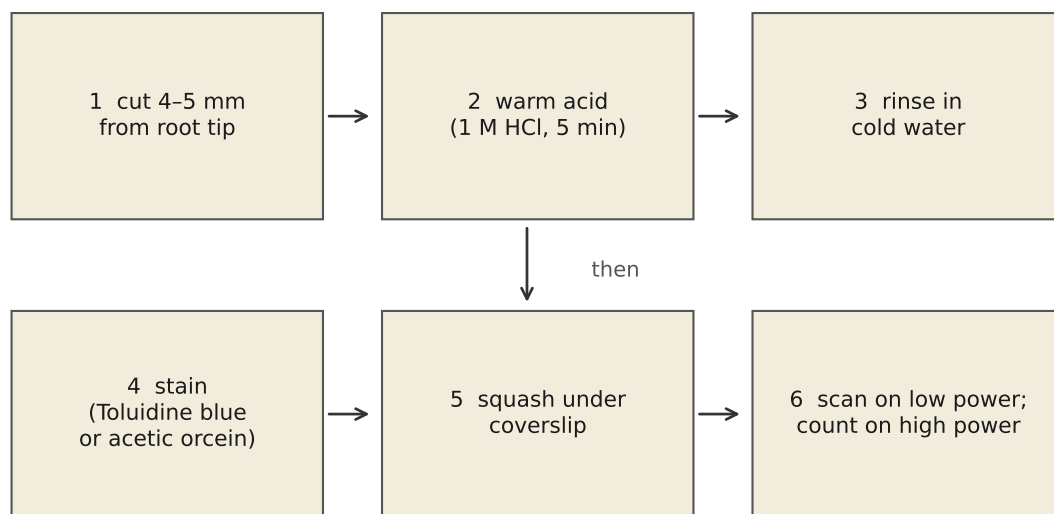
## The nine IAS core practicals

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 – <b>semi-quantitative</b>       |
| 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 <b>colorimeter</b> (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; <b>graticule</b> 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; <b>mitotic index</b>               |

| Core practical           | Method core                                                                                                                      | What is measured                           |
|--------------------------|----------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| 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.



mitotic index = cells in mitosis ÷ total cells counted

## 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.

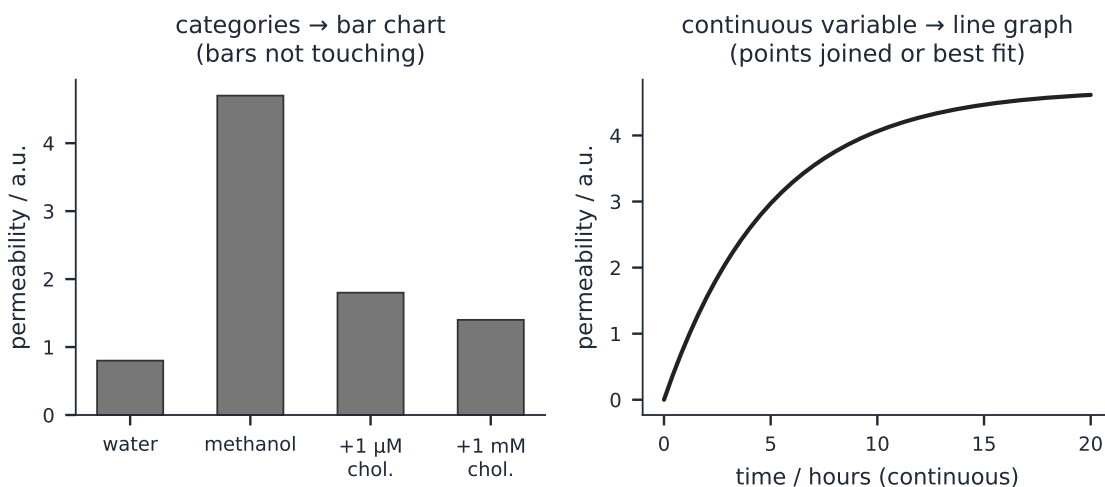
## Making measurements honestly

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** of  $\pm$  half a division ( $\pm 0.5$  mm) or  $\pm$  one division by the conservative course convention – state which you use.

**Percentage uncertainty** = (absolute uncertainty  $\div$  measurement)  $\times 100\%$ . For the maximum-uncertainty model used here, add percentage uncertainties for products or quotients, and absolute uncertainties for sums or differences. **Significant figures** 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.

## Presenting data: tables and graphs

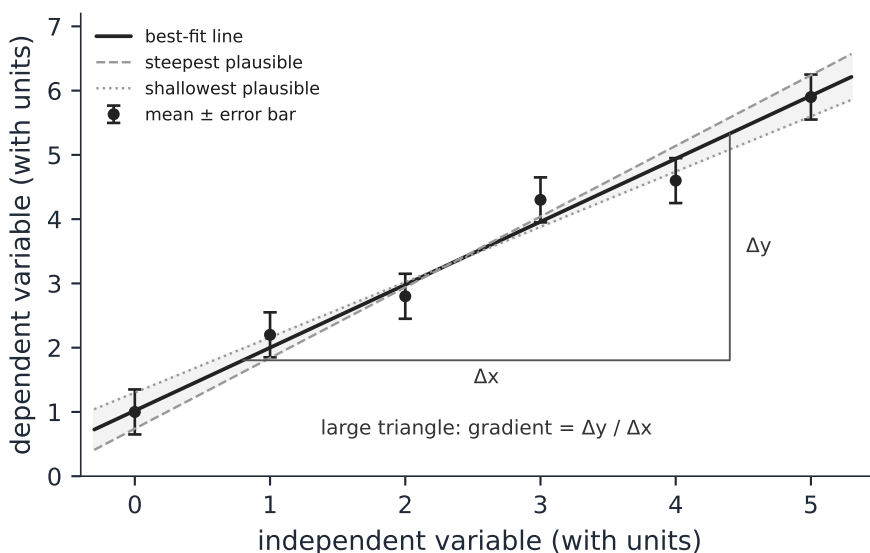
A table earns its marks by rule: each column headed with quantity *and* unit (permeability / a.u.), units never written inside cells, all data entered exactly, and no units or units-symbols invented for arbitrary instrument readings – the paper supplies a.u. (arbitrary units). Draw the table before entering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



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



The percentage family recurs every year. **Percentage change:**  $\frac{\text{final} - \text{initial}}{\text{initial}} \times 100\%$ .

**Percentage difference** (the 2025 formula):  $\text{difference} \div \text{mean of the two values} \times 100\%$ . From a bar chart, percentage of cells in a stage  $\times$  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** 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** (SD), standard error or range, then drawing **error bars**. 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.

## What written practice cannot do

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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

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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 root tip, warm dilute acid, rinse, stain (e.g. Toluidine blue or acetic orcein), squash under a coverslip, 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-sized pieces so surface area does not change pigment loss; rinse first so absorbance reflects membrane leakage not cut damage; a named control variable with reason (e.g. temperature – it affects membrane permeability); 6 (a) bar chart, (b) line graph; 7 quantitative gives an objective measured value (DCPIP volume; colorimeter absorbance), semi-quantitative gives an estimate by judgement against standards (colour matching in Benedict's); 8 reliability and an estimate of spread (mean, SD); a systematic error such as a zero offset; 9 measure roots grown under the same conditions, repeat measurements across different roots, report the mean with SD (or standard error/range/error bars); 10 the calculated value is approximately 12.6718 %, which rounds to 12.67 % at 4 s.f.; 12.70 % also has 4 s.f. but is not the correctly rounded result. The final zero is not itself the error.

# 4 • Energy, Environment, Microbiology and Immunity

Pearson Edexcel • International A-Level • Biology

## Energy in, energy through, energy lost

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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

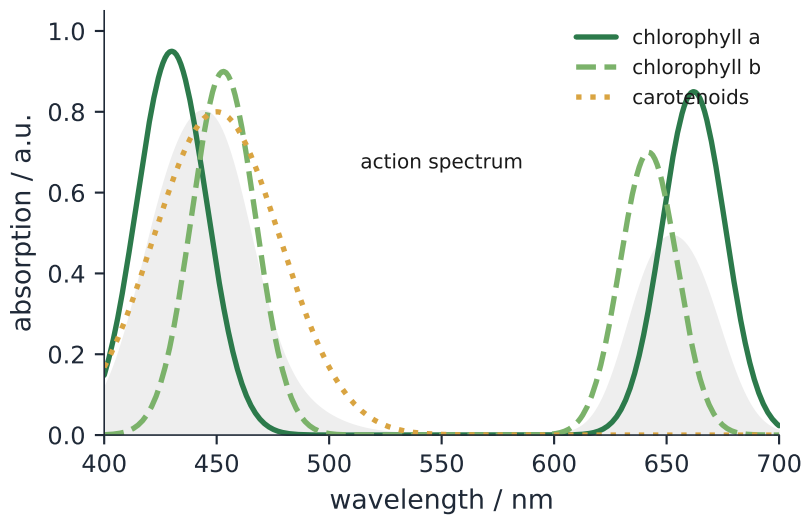
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The overall reaction:  $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$ , driven by light energy. In the **thylakoid** membranes, the **light-dependent reactions** photolyse water (releasing  $\text{O}_2$  and  $\text{H}^+$ ), **photophosphorylate** ADP and reduce NADP. In the **stroma**, the **light-independent reactions** (Calvin cycle) fix carbon dioxide onto ribulose biphosphate with rubisco, reduce the products using the ATP and reduced NADP from stage one, and make **GALP** – some to glucose, most to regenerate RuBP.

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

### ■ Pigments and spectra

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



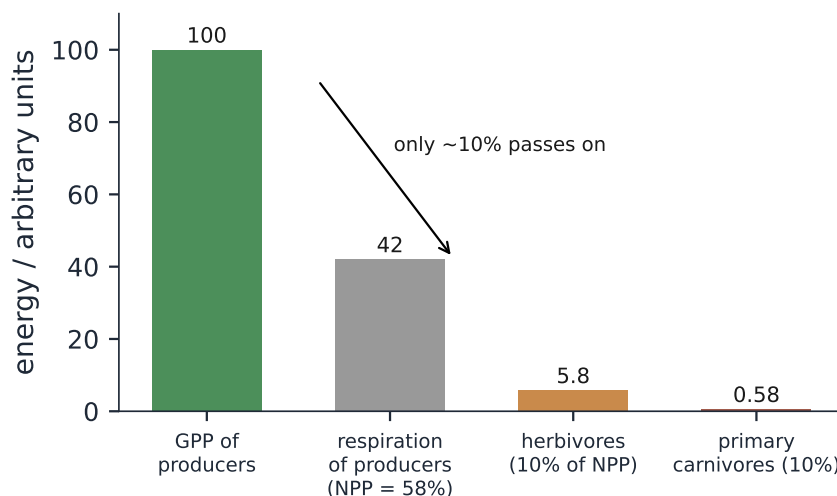
**Limiting factors** : light intensity, CO<sub>2</sub> concentration, temperature. A greenhouse raises the weakest of the three – and exam answers say which and why.

## Productivity and the short food chain

**Gross primary productivity** (GPP) is the energy fixed by photosynthesis per area per time (kJ m<sup>-2</sup> yr<sup>-1</sup>). Plants spend much of it on their own respiration; what remains is **net primary productivity** :

$$NPP = GPP - R$$

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.

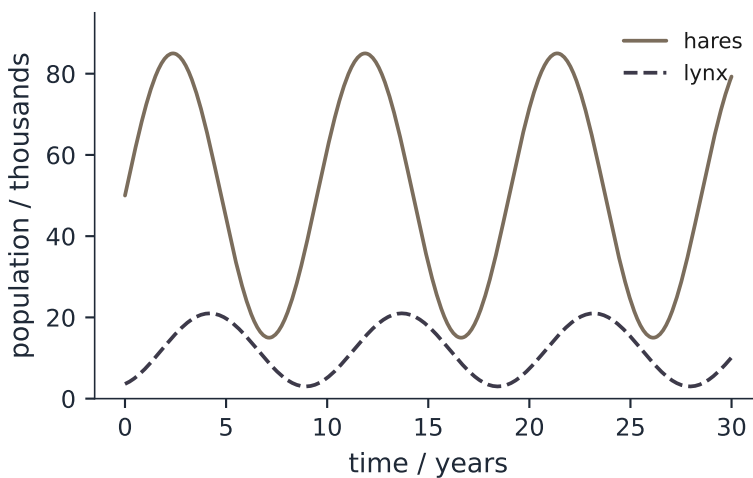


**Worked check.** A grassland fixes  $45\,000\text{ kJ m}^{-2}\text{ yr}^{-1}$  and respirers  $19\,000$ .  $\text{NPP} = 26\,000\text{ kJ m}^{-2}\text{ yr}^{-1}$ . Cattle eating that grass keep about 10 %:  $2\,600\text{ kJ m}^{-2}\text{ yr}^{-1}$ . Humans eating the cattle keep 260 – the energy arithmetic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

## Ecosystems, populations and succession

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

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



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

## Climate change: evidence, causes, effects

Evidence comes from direct temperature records, ice cores (trapped air giving ancient  $\text{CO}_2$ ), tree rings (**dendrochronology** ) and pollen layers in peat. The **enhanced greenhouse effect** : outgoing long-wave radiation is absorbed by  $\text{CO}_2$ , methane and nitrous oxide and re-emitted downward. The gases differ – methane is potent but short-lived;  $\text{CO}_2$  lasts centuries; nitrous oxide combines both – so policy weighs **global warming potential** against lifetime.

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 warming potential is about  $28 \times \text{CO}_2$ ’s per kg, but it lasts ~12 years against centuries. A one-tonne methane leak matters  $28 \times$  a one-tonne  $\text{CO}_2$  leak this decade, but fades while the  $\text{CO}_2$  persists – the arithmetic of “warming potential vs cumulative load”.

## Evolution and speciation

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

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

## Culturing microorganisms

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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** in broth, or viable counts by **dilution plating** (colony count  $\times$  dilution factor  $\div$  volume plated, giving colony-forming units per unit volume).

The growth curve: **lag** (enzymes synthesising), **log** (exponential doubling), **stationary** (deaths = divisions), **death** . The exponential constant:

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

**Worked check.** From  $2 \times 10^4$  to  $1.6 \times 10^7$  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.

## Pathogens and the body's barriers

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Bacteria: cell wall, plasmids, ribosomes, circular DNA, some with capsule and flagellum. Viruses: nucleic acid (DNA or RNA) in a **capsid**, some with an envelope – no organelles, no metabolism of their own; they hijack host cells. **Mycobacterium tuberculosis** infects lungs, surviving inside macrophages; **HIV** 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.

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

## The immune response

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

- **Humoral** : B effector cells → plasma cells → **antibodies** ; **B memory cells** remain for the faster, stronger secondary response.
- **Cellular** : T helper cells coordinate, **T killer cells** T 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** whose shape helps determine antigen specificity. Immunity splits two ways: **active** (your own antibodies – natural infection or vaccination) vs **passive** (given antibodies – mother to baby, antiserum); natural vs artificial in each. Vaccination works at the scale of populations too (**herd immunity**) – 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

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**Bacteriostatic** antibiotics stop bacterial growth; **bactericidal** 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.

## Decomposition, PCR, profiling and time of death

Decomposers recycle carbon and nitrogen – the ecosystem’s waste system. The **polymerase chain reaction** 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** drags negatively charged DNA fragments through gel – short fragments run furthest. The **profile**

of band positions supports comparisons between samples and investigation of family relationships.

Time of death narrows by four clocks: body temperature (falls ~1 °C per hour, modified by size, clothing, air), **rigor mortis** (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:  $(37 - 22)/(1 \text{ °C per hour}) \approx 15$  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  $60\,000 \text{ kJ m}^{-2} \text{ yr}^{-1}$  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  $5 \times 10^3$  to  $4 \times 10^6$  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.
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  $\text{NPP} = 40\,000$ ; third level =  $400 \text{ kJ m}^{-2} \text{ yr}^{-1}$  (10 % 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 to respiration/heat/egestion, so little remains; producers also lose to respiration before the first transfer; 6 log difference 2.903,  $k = 2.903/(0.301 \times 6) = 1.61 \text{ h}^{-1}$ , doubling  $\approx 37$  min; 7 memory B cells persist; the second encounter selects clones that divide rapidly into plasma cells – the secondary response; 8 bacteriostatic stops growth (im-

immune system must clear), bactericidal kills outright – a weak immune system needs bactericidal support;  $9 \times 2^3 = 8$  copies;  $10 \times (37 - 30)/1 = 7$  hours; heavy clothing or a warm room slows cooling, so true time is longer.

# 5 · Respiration, Internal Environment, Coordination and Gene Technology

Pearson Edexcel · International A-Level · Biology

## 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

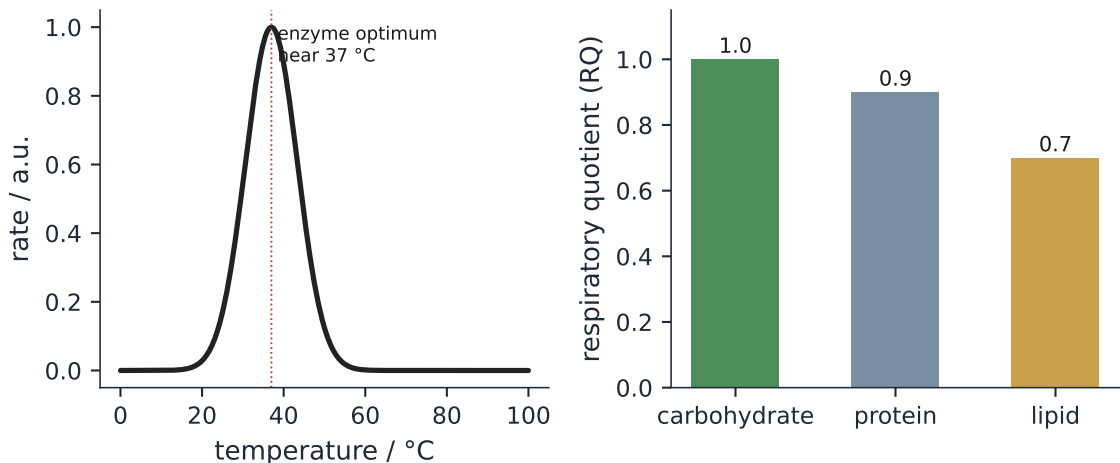
Respiration releases energy in steps, each catalysed by a specific enzyme. Aerobic respiration's summary:



| Stage                     | Where                | What happens                                                                                                         | Net yield                                       |
|---------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------|
| Glycolysis                | cytoplasm            | hexose phosphorylated then split; pyruvate formed                                                                    | 2 ATP, 2 reduced NAD                            |
| Link reaction             | mitochondrial matrix | pyruvate oxidised and decarboxylated to acetyl                                                                       | 1 CO <sub>2</sub> , 1 reduced NAD per pyruvate  |
| Krebs cycle               | matrix               | acetyl fully oxidised; substrates regenerate                                                                         | CO <sub>2</sub> , ATP, reduced NAD, reduced FAD |
| Oxidative phosphorylation | cristae              | electron transport chain pumps H <sup>+</sup> ; chemiosmosis through ATP synthase; O <sub>2</sub> the final acceptor | most ATP                                        |

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

**Respiratory quotient** :  $RQ = \text{CO}_2 \text{ produced} / \text{O}_2 \text{ consumed}$ . Carbohydrate 1.0, protein 0.9, lipid  $\approx 0.7$  – an organism's RQ reveals what it is burning.



**Worked check.** A respirometer shows  $60 \text{ cm}^3 \text{ CO}_2$  produced and  $60 \text{ cm}^3 \text{ O}_2$  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** joins muscle to bone; a **ligament** joins bone to bone across a joint; muscles work in antagonistic pairs. A skeletal muscle fibre is a fused, multinucleate cell packed with **myofibrils** of **actin** and **myosin**.

Contraction is the sliding filament cycle: an action potential releases  $\text{Ca}^{2+}$ ; 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** : it beats without nerve input. The **sino-atrial node** 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.

The cardiovascular control centre and the ventilation centre in the **medulla oblongata**.

**gata** adjust both systems to demand: chemical receptors sense CO<sub>2</sub> 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  $\times$  breathing rate = **minute ventilation**).

## Homeostasis and feedback

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**Homeostasis** holds the internal environment in dynamic equilibrium – not stillness, but variables oscillating inside narrow limits. **Negative feedback** corrects deviations in either direction (the thermostat pattern); **positive feedback** amplifies them (a self-reinforcing loop, as voltage-gated sodium channels open during an action potential).

Thermoregulation runs through the **hypothalamus**: heat loss by vasodilation and sweating; heat conservation by vasoconstriction, shivering and hair erection.

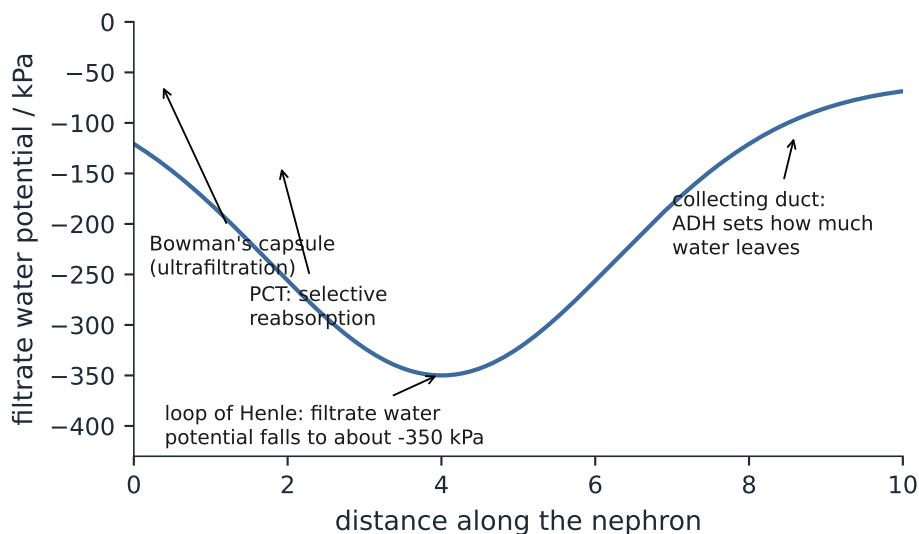
**Adrenaline** prepares the fight-or-flight response – heart rate, blood glucose and airways all respond together.

## The kidney: filter, reabsorb, fine-tune

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Blood enters the **nephron**'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** (ultrafiltration: everything except cells and large proteins). The **proximal convoluted tubule**

reabsorbs all glucose and amino acids plus most salts and water (active transport then osmosis). The **loop of Henle** builds a water-potential gradient down the medulla by countercurrent multiplication. The **collecting duct** makes the final decision: **ADH** 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.



Excess amino acids are **deaminated** in the liver; the toxic ammonia becomes **urea** for excretion.

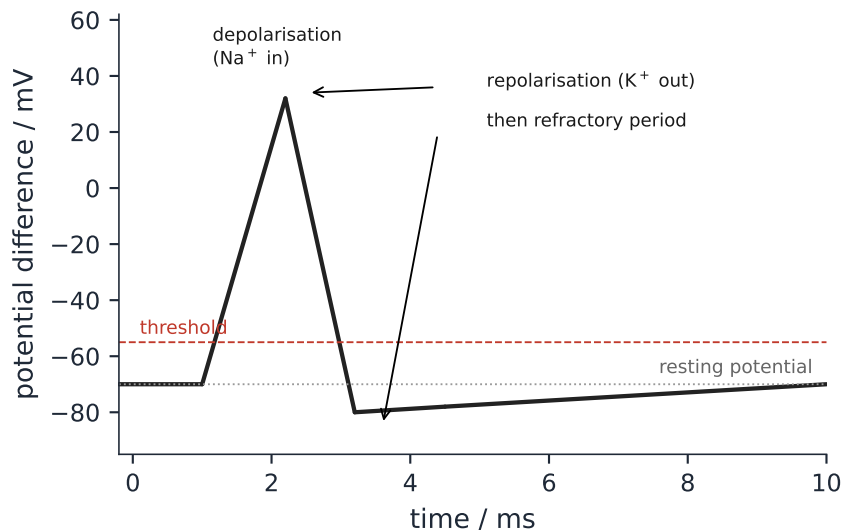
**Worked check.** ADH present → collecting duct walls permeable → water leaves down the gradient into the medullary blood → small volume, concentrated urine. Alcohol suppresses ADH – large volume, dilute.

## Switching genes: transcription factors and epigenetics

A **transcription factor** 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** concerns changes in gene activity without changing the DNA base sequence. Promoter DNA **methylation** 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.

## Nerve impulses and synapses

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



In **myelinated** neurones the impulse jumps node to node (**saltatory conduction**) – far faster. At the **synapse**, 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** (pain). The spinal **reflex arc** passes sensory → relay → motor neurone in the cord's grey matter – fast, involuntary, protective. **Habituation** is a decreasing response to a repeated harmless stimulus.

## Plants: light and growth switches

**Phytochrome** 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** elongates cells by acidifying walls; **gibberellins** induce enzymes (amylase in the aleurone layer) that mobilise starch in germination.

## The brain and its chemistry

Landmarks and jobs: **cerebral hemispheres** (voluntary, thought), **cerebellum** (coordination, balance), **hypothalamus** and **pituitary** 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** 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** DNA: a **restriction enzyme** cuts DNA at its recognition sequence, leaving **sticky ends**; the human gene (made without introns from mRNA) is spliced into a **plasmid** with **DNA ligase**; 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** – 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.

**Microarrays** identify active genes: sample mRNA hybridises to complementary probes on the chip; spots that fluoresce mark genes being transcribed. **Bioinformatics** 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  $85 \text{ cm}^3$  and heart rate  $140 \text{ min}^{-1}$ .
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  $-55 \text{ mV}$ . A stimulus moves it to  $-60 \text{ mV}$ . 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;  $4\ 85 \times 140 = 11\ 900\ \text{cm}^3\ \text{min}^{-1} = 11.9\ \text{dm}^3\ \text{min}^{-1}$ ; 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 (fever rising); 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.

# 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 from a hypothesis you did not choose. Everything comes from the practical work of Units 4 and 5 – respirometers, spirometers, quadrats, 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)

| Core practical              | Method core                                                                                                            | What is measured                                       |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|
| 10<br>Photosynthesis rate   | Aquatic plant under light of varied intensity/wavelength, temperature, CO <sub>2</sub> supply; gas collected over time | Gas volume per time; rate and limiting-factor plateaus |
| 11 Ecology of a habitat     | Quadrats and transects; <b>abiotic</b> factors measured at each site                                                   | Distribution and abundance; means with spread          |
| 12<br>Development rate      | Seedling growth or brine-shrimp hatching at different temperatures, ethical use of organisms                           | Growth/hatch rate per temperature                      |
| 13<br>Liquid-culture growth | Microorganism grown in broth; samples over time, safe and ethical use                                                  | Growth curve by cell count, mass or turbidity          |
| 14 Antibiotics on bacteria  | Aseptic plating; antibiotic discs or plant extracts on a seeded lawn; incubate inverted below 30 °C                    | Zones of inhibition                                    |

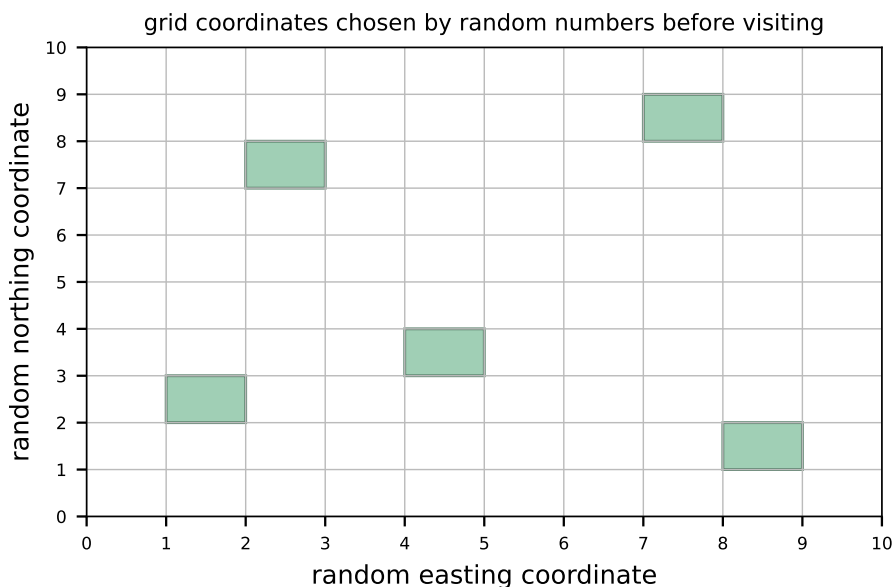
| Core practical                  | Method core                                                                                                                                                  | What is measured                                                                                    |
|---------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|
| 15 Respiration in yeast         | Artificial hydrogen carrier – <b>redox indicator</b> (TTC, methylene blue, DCPIP) – changes colour as yeast respire; the direction depends on the indicator  | Time to colour change at each condition                                                             |
| 16 Respirometer and RQ          | Organism in a sealed chamber; CO <sub>2</sub> absorbent (soda lime) draws the fluid marker as O <sub>2</sub> is used; with and without the absorber gives RQ | O <sub>2</sub> uptake per time; $RQ = \frac{\text{CO}_2 \text{ produced}}{\text{O}_2 \text{ used}}$ |
| 17 Exercise and ventilation     | Spirometer trace: tidal volume, breathing rate, minute ventilation, O <sub>2</sub> 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                                                       |

## The 16-mark plan, taken apart

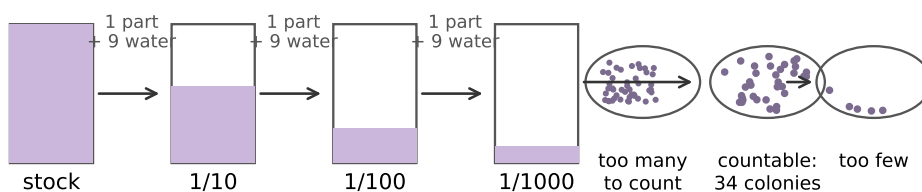
The closing question (2025: fitness programmes and recovery time) pays out in named blocks – answer in the same order. **Ethics** : informed consent of volunteers; no one is forced to participate. **Safety**: sterilise or replace the mouthpiece between students (infection); check volunteers are healthy enough for the exercise. **Method, nine marks**: two groups (with and without the fitness programme); the dependent variable 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 **and** the method of control for one; repeats giving means **and** standard deviations. **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**  $t$  , or a line/scatter graph (several fitness levels) tested with a correlation test. **Limitations**: volunteers' lives outside the experiment cannot be fully controlled; apparatus difficulties (leaks, soda lime exhausted, abnormal breathing through a mouthpiece).

## Sampling a habitat fairly

Random sampling has a method: lay a grid over the area, generate random coordinate 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** is  $\text{image} \div \text{actual}$ : an earthworm 5.0 cm in a photograph and 13.5 cm real gives  $\times 0.37$  – photographs can be smaller than life.



## 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

A drop of soil suspension holds too many bacteria to count, so **dilution plating** justifies each step: serially dilute 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 can be counted; incubate for a fixed time and temperature *so that* colonies become visible; work aseptically *to avoid* contamination and counting errors. Use a countable plate and the method's accepted count range. Colony count  $\times$  dilution factor  $\div$  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

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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 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  $\pm$  SD** (error bars): if the bars do not overlap, the difference is likely significant – properly, a t-test decides.

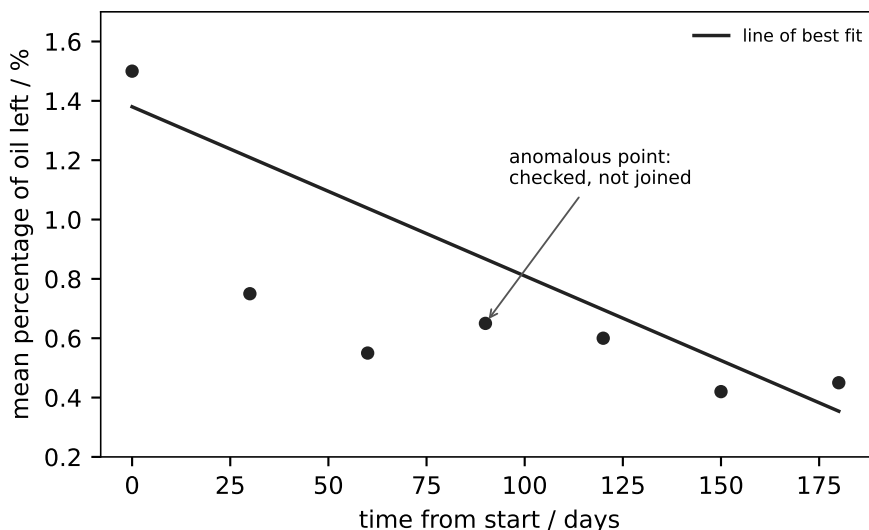
## Statistics II: Spearman's rank and the null hypothesis

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**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 between oil remaining and time. Write all three sentences – comparison, reject, conclusion.



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** – time is continuous – with labelled axes and units (days; mean % oil left), linear scales, points plotted exactly, and a single best-fit line. The 90-day reading (0.65 %) sits above every neighbour: it is anomalous. 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 respire.
2. Write a null hypothesis for: “the number of bacteria in soil increases as crude oil is broken down.”
3. Masses 18.1, 19.7, 16.2, 13.8, 17.1 g. Compute  $\sum(X - \bar{X})^2$  and the standard deviation.
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 statistical test? What changes if five fitness levels are compared?
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 TTC, methylene blue or DCPIP; they lose colour (decolourise) as they accept hydrogen/electrons from respiration; 2 there is no correlation between the number of bacteria and the amount of crude oil broken down (equivalently, the correlation coefficient is zero); 3 deviations  $-0.1\dots$ ;  $\sum(X - \bar{X})^2 = 1.21 + 7.29 + 0.64 + 10.24 + 0.01 = 19.39$ ;  $s = \sqrt{19.39/4} = 2.2$  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 %): the best-fit line ignores it, and it is checked by repeating that measurement; 6 any two of soil pH, moisture, minerals, light intensity, season; control e.g. measure soil moisture at each site and compare only matched sites; 7 bar graph of means and a t-test; with five levels, a scatter/line graph and a correlation test; 8 informed consent of volunteers (no compulsion); sterilise or replace the mouthpiece to prevent infection; 9 dilution reduces bacterial numbers because the raw sample has too many to count; the lawn separates individual bacteria so each forms a countable colony; 10  $5.4/13.5 = 0.40$  ( $\times 0.4$ ).