



Biology (0610)

IGCSE • Core • CAIE

Standard Cheat Sheet

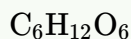
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1 Biological molecules

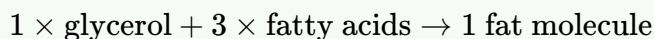
KEY FORMULAS

Chemical formula of glucose



The chemical formula of glucose, the simple sugar that starch, glycogen and cellulose are all built from. Six carbon atoms, twelve hydrogen atoms and six oxygen atoms per molecule.

Composition of a fat molecule



A fat (or oil) is built from one glycerol molecule joined to three fatty acid molecules. Glycerol is the same in every fat; the fatty acid type decides whether the lipid is solid (a fat) or liquid (an oil) at room temperature.

Percentage change

$$\text{percentage change} = \frac{\text{change in value}}{\text{original value}} \times 100$$

Used to compare a change in a quantity, such as vitamin C concentration, with its starting value. Always divide by the *original* value, never the final value, and state whether the change is an increase or a decrease.

KEY CONCEPTS

- **Amino acids build proteins:** A *protein* is a long chain of *amino acids* joined together. About twenty different amino acids exist, and the order in which they are joined determines the protein's shape and job, which is why proteins can perform so many different roles from only twenty building blocks.
- **Elements in carbohydrates:** A *carbohydrate* contains only three elements: carbon, hydrogen and oxygen. Sugars and starches are all built from these three and nothing else.
- **Elements in fats:** A *fat (lipid)* contains the same three elements as a carbohydrate, carbon, hydrogen and oxygen, but in a higher proportion of hydrogen relative to carbon. That higher hydrogen proportion is why fats release more energy per gram than carbohydrates.
- **Elements in proteins:** A *protein* contains carbon, hydrogen and oxygen plus a fourth element, nitrogen. Nitrogen is present in every protein and absent from pure carbohydrates and pure fats, so it is the defining chemical test for identifying a protein.
- **Starch, glycogen and cellulose share one sub-unit:** *Starch* (the energy store of plants), *glycogen* (the energy store of animals) and *cellulose* (the structural carbohydrate of plant cell walls) are all long chains built from many *glucose* molecules joined together. The three differ in job and in how the chains are arranged, not in the sub-unit they are built from.
- **Synthesis versus digestion:** *Synthesis* joins small sub-units into a large molecule: glucose into starch, amino acids into protein, fatty acids and glycerol into fat. *Digestion* is the exact reverse, breaking each large molecule back down into its own small sub-units. The same three sub-unit pairings run in both directions.
- **Why an insoluble store suits starch and glycogen:** Starch and glycogen are insoluble, unlike glucose. Being insoluble means they do not dissolve and disturb a cell's water balance, and they do not leak away, which is exactly why a large, compact, insoluble molecule makes a better energy store than the small, soluble sugar it is built from.
- **Benedict's test for reducing sugars:** Add Benedict's solution (blue) to the food sample and *heat* it in a water bath, heating is essential. A colour change through green and yellow to orange or brick-red is a positive result (reducing sugar present, with more sugar giving a redder colour); staying blue is negative.
- **Biuret test for protein:** Add biuret solution (pale blue) to the food sample and mix; no heating is needed. A colour change from pale blue to *purple / violet* is a positive result (protein present); staying blue is negative.

- **DCPIP test for vitamin C:** Add vitamin C solution drop by drop to a fixed small volume of blue DCPIP solution until the blue colour just disappears. A colour change from blue to *colourless* is a positive result (vitamin C present); staying blue is negative. This is the one test where the *positive* result loses colour rather than gaining one.
- **Ethanol emulsion test for fats:** Dissolve/shake the food sample with ethanol, then pour the ethanol into water. A *cloudy white emulsion* forming in the water is a positive result (fat present); the mixture staying clear is negative. Ethanol is highly flammable and must be kept away from naked flames.
- **Iodine test for starch:** Add a few drops of iodine solution (yellow-brown) to the food sample; no heating is needed. A colour change from yellow-brown to *blue-black* is a positive result (starch present); staying yellow-brown is a negative result (no starch).

EXAM TIPS

TIP Glycerol (part of a fat) and glucose (the sub-unit of carbohydrates) are similar-looking words for two completely different molecules. Confusing the two is a common and costly slip.

TIP If a purified substance is described as containing nitrogen, it is a protein, never a pure carbohydrate or a pure fat. Carbohydrates and fats share the same three elements (carbon, hydrogen, oxygen); only protein adds nitrogen.

TIP Percentage change is divided by the value the quantity *started at*, never the final value and never the bare difference. Forgetting to state "increase" or "decrease" is the other common way this question type loses marks.

TIP A tube that shows no colour change after Benedict's solution is added but was never heated tells you nothing, the test cannot work without heat. Always check whether heating was carried out before concluding "no reducing sugar present".

TIP Iodine → starch (blue-black). Benedict's → reducing sugar (brick-red, heat). Biuret → protein (purple). Ethanol emulsion → fat (cloudy white). DCPIP → vitamin C (goes colourless). Reproducing this five-row grid from memory answers almost every "which reagent / which colour / which nutrient" question in this chapter.

TIP Iodine, Benedict's and biuret all *gain* a colour on a positive result; DCPIP *loses* its colour. Fix this contrast in memory to avoid muddling the direction of the colour change.

2 Biotechnology and genetic modification

KEY FORMULAS

Anaerobic respiration in yeast

glucose $\rightarrow$ ethanol + carbon dioxide

The fixed word equation for anaerobic respiration in yeast. The same reaction is harnessed in both bread-making (the carbon dioxide is wanted) and biofuel production (the ethanol is wanted).

Bacterial population growth by binary fission

number of bacteria = 2^n

n is the number of divisions that have occurred since a population started from a single cell. Growth is doubling, not adding a fixed amount each division.

Percentage increase

percentage increase = $\frac{\text{change}}{\text{original value}} \times 100$

Use whenever a quantity such as juice yield rises from one value to another. Always divide by the *original* (starting) value, not the new value.

Combined growth formula

number of bacteria = $2^{\frac{t}{d}}$

A one-line combination of the two steps above, where t is the total time elapsed and d is the time for one division. Use when a calculation must be done in a single expression rather than two separate steps.

Number of divisions in a given time

$n = \frac{\text{total time}}{\text{time per division}}$

Find n first whenever a question gives a division time and a total time, then substitute n into the population formula 2^n .

KEY CONCEPTS

- **Bread-making: the gas is the useful product:** In bread-making, yeast respire the sugars in warm dough anaerobically. The *carbon dioxide* produced is trapped as bubbles, making the dough *rise*. The ethanol produced at the same time evaporates away during baking and plays no part in the rise.
- **Definition of genetic modification:** *Genetic modification (genetic engineering)* means changing the genetic material of an organism, usually by adding a gene from another organism, so it gains a new characteristic it did not have before.
- **Human insulin from genetically modified bacteria:** The flagship example of genetic modification is *human insulin*: the human insulin gene is inserted into bacteria, which then manufacture human insulin in bulk for treating diabetes, replacing the older practice of extracting animal insulin from pigs and cattle.
- **Pectinase breaks down pectin in fruit pulp:** Crushed fruit pulp contains *pectin*, a carbohydrate that holds plant cell walls together and traps juice, leaving the pulp thick and cloudy. *Pectinase* is the enzyme that breaks pectin down.

- **Proteases and lipases in biological washing powders:** Biological washing powders contain enzymes that digest stain molecules into small, soluble products that rinse away. *Proteases* digest protein-based stains (blood, egg, grass); *lipases* digest fat (lipid)-based stains (grease, oil).
- **Three kinds of genetically modified crop:** Genes are inserted into crops for three named traits: *herbicide resistance* (the crop is unharmed by a weedkiller so weeds can be sprayed away), *insect (pest) resistance* (the crop makes its own protein toxic to pests), and *improved nutritional content* (the crop makes an extra nutrient it normally lacks, such as beta-carotene or lycopene).
- **Two reasons bacteria are useful in biotechnology:** Bacteria are used in biotechnology and genetic modification because of *two* properties only: a *rapid reproduction rate* (a small culture becomes a huge one quickly, since bacteria divide by binary fission every 20 to 60 minutes) and the *ability to make complex molecules* such as proteins. A cell wall, being a decomposer, or causing disease are true facts about some bacteria but are not reasons for their use.
- **Binary fission:** *Binary fission* is the way bacteria reproduce: one cell divides into two identical cells. Repeated binary fission makes a bacterial population grow *exponentially*, doubling again and again rather than increasing by a fixed amount each time.
- **Biofuel: the ethanol is the useful product:** To make a biofuel, the same anaerobic respiration is run in yeast on a sugar solution, but this time the *ethanol* is collected and used as fuel. Carbon dioxide is released as a by-product here, the reverse of the roles in bread-making.
- **Genetic modification is not selective breeding:** *Selective breeding* chooses which existing individuals of the *same species* reproduce, over many generations. *Genetic modification* adds a specific gene directly to an organism's genetic material, often from a *different* species, in a single controlled step. Keep the two firmly separate.
- **Lower wash temperature, but a limit set by denaturing:** Because the enzymes chemically attack stains, biological powders clean effectively at *lower temperatures* than a wash without enzymes, saving energy. But each enzyme has an *optimum temperature*; a wash that is too hot *denatures* the enzymes, so a very hot wash cleans *worse*, not better.
- **Two benefits of adding pectinase before pressing:** Breaking down pectin releases juice that was trapped in the pulp, which *increases the volume (yield) of juice* extracted from a given mass of fruit, and removes the substance that would otherwise cloud the liquid, so the juice is also *clearer*.

EXAM TIPS

TIP "Evaluate" questions on washing powders almost always turn on the same idea: identify the enzyme, state its optimum temperature, and reason about whether the given wash temperature is above or below that optimum.

TIP "Pectinase breaks down pectin" alone is only half the answer if the question asks *why* pectinase is useful. Always go on to state the two consequences: *more juice (higher yield)* and *clearer juice*.

TIP A common item names a microorganism used in *both* bread-making and biofuel production, or gives a flow chart with unlabelled boxes. The organism is always *yeast*, the process is always *anaerobic respiration*, and the two products are always *carbon dioxide* and *ethanol* in that fixed order.

TIP Examiners mix true statements about bacteria, such as "they have a cell wall" or "they are easy to see", into multi-statement questions. Neither is one of the two accepted reasons bacteria are useful. Anchor an answer only on *rapid reproduction rate* and *ability to make complex molecules*.

KEY CONCEPTS

- **Classification groups organisms by shared features:** Organisms are placed in the same group because they share *features*, never because of where they live, their colour, or their size. A fish and a whale both live in the sea and are streamlined, yet a fish breathes with gills while a whale breathes air and feeds its young on milk, so classification places them in very different groups.
- **Definition of a species:** A species is a group of organisms that can reproduce to produce *fertile* offspring. The load bearing word is *fertile*: two organisms that mate and produce living offspring whose offspring are sterile are, by this definition, not the same species.
- **The binomial naming system:** Every species has a unique two part scientific name. The *genus* name is written first with a capital initial letter; the *species* name is written second, entirely in lower case. The whole name is written in italics, or underlined if handwritten. The human species is *Homo sapiens*: genus *Homo*, species *sapiens*.
- **The five vertebrate groups and their defining features:** A vertebrate is an animal with a backbone. *Fish*: wet scales, gills, fins, soft eggs laid in water. *Amphibians*: moist skin with no scales, soft eggs laid in water. *Reptiles*: dry scaly skin, lungs, soft shelled eggs laid on land. *Birds*: feathers, lungs, hard shelled eggs, constant body temperature. *Mammals*: hair or fur, produce milk, lungs, external ears, constant body temperature.
- **The four arthropod groups and their defining features:** All arthropods have a hard exoskeleton and jointed legs. *Insects*: three body parts, three pairs of legs, one pair of antennae. *Arachnids*: two body parts, four pairs of legs, no antennae. *Crustaceans*: more than four pairs of legs, two pairs of antennae. *Myriapods*: many segments with legs on most of them, one pair of antennae.
- **The four kingdoms and their defining features:** *Animals*: multicellular, cells have a nucleus but no cell wall, feed on organic substances made by other organisms. *Plants*: multicellular, cellulose cell wall, usually chloroplasts, make their own food by photosynthesis. *Fungi*: cell wall made of chitin (not cellulose), no chlorophyll, feed by absorbing nutrients from dead or living matter. *Prokaryotes* (bacteria): single celled, no true nucleus, genetic material a free loop in the cytoplasm.
- **The MRS GREN checklist and the all seven rule:** A living organism is anything that carries out all seven life processes, remembered by the mnemonic *MRS GREN*: Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition. A thing is treated as living only if it shows *all seven*, not most of them; showing one or two (a candle flickers and gives out heat) is never enough.
- **The seven characteristic definitions in full:** *Movement*: an action by an organism or part of an organism causing a change of position or place. *Respiration*: the chemical reactions in cells that break down nutrient molecules and release energy for metabolism. *Sensitivity*: the ability to detect and respond to changes in the internal or external environment. *Growth*: a permanent increase in size and dry mass. *Reproduction*: the processes that make more of the same kind of organism. *Excretion*: the removal of the waste products of metabolism, toxic materials, and substances in excess of requirements. *Nutrition*: the taking in of materials for energy, growth and development.
- **What a dichotomous key is and how to follow one:** A dichotomous key identifies an unknown organism through a numbered series of steps, each offering exactly *two* contrasting choices based on observable, unambiguous features (has fur or does not; pincers present or absent). Whichever choice matches the specimen either names it or sends the user to another step; never skip ahead to a name that "sounds right".
- **Telling a fungus from a plant despite a cell wall:** Fungi are plant-like at a glance because they do not move and have a cell wall, but they are not plants: the fungal wall is made of chitin rather than cellulose, and fungi have no chlorophyll so they cannot photosynthesise. Always check for cellulose *and* chloroplasts before committing to the plant kingdom.

EXAM TIPS

TIP Excretion removes waste made by the body's *own* chemical reactions (carbon dioxide, excess water and salts). Undigested food removed as faeces was never absorbed into the body and never took part in any metabolic reaction, so removing it is not excretion. Anchor the distinction on the word *metabolism*.

TIP "Growth" is not just getting bigger. It must be *permanent* (a wilted plant that swells with water and then shrinks back has not grown) and it must be measured in *dry mass* as well as size, because ordinary wet mass fluctuates with water content.

TIP The single most examined arthropod distinction is insect versus arachnid. An insect has six legs, three body parts, and antennae; an arachnid has eight legs, two body parts, and no antennae. A spider is not an insect.

TIP A well designed first question in a dichotomous key divides the organisms into two roughly equal groups rather than one group of one and one group of many; that is what makes a key efficient. Each feature used must also be visible and unambiguous, never a judgement call such as "large" or "small".

TIP If two organisms mate and produce living offspring, that alone does not make them the same species; the offspring must themselves be able to reproduce. A mule (horse times donkey) is sterile, which is why horses and donkeys are classed as different species despite being able to interbreed.

TIP A plant that swells overnight after absorbing water and shrinks back the next day has changed size, but the change is not permanent, so it is not growth. Real growth is a *permanent* increase in size and dry mass built from new tissue, not a reversible change in water content.

4 Coordination and response

KEY CONCEPTS

- **Adrenaline:** Adrenaline is released by the adrenal glands, one on top of each kidney, in situations of fear, stress or excitement, the fight or flight response. It increases the heart rate and the breathing rate, delivering more oxygen and glucose to the muscles faster, and widens the pupils, letting in more light.
- **CNS and PNS:** The central nervous system (CNS) is the brain and spinal cord. The peripheral nervous system (PNS) is all the other nerves, carrying impulses to the CNS from receptors and from the CNS out to effectors. The nervous system's general role is that it coordinates and regulates the body's functions.
- **Homeostasis definition:** Homeostasis is the maintenance of a constant internal environment. Cells only work properly within a narrow range of conditions, so the body must continually detect and correct any drift away from normal, for example the blood glucose concentration.
- **Hormone definition:** A hormone is a chemical substance, produced by a gland, that is carried by the blood and alters the activity of one or more target organs. The glands that make hormones are called endocrine glands.
- **Reflex action:** A reflex action is a rapid, automatic response to a stimulus that does not need conscious thought. Because it bypasses the brain's conscious, decision making parts, it happens faster than a considered movement, which is exactly what protects the body from harm.
- **Sensory, relay and motor neurones:** A sensory neurone carries impulses from a receptor to the CNS. A relay neurone lies within the CNS, connecting a sensory neurone to a motor neurone. A motor neurone carries impulses from the CNS to an effector. Anchor the direction with the initial letters: sensory senses the stimulus and carries the signal in; motor moves the effector and carries the signal out.
- **The coordination pathway:** Every response follows the same chain: stimulus, a change in the environment, is detected by a receptor, which passes information to a coordinator (the central nervous system, or a gland), which passes information to an effector (a muscle or a gland), which produces the response. Write this chain out in order for "describe how the body responds to..." questions.
- **The eye's structures:** A sense organ is a group of receptor cells that respond to a specific stimulus. The eye detects light. The cornea refracts most of the light entering the eye. The iris controls how much light enters by changing the pupil's size. The lens focuses light onto the retina, which contains the receptor cells that detect light. The blind spot is the small area of retina with no receptors, where the optic nerve leaves the eye. The optic nerve carries electrical impulses from the retina to the brain.
- **The pupil reflex:** In dim light the pupil widens (dilates), letting more light in so the retina can form a usable image. In bright light the pupil narrows (constricts), letting less light in and protecting the delicate receptor cells from damage. The response is automatic and is not under conscious control.
- **Tropism definition:** A tropism (tropic response) is a growth response of a plant in which the direction of growth is determined by the direction of the stimulus. Gravitropism (geotropism) is a growth response to gravity; phototropism is a growth response to light.
- **Blood glucose and insulin:** Blood glucose concentration is a Core example of homeostasis. The pancreas releases the hormone insulin, and insulin decreases the blood glucose concentration. When blood glucose rises too high, for example after a sugary meal, insulin is released and brings the level back down toward normal.
- **Comparing nervous and hormonal control:** Nervous control uses an electrical impulse, carried by neurones, and is fast with short-lived effects. Hormonal control uses a chemical (hormone), carried by the bloodstream, and is slower but its effects last longer. Both systems can be involved in homeostasis; the body reaches for whichever tool suits the timescale of the job.
- **Gravitropism:** Gravitropism (geotropism) is a growth response to gravity. A root grows towards gravity, downwards: positive gravitropism, anchoring the plant and reaching water. A shoot grows away from gravity, upwards: negative gravitropism.
- **Job-sort framework for the eye:** Sort every eye-structure question into one of three jobs: refracting (the cornea, mainly), controlling light in (the iris and pupil), or detecting (the retina). Most "what does this structure do" questions are really asking which of these three jobs a structure has.
- **Phototropism:** Phototropism is a growth response to light. A shoot grows towards light: positive phototropism, bringing its leaves more light for photosynthesis. A root grows away from light:

negative phototropism.

- **Synapse:** A synapse is the junction between two neurones, the point where an impulse is passed from one neurone to the next. The two neurones do not actually touch; there is a tiny gap between them.
- **The reflex arc:** The pathway an impulse follows from receptor to effector is the reflex arc: stimulus, receptor, sensory neurone, relay neurone (in the CNS), motor neurone, effector, response. Only the relay neurone lies entirely inside the CNS; the sensory and motor neurones both run between the body and the CNS and so are part of the peripheral nervous system.

EXAM TIPS

TIP The cornea refracts light, the iris and pupil control how much light enters, and the retina detects light with its receptor cells. A wrong option usually swaps a structure's job for one of the other two; check which of the three jobs the question is actually asking about before choosing.

TIP The single most common exam error in this section is reversing the direction of the sensory and motor neurones. Keep them apart with the initial letters: sensory senses the stimulus and carries the signal in toward the CNS; motor moves the effector and carries the signal out from the CNS.

5 Diseases and immunity

KEY CONCEPTS

- **Blood clotting and white blood cells at a wound:** If a pathogen gets in, for example through a cut, *blood clotting* seals the wound, physically closing the entry point, and any bacteria that do get in are engulfed by *white blood cells*. These two defences act specifically at the wound, on top of the general barriers above.
- **Chemical barrier: stomach acid:** *Stomach acid* (hydrochloric acid in gastric juice) kills pathogens swallowed in food and drink, before they can infect the gut. It is the one star example of a *chemical* barrier: it destroys pathogens rather than trapping them.
- **Direct transmission: person to person, nothing in between:** *Direct transmission* passes a pathogen straight from one person to another. Routes: direct contact (touching infected skin, kissing); infected body fluids (blood touching an open cut); across the placenta or in breast milk, mother to baby.
- **Four measures that control the spread of disease:** *Providing clean drinking water* removes pathogens spread indirectly through water. *Treating sewage* stops waste (and its pathogens) reaching water or food. *Washing hands regularly*, before and after handling raw food and after using the toilet, removes pathogens before they pass on. *Careful food handling* (separate raw/cooked equipment, keeping food covered) stops pathogens transferring onto food.
- **Indirect transmission: through the environment:** *Indirect transmission* passes a pathogen through something in the environment on its way to a new host. Routes: contaminated food or water; contaminated surfaces or objects; airborne droplets from coughing or sneezing; animal vectors (an insect carrying the pathogen).
- **Mechanical (physical) barriers:** *Mechanical barriers* physically block or trap pathogens: the *skin*, a tough continuous covering pathogens cannot easily cross when unbroken; *hairs in the nose*, trapping dust and pathogens in the air breathed in; *mucus* in the nose and airways, trapping pathogens and dust (a trapping action, so mechanical, not chemical).
- **Pathogen: the exact definition:** A *pathogen* is a disease-causing organism. The four groups to name with an example each: *bacteria* (food-poisoning bacteria, tuberculosis), *viruses* (influenza, chickenpox, measles), *fungi* (athlete's foot) and *protocista* (the parasite that causes malaria).
- **Transmissible disease versus a diet deficiency:** A *transmissible disease* (communicable or infectious disease) is one in which the pathogen can be passed from one host to another. A disease with no pathogen, such as scurvy (caused by a lack of vitamin C), can never be transmissible, however close the contact between two people.
- **Wound response is local; barriers are general:** Blood clotting and white blood cells engulfing bacteria act specifically at the site of a wound, responding only once a pathogen has already breached the skin there. The mechanical and chemical barriers, by contrast, act generally over the whole body before any breach occurs.

EXAM TIPS

TIP Ask whether a defence *blocks or traps* (mechanical) or *chemically destroys* (chemical). Mucus is secreted, which tempts a "chemical" label, but its job is trapping, so it is mechanical.

TIP Ask: did the pathogen travel through something in the environment (food, water, a surface, the air, an animal) on its way to the new host? Yes means indirect; body-to-body with nothing in between means direct.

TIP "Explain the importance of controlling the spread of disease" wants a measure named *and* the transmission route it blocks. "Providing clean water" alone is a fact; "providing clean water removes pathogens otherwise spread indirectly through contaminated drinking water" is the full explanation.

TIP Transmission across the placenta or in breast milk is counted as *direct*, even though it can feel indirect because it happens inside the mother's body. The pathogen passes straight from one body into another with nothing environmental in between.

KEY CONCEPTS

- **Definition of a drug:** A drug is any substance taken into the body that modifies or affects chemical reactions in the body. The definition has two load bearing parts: the substance must be *taken into the body* (swallowed, inhaled, injected, absorbed), and it must *change* a chemical reaction already happening inside the body.
- **The definition ignores harm, legality and medicine:** The syllabus definition says nothing about whether a substance is helpful, harmful, legal or a medicine. Caffeine, nicotine and alcohol are all drugs by this definition because each one enters the body and changes a chemical reaction, even though none of them is a prescribed medicine. Whether a drug is good or bad for you is a separate, social judgement layered on top of the biology.
- **The one rule to know cold:** Antibiotics kill bacteria but do not affect viruses. This is a standalone fact, separate from "antibiotics treat bacterial infections", because the exam tests it both ways: which organism an antibiotic kills, and why an antibiotic fails against a named viral illness such as influenza, the common cold or measles.
- **What an antibiotic does:** An antibiotic is a drug used to treat *bacterial* infections. It kills the bacteria, or stops them multiplying, so the body's own immune system can clear the rest. Penicillin, discovered by Alexander Fleming in 1928, is the classic example.
- **What resistant means:** Some bacteria are resistant to antibiotics, meaning they are not killed by an antibiotic that would kill most members of their species, even at the correct dose. A resistant infection does not clear up in the normal way, and a doctor may have to try a different antibiotic to find one that still works.

EXAM TIPS

TIP If a question asks you to *define* a drug, write the syllabus sentence word for word: "a substance taken into the body that modifies or affects chemical reactions in the body." If it instead asks you to *explain why substance X is a drug*, name X, state that it is taken into the body, and state which chemical reaction it changes.

TIP A bacterium that survives an antibiotic is *resistant* to that drug, not "immune". "Immune" describes an organism's own defences against a pathogen and belongs to the Diseases and immunity chapter; examiners mark it wrong in this context.

TIP Whenever a question mentions "antibiotic" or "penicillin", the first mental note should be *treats bacterial infections*. A question listing several illnesses and asking which one an antibiotic can treat is really asking you to sort bacterial from viral, and from anything else such as a vitamin deficiency or an allergic reaction.

TIP Wrong options in this topic usually name a completely different biological idea, "a harmful substance", "a microorganism", "a white blood cell", rather than a subtly wrong version of the real definition. If an option describes something belonging to a different chapter (pathogens, immunity), it is the distractor.

TIP The word "infection" by itself is not a complete answer, the exam wants the word *bacterial* stated explicitly. Writing "antibiotics treat infections" without naming the type of infection typically only earns partial credit.

7 Enzymes

KEY FORMULAS

Converting cubic millimetres to cubic centimetres

$$1 \text{ cm}^3 = 1000 \text{ mm}^3$$

Divide a volume calculated in mm^3 by 1000 to convert it to cm^3 . Do the substitution into $V = \pi r^2 h$ in millimetres first, and convert to cm^3 only as the last step.

Enzyme-substrate reaction sequence



Summarises the whole cycle of enzyme action. The enzyme leaves the right hand side chemically identical to how it entered the left hand side, so it is free to repeat the cycle with another substrate molecule.

Radius from diameter

$$r = \frac{d}{2}$$

The radius needed for the cylinder volume formula is always half of the measured diameter. Substituting the diameter directly into r^2 inflates the answer by a factor of four.

Volume of a cylinder (foam column)

$$V = \pi r^2 h$$

Used when a practical, for example a catalase and hydrogen peroxide foam column, asks for the volume of the reaction product treated as a cylinder. Substitute the radius and height in the same unit, then convert the final answer as needed.

KEY CONCEPTS

- **Active site and substrate:** The *active site* is the region on an enzyme's surface, folded into a precise shape, where the molecule it acts on, the *substrate*, binds. Enzyme action depends on the active site's shape being *complementary* to the substrate's shape, in the same way a key fits a specific lock.
- **Catalyst:** A *catalyst* is a substance that increases the rate of a chemical reaction and is not itself changed, used up, or consumed by that reaction. A tiny amount of catalyst can process a large amount of reactant because it is reused rather than consumed.
- **Enzyme:** An *enzyme* is a protein that functions as a biological catalyst. Because every enzyme is a protein, it depends on keeping a precise folded shape; this is why heat and extreme pH, which disrupt that shape, stop an enzyme working.
- **Enzyme-substrate complex:** When a substrate binds into a complementary active site, the temporary structure formed is called the *enzyme-substrate complex*. The products formed no longer fit the active site and are released, leaving the enzyme chemically unchanged and free to bind a fresh substrate molecule; this is why the enzyme itself is never used up.
- **Why every organism depends on enzymes:** Without enzymes, the reactions that keep an organism alive, digesting food, releasing energy, building new molecules, would proceed far too slowly at normal body temperature to sustain life. Enzymes speed these reactions up to a useful rate without the cell having to raise its own temperature.
- **Effect of pH on enzyme activity:** Each enzyme has an *optimum pH* at which it works fastest. Moving away from the optimum pH in either direction, more acidic or more alkaline, reduces activity, and an extreme enough pH denatures the enzyme just as extreme heat does, giving a single hump shaped activity curve.

- **Effect of temperature on enzyme activity:** As temperature rises from a low value, enzyme activity increases up to the enzyme's *optimum temperature*, the temperature at which it works fastest. Beyond the optimum, the heat begins to permanently change the enzyme's shape, and activity falls away, reaching zero once the enzyme is fully denatured.
- **Independent, dependent and controlled variables:** In a temperature or pH investigation, the *independent variable* is the condition deliberately changed, temperature, or pH set using buffer solutions. The *dependent variable* is the measured outcome, for example the height of foam or the time for a colour change. Every other condition, enzyme concentration, substrate concentration, volumes used, must be a *controlled variable*, kept the same across every tube.

EXAM TIPS

TIP Below the optimum temperature, warming an enzyme always makes it work faster. Only past the optimum does further warming make it work slower, because the enzyme starts to denature. Before describing a change in rate, check which side of the optimum the two temperatures being compared are on.

TIP "Killed" and "died" are everyday words that do not appear in a correct answer about enzymes; enzymes are molecules, not living organisms. The precise term is *denatured*, meaning the active site's shape has been permanently changed by heat or extreme pH so the substrate no longer fits. A denatured enzyme does not work again even if cooled or returned to a normal pH.

TIP "Not changed by the reaction" describes only the reaction the catalyst speeds up. An enzyme is still very much affected by heat and extreme pH; do not write that an enzyme cannot be affected by anything just because it is a catalyst.

TIP Buffer solutions are used in a pH investigation because they resist changes to pH, so once a tube is set to a chosen value, that value stays steady for the whole reaction. This keeps pH as the only variable being tested.

8 Excretion in humans

KEY CONCEPTS

- **Excretion, defined against egestion:** *Excretion* is the removal from the body of the toxic or waste products of metabolism (the chemical reactions in cells), together with substances in excess of requirements. *Egestion*, the removal of undigested food (faeces) through the anus, is not excretion, because that food was never absorbed and never took part in the body's own chemical reactions.
- **Renal artery and renal vein carry blood, not urine:** Blood enters each kidney through the *renal artery* and leaves, cleaned, through the *renal vein*. Both vessels carry blood only; the vessel that carries urine away from the kidney is the ureter, which connects to the bladder rather than to the aorta or vena cava.
- **The kidneys excrete urea, excess water and excess ions:** The *kidneys* remove three substances from the blood and expel them dissolved in water as *urine*: *urea*, *excess water*, and *excess ions*. Urea is a genuine toxic waste substance; excess water and excess ions are things the body needs but only in a set amount, so only the surplus is removed.
- **The lungs excrete carbon dioxide:** Every living cell respire, and aerobic respiration produces *carbon dioxide* as a waste product. This carbon dioxide diffuses into the blood, is carried to the *lungs*, and is breathed out. Because it is a genuine waste product of a metabolic reaction that leaves the body, this makes the lung an excretory organ as well as a gas exchange organ.
- **The urinary system: four organs and their jobs:** The *kidneys* (a pair) filter the blood and make urine. The *ureters* (one per kidney) are muscular tubes carrying urine from each kidney down to the bladder. The *bladder* is a muscular, stretchy sac that stores urine until it is released. The *urethra* is the single tube carrying urine from the bladder to the outside of the body.
- **The bladder only stores, never excretes:** The bladder's job is purely storage: it stores urine until it is convenient to release it. It never filters the blood, never carries urine between organs, and is never the organ that excretes a waste substance; that job belongs only to the lungs or the kidneys.
- **Tracing the route: from kidney to bladder to urethra:** Follow a single drop of urine to fix the order in memory: made in the *kidney*, carried down a *ureter*, stored in the *bladder*, and finally released through the *urethra*. There are two ureters (one per kidney, carrying urine to the bladder) and one urethra (carrying urine out of the bladder).
- **Urea is toxic waste; excess water and ions are a managed surplus:** Urea is a genuine toxic waste substance the body cannot use, and it must be removed. Excess water and excess ions are different: water and dissolved mineral salts are things the body actually needs, just not in whatever amount happens to be in the blood at a given moment, so the kidneys remove only the surplus, keeping the blood's composition roughly steady.
- **Why continuous removal of carbon dioxide matters:** Carbon dioxide dissolved in the blood forms an acid, lowering blood pH; enzymes work properly only within a narrow pH range. A rising level of carbon dioxide would make the blood too acidic and disrupt enzyme-controlled reactions throughout the body, so the lungs' continuous removal of it keeps blood pH within safe limits.

EXAM TIPS

TIP Whenever a question names a waste substance and asks which organ excretes it, sort by substance first. *Carbon dioxide* always means the *lungs*; *urea*, *excess water* or *excess ions* always mean the *kidneys*. There is no third excretory organ in the Core specification, so the answer is always one of those two.

TIP A common diagram trap is to mislabel the renal artery or renal vein as a ureter, because all three vessels enter or leave the kidney in roughly the same place. The reliable check is what each one carries: blood vessels carry blood and connect to the aorta or vena cava, while the ureter carries urine and connects to the bladder.

TIP Fix the ureter/urethra pair with a simple hook: there are two ur-*E*ters (*E*ntering the bladder, two of them) and one ure-*TH*RA (the single tube out *TH*Rough to the outside). Say it once out loud and the spelling-to-function pairing tends to stick.

9 Gas exchange in humans

KEY FORMULAS

Depth of breath

$$\text{depth of breath} = \frac{\text{total volume of air per minute}}{\text{breathing rate}}$$

Used to calculate the average volume moved per breath from a total volume of air and a breathing rate given in breaths per minute.

Percentage-point difference

$$\text{change} = \text{value}_1 - \text{value}_2$$

Used to find how many percentage points a gas's composition has changed between inspired and expired air, e.g. oxygen falling from 21% to 16% is a fall of 5 percentage points. This is a subtraction, not a ratio.

Linear interpolation between two data points

$$y \approx y_1 + \frac{x - x_1}{x_2 - x_1}(y_2 - y_1)$$

Used to estimate a value that lies between two plotted data points, for example a vital capacity at a height between two measured heights. When x is exactly halfway between x_1 and x_2 , this reduces to the simple average of y_1 and y_2 .

Ratio comparison ("how many times")

$$\text{ratio} = \frac{\text{larger value}}{\text{smaller value}}$$

Used when a question asks "how many times more/less", as distinct from a percentage-point difference. A percentage-point fall is a subtraction; a "how many times" question needs a division.

KEY CONCEPTS

- **Direction of oxygen and carbon dioxide diffusion:** Blood arriving at the alveoli is low in oxygen and high in carbon dioxide; alveolar air is the reverse. *Oxygen* diffuses from the alveolar air into the blood, and *carbon dioxide* diffuses from the blood into the alveolar air, both down their concentration gradients.
- **Exercise increases both rate and depth:** During exercise, muscles respire faster, needing more oxygen and producing more carbon dioxide. This increases both the *rate* of breathing (breaths per minute) and the *depth* of breathing (volume of air per breath).
- **Gas exchange surface:** A *gas exchange surface* is any surface across which oxygen and carbon dioxide are exchanged between an organism and its environment. The alveolus, the villus and the leaf all use the same design logic to make diffusion as fast as possible.
- **Limewater as the test for carbon dioxide:** *Limewater* turns milky (cloudy) when carbon dioxide is bubbled through it. In the standard apparatus, inspired air is drawn through one tube of limewater and expired air is pushed through another; the expired-air tube turns milky much faster because expired air contains far more carbon dioxide.
- **Order of structures from nose to alveoli:** Air travels *nose* → *larynx* → *trachea* → *bronchi* → *bronchioles* → *alveoli*. The trachea divides into two bronchi, one per lung; each bronchus branches repeatedly into bronchioles, which end in alveoli.
- **Table of composition changes:** Compared with inspired air, expired air has *less oxygen* (~21% to ~16%), *more carbon dioxide* (~0.04% to ~4%) and *more water vapour*; *nitrogen* stays at ~78% because the body neither uses nor produces it.

- **The alveoli as the gas exchange surface:** The *alveoli* are hundreds of millions of tiny air sacs, each with a wall one cell thick and wrapped in a dense network of capillaries, giving the lungs roughly 70 m² of exchange surface.
- **The four features of an efficient exchange surface:** An efficient gas exchange surface always has a *large surface area*, a *thin wall* (short diffusion distance), a *good blood supply* (maintains a steep concentration gradient) and a *moist surface* (lets oxygen dissolve before crossing). Every feature exists to speed up diffusion.
- **Apparatus and fair-test control variables:** A person breathes through a two-way system of tubes so that inspired air is drawn through one tube of limewater and expired air is pushed through another. For a fair comparison, the *volume and concentration of limewater* and the *volume of air* passed through must be kept the same in each tube.
- **Breathing stays raised after exercise:** After exercise stops, breathing does not return to normal instantly; it stays fast and deep for a while, because the body still needs extra oxygen and must clear the carbon dioxide built up during the activity.
- **Identifying ribs, intercostal muscles and diaphragm:** *Ribs* are curved bones forming a protective cage around the lungs. *Intercostal muscles* fill the gaps between adjacent ribs. The *diaphragm* is a dome-shaped sheet of muscle forming the floor of the thorax, separating chest from abdomen.

EXAM TIPS

TIP "Describe the features of an efficient gas exchange surface" hands out one mark per feature named correctly (large surface area, thin wall, good blood supply, moist surface). Do not fold two features into one sentence, and avoid vague answers such as "the lungs work well".

TIP Nitrogen is unchanged at ~78% in both inspired and expired air, and remains the single biggest gas in both. A common wrong answer claims nitrogen "rises sharply" or that expired air is "mostly carbon dioxide"; carbon dioxide rises a hundredfold in relative terms but is still only ~4% overall.

TIP The *oesophagus* runs next to the trachea but carries food to the stomach, not air to the lungs. On a labelled diagram, the tube leading towards the lungs is the trachea; the one leading towards the stomach is the oesophagus.

TIP At Core you are expected to *identify* the ribs, intercostal muscles and diaphragm on a diagram and state their general role in breathing, not to explain the detailed sequence of muscle contraction and relaxation.

TIP Do not describe the alveoli as "absorbing" or "pumping" gases. Every gas movement across the alveolar wall is passive diffusion down a concentration gradient; the energy nearby is spent on breathing and on the heart pumping blood, which keep the gradients steep, not on the crossing itself.

TIP For "estimate from the graph" questions, first check where the target value sits between the given points. Halfway across in one variable means halfway up (or down) in the other; a quarter of the way across means a quarter of the way up.

TIP "What variable must be controlled for a fair test" answers should name a quantity that could otherwise differ between the two tubes, such as the volume or concentration of limewater or the volume of air passed through. "Room temperature" is not the kind of variable the mark scheme wants here.

10 Human influences on ecosystems

KEY CONCEPTS

- **Biodegradable and non-biodegradable:** A biodegradable material can be broken down by decomposers (bacteria and fungi). A non-biodegradable material cannot, so it persists in the environment for decades or centuries. Plastic is the classic non-biodegradable pollutant; it gradually fragments into microplastics that small aquatic animals eat and cannot remove.
- **Biodiversity: definition:** Biodiversity is the number of different species present in an area. It is the central measure that falls when a habitat is destroyed.
- **Carbon dioxide and methane: sources:** Carbon dioxide is released by the combustion of fossil fuels and by deforestation (burning or decay of felled trees, plus the loss of the photosynthesis that used to remove it). Methane is released from cattle, as a by-product of digestion, and from rice paddy fields.
- **Deforestation: definition:** Deforestation is the large-scale removal of forest, usually for timber or to clear land for farming, mining or building.
- **Endangered and extinction: three factors:** An endangered species is one whose numbers have fallen so low it is at risk of extinction, dying out completely and permanently. Three factors commonly cause organisms to become endangered: habitat loss, hunting, and pollution.
- **Eutrophication: the five-step chain:** Fertiliser or untreated sewage adds nitrate and phosphate ions to water. Algae and water plants grow explosively, forming an algal bloom. The bloom blocks light from plants below the surface, which die. Decomposing bacteria feed on the dead plant material and multiply rapidly, respiring aerobically. The huge bacterial population uses up the dissolved oxygen, so fish and other aquatic animals suffocate and die.
- **Greenhouse effect and enhanced greenhouse effect:** The greenhouse effect keeps Earth warm: gases including carbon dioxide and methane absorb heat radiated from the warmed Earth and re-radiate some of it back to the surface. The enhanced greenhouse effect is the extra warming caused by human activity raising the concentration of these gases, so more heat is trapped and average global temperatures rise.
- **Habitat destruction: definition and three reasons:** A habitat is the place where an organism lives. Habitat destruction is the damage to or complete removal of habitats by human activity. Humans destroy habitats for three broad reasons: increased land use for farming, housing and industry; extraction of natural resources such as mining and timber; and pollution, which degrades a habitat even where the land is not physically cleared.
- **Intensive livestock production: advantages and disadvantages:** Intensive livestock production keeps large numbers of animals in a small, controlled space. Advantages: more meat, milk or eggs per unit of feed and land because animals kept warm and confined lose less energy to movement and heat, so more of their food energy goes into growth; lower costs; easier control of diet and health. Disadvantages: little of the land is left as natural habitat, and crowding lets disease spread easily between animals.
- **Methods of increasing food production:** Humans raise food production by growing monocultures, applying chemical fertilisers, using insecticides and herbicides, using intensive livestock production, and using modern agricultural machinery and selective breeding. Each method raises yield but carries a cost.
- **Monoculture: advantages and disadvantages:** A monoculture is growing one crop species, usually one variety, over a large area. Advantages: very high yield per area, efficient machinery use in a single pass, lower labour costs. Disadvantages: every plant is genetically near-identical so a new disease can destroy the whole field, the field supports low biodiversity, and repeated growth of the same crop depletes the specific mineral ions that crop needs.
- **Pollution: definition and sources of water pollution:** Pollution is the addition to the environment of substances that harm living organisms. Water pollution comes from chemical waste from industry, discarded rubbish (particularly plastics), untreated sewage, and fertiliser washed off farmland.
- **Species-specific conservation: seed banks and captive breeding:** Seed banks are collections of seeds from many plant varieties, stored dried and frozen as a long-term backup of plant genetic diversity, since seeds stay viable for decades without needing growing space. Captive breeding programmes breed endangered animals in zoos or specialised centres, aiming to increase their numbers and reintroduce individuals to protected wild habitat.
- **Sustainable resource: definition and management methods:** A sustainable resource is produced or replaced as rapidly as it is removed from the environment, so it does not run out. Forests are

managed sustainably by replanting a new tree for every mature tree felled. Fish stocks are managed sustainably using quotas, net mesh-size limits, closed seasons and protected areas.

- **Three undesirable effects of deforestation:** Deforestation causes loss of habitat and biodiversity, because the food and shelter of many species disappear at once; soil erosion, because tree roots no longer bind the soil so heavy rain washes the fertile topsoil away; and increased atmospheric carbon dioxide, because living trees remove carbon dioxide by photosynthesis and burning or rotting felled timber releases the carbon they had stored.
- **Conservation methods: habitats, legislation, education:** Habitat-scale methods, protected habitats such as national parks and marine protected areas, are generally the most efficient because protecting a habitat conserves an entire community of species at once. Legislation includes laws against hunting and trade in endangered species. Education helps people understand why conservation matters and encourages behaviour that supports it.
- **Habitat destruction disrupts food webs:** Organisms are linked by feeding relationships, so removing one species from a habitat can remove the food source of another. A pollinating insect removed from a habitat means the flower it pollinated produces fewer seeds; a herbivore's food plant removed means the herbivore population falls, and so does the population of whatever preys on that herbivore.
- **Microplastics build up along a food chain:** Plastic gradually fragments, through wave action and sunlight rather than decomposition, into tiny microplastics. Small aquatic animals eat these fragments and cannot digest or remove them, so the microplastics build up most in the animals at the top of the food chain.
- **Why confinement raises meat yield:** Chickens or other livestock kept warm and unable to move much use less energy on movement and on keeping warm. Energy that would otherwise be lost that way is instead available for growth, so more of the food eaten is converted into body mass.
- **Why disease destroys a whole monoculture:** Every plant in a monoculture is the same variety, so they are genetically identical or nearly so. If one plant is susceptible to a new disease, every other plant shares exactly the same susceptibility, so there is no resistant individual to slow the infection down, and the plants growing close together let it spread from plant to plant across the whole field.

EXAM TIPS

TIP Biodiversity is the number of *different* species, not the number of individuals. A field of a million wheat plants has a huge population but very low biodiversity. Writing "biodiversity means lots of organisms" instead of "lots of different species" is a recurring, penalised error.

TIP A fertiliser *feeds* the crop, adding mineral ions, and does nothing to weeds. A herbicide *kills weeds*. An insecticide *kills insect pests*. Writing that "fertiliser kills weeds" is one of the most common single-mark losses in this topic.

TIP Dissolved oxygen is used up by decomposing bacteria respiring, not by the algae or plants "breathing it in" and not by the sewage or fertiliser directly. Name the bacteria and say they respire aerobically.

TIP Education is described as increasing the chance of successful conservation rather than being a conservation method on its own, because conservation works better when people understand why a species needs protecting and change their behaviour accordingly.

TIP The classic error on "state three effects of deforestation" is giving three versions of the same effect, such as "animals die", "plants die", "species lost", which are all the single idea of lost biodiversity. A full-marks answer names three genuinely different effects: biodiversity loss, soil erosion, and increased atmospheric carbon dioxide.

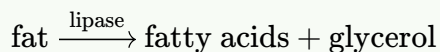
TIP Do not confuse the enhanced greenhouse effect, carbon dioxide and methane trapping heat, with the destruction of the ozone layer, a separate problem caused by different chemicals that lets through harmful ultraviolet radiation. Core does not examine the ozone layer in this chapter.

TIP "Why does disease spread so easily through a monoculture?" always wants two linked ideas: the plants are genetically identical, so none are resistant, and they are grown close together, so the disease spreads easily between them. Give both for full marks.

11 Human nutrition

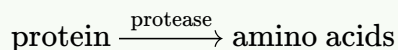
KEY FORMULAS

Fat digestion by lipase



Used to state what lipase does to fat. Lipase is made in the pancreas and acts in the small intestine.

Protein digestion by protease



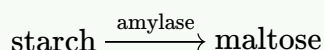
Used to state what protease does to protein. Core recognises two proteases: one from the stomach lining, acting in the stomach in acidic conditions, and one from the pancreas, acting in the small intestine.

Scaling a per-100 g nutrient value to the mass eaten

$$\text{amount eaten} = \text{value per 100 g} \times \frac{\text{mass eaten (g)}}{100}$$

Used whenever a food label gives a nutrient content "per 100 g" and the question describes a different mass eaten. Find the scale factor between the mass eaten and 100 g, then multiply, before doing any further subtraction against a daily requirement.

Starch digestion by amylase



Used to state what amylase does to starch. Amylase is secreted by the salivary glands (acts in the mouth) and the pancreas (acts in the small intestine).

KEY CONCEPTS

- **Balanced diet:** A *balanced diet* contains all the nutrient groups the body needs, in the right proportions and in enough quantity to supply energy and materials, neither too much nor too little of any one nutrient. A diet with plenty of variety but too much or too little of one nutrient is still unbalanced.
- **Chemical digestion breaks large insoluble molecules into small soluble ones:** *Chemical digestion* uses enzymes to break large, insoluble food molecules into small, soluble molecules. Physical digestion changes only size and shape; chemical digestion breaks actual chemical bonds, so the food comes out as a genuinely different, smaller molecule.
- **Digestive organs and their main functions:** Food travels mouth, oesophagus, stomach, small intestine, large intestine/colon, rectum, anus in that order. The liver makes bile; the gall bladder stores it; the pancreas makes amylase, protease, and lipase, all released into the small intestine.
- **Four types of human teeth:** *Incisors* (chisel-shaped, at the front) cut and bite food. *Canines* (pointed) tear tough food. *Premolars* (broad, ridged) crush and begin grinding. *Molars* (broad, flat, largest, at the back) grind and chew food into small pieces.
- **Ingestion, digestion, absorption, egestion:** The digestive system is a single tube, the *alimentary canal*, running from mouth to anus. Four stages happen in order: *ingestion* (taking food into the mouth), *digestion* (breakdown of large molecules into smaller ones), *absorption* (movement of small soluble molecules into the blood), and *egestion* (passing undigested food out as faeces, through the anus).
- **Physical digestion increases surface area:** *Physical digestion* breaks food into smaller pieces by mechanical means without changing the food molecules themselves. Its purpose is to increase the surface area of food, which increases the rate at which enzymes can act on it in chemical digestion.

- **Rickets:** *Rickets* is caused by a lack of vitamin D. Vitamin D is needed for the body to absorb and use calcium, so a long-term shortage means bones fail to harden normally and become soft and weak, most visibly as bowed leg bones in children.
- **Scurvy:** *Scurvy* is caused by a lack of vitamin C. Vitamin C keeps connective tissue healthy and is needed for wound healing, so a long-term shortage causes swollen, bleeding gums and unusually slow wound healing.
- **The small intestine is the main site of absorption:** *Absorption* is the movement of the small, soluble molecules produced by digestion out of the gut and into the blood. The small intestine is the region of the alimentary canal where nutrients are absorbed.
- **Assimilation:** *Assimilation* is the uptake and use of absorbed nutrients by the body's cells, the step that happens after absorption. Absorption gets a molecule into the blood; assimilation is the cells actually using it, two separate steps tested as two separate marks.
- **Functions of hydrochloric acid:** The stomach lining releases hydrochloric acid, which kills many of the pathogens taken in with food and provides the optimum acidic pH for the stomach's protease to work at its best.
- **The stomach's role in physical digestion:** The stomach's muscular walls contract to churn food, mixing it with gastric juice and continuously breaking large lumps into smaller ones, separately from the chemical digestion that is also happening there.
- **Tooth structure:** Every tooth shares the same structure: *enamel* (hard, white, outer covering of the crown), *dentine* (beneath the enamel, forming most of the tooth's bulk), the *pulp cavity* (central, containing nerves and blood vessels), and the *gum* (soft tissue surrounding the neck of the tooth).
- **Water absorption in the small intestine and colon:** Most water is absorbed in the small intestine, with some further water absorbed in the colon, which is why material reaching the rectum is far more solid than the watery mixture that first left the stomach.

EXAM TIPS

TIP The liver makes bile and the gall bladder stores it; bile emulsifies fats once released into the small intestine. Exam options frequently test whether bile is mistaken for an enzyme; it is not one.

TIP Fat carries more energy per gram and is the body's concentrated energy store, but *carbohydrate* is the nutrient the body uses first and in the largest quantity for everyday energy. If a question asks for the "main" energy source with no other qualification, the answer is carbohydrate, not fat.

TIP Learn this as a fixed pair: the colon absorbs water only, while the small intestine absorbs digested food *and* water. Wrong options often swap these two roles or claim the colon absorbs digested food.

TIP Rickets is really a *calcium-use* problem caused by a vitamin D shortage: vitamin D is the nutrient that controls how much dietary calcium actually gets absorbed. A child with plenty of dietary calcium but almost no vitamin D can still develop soft bones.

TIP Iodine solution turns blue-black in the presence of starch and stays yellow-brown if no starch is present. A tube where amylase has had time to act should show *less* colour change, not more, because the starch has been digested away.

12 Inheritance

KEY FORMULAS

Sex determination: expected 1:1 ratio

$X\text{-sperm} + X\text{-egg} \rightarrow XX$ (female); $Y\text{-sperm} + X\text{-egg} \rightarrow XY$ (male)

Because roughly half of all sperm carry an X and half carry a Y, the expected ratio of female to male offspring in a large population is close to 1:1.

Two-heterozygote cross ratio

$Tt \times Tt \rightarrow 1TT : 2Tt : 1tt \Rightarrow 3 \text{ dominant} : 1 \text{ recessive}$

Use for any cross between two heterozygous parents for the same gene. Always derive the ratio from a Punnett square rather than quoting it, since the exam awards marks for the working.

Heterozygote crossed with homozygous recessive

$Tt \times tt \rightarrow 1Tt : 1tt \Rightarrow 1 \text{ dominant} : 1 \text{ recessive}$

Use for a cross between a heterozygote and a homozygous recessive individual (sometimes called a test cross). The recessive parent can only ever contribute the recessive allele.

Probability from a Punnett square

$$P(\text{phenotype}) = \frac{\text{boxes showing that phenotype}}{\text{total boxes}}$$

For a cross between two heterozygotes there are always 4 boxes, so probabilities come in quarters. Give the answer as a fraction, decimal or percentage, matching whatever form the question asks for.

KEY CONCEPTS

- **A gene codes for a protein:** A *gene* is a length of DNA that codes for a particular *protein*. If a question asks what a gene codes for, the required word is protein, not "a characteristic" or "a feature".
- **Allele: an alternative form of a gene:** An *allele* is an alternative form of a gene. A gene names the feature being controlled (for example the pea-height gene); an allele names one particular version of the instructions for that feature (for example the tall-pea allele).
- **Chromosome, gene and DNA: the size hierarchy:** The nucleus contains *chromosomes*; a chromosome is *made of DNA*; a *gene* is a length of that DNA. Keep the terms in this strict order of size when answering a definition question: nucleus contains chromosomes, chromosome is made of DNA, gene is a length of DNA.
- **Dominant vs recessive allele:** A *dominant* allele is expressed in the phenotype whenever it is present, even with only one copy. A *recessive* allele is only expressed when two copies are present (homozygous), since a dominant allele present alongside it would mask it.
- **Genotype vs phenotype:** *Genotype* is the genetic make-up of an organism in terms of the alleles present, written as a pair of letters (for example Tt). *Phenotype* is the observable characteristics of an organism, described in words (for example "tall").
- **Homozygous vs heterozygous:** *Homozygous* means an organism has two identical alleles of a gene (TT or tt). *Heterozygous* means it has two different alleles (Tt). Two homozygous individuals of the same genotype bred together are *pure-breeding*; a heterozygous individual is not.
- **Inheritance: transmission of genetic information:** *Inheritance* is the transmission of genetic information from generation to generation. Offspring receive alleles from both parents, one of each gene from each parent, so they resemble but are never identical to either parent.

- **Sex chromosomes: XX female, XY male:** In humans, a *female* has genotype **XX** (two X chromosomes); a *male* has genotype **XY** (one X and one Y chromosome). Every egg carries an X; a sperm carries either an X or a Y.
- **Gene vs allele: general to specific:** A gene names the feature being controlled (general); an allele names one particular version of the instructions for that feature (specific). Every gene has at least two alleles across a population, though any one individual only ever carries two of them.
- **Pedigree diagram symbols:** A pedigree diagram is a family tree recording which individuals show a characteristic across generations. A square represents a male, a circle a female, and a shaded symbol represents an individual who shows the characteristic (is affected).
- **Pure-breeding depends on being homozygous:** Two homozygous individuals of the same genotype bred together are pure-breeding, every offspring matches the parents' genotype. A heterozygous individual is not pure-breeding, since it can pass on either of its two different alleles, so its offspring can differ from it.

EXAM TIPS

TIP When one parent is homozygous, list its gametes as the same letter written twice, not two different letters. Writing two different gametes for a homozygous parent produces the wrong Punnett square and the wrong ratio.

TIP To find out whether a dominant-phenotype individual is homozygous or heterozygous, cross it with a known homozygous recessive and examine the offspring. If any recessive-phenotype offspring appear, the unknown parent must have been heterozygous.

TIP Every egg is identical in its sex-chromosome content, always X, while sperm come in two types, X or Y. A common wrong answer blames the mother's genes for a child's sex; it is the type of sperm that varies and therefore decides it.

13 Movement into and out of cells

KEY FORMULAS

Direction of active transport (word relation)

lower concentration → higher concentration

Active transport moves particles against their concentration gradient, the opposite direction to diffusion, and this uphill movement is only possible because it is powered by energy from respiration.

Percentage change in mass

$$\text{percentage change in mass} = \frac{\text{final mass} - \text{initial mass}}{\text{initial mass}} \times 100\%$$

Used to compare potato pieces of different starting mass fairly in an osmosis practical. A positive result means the piece gained water; a negative result means it lost water.

Direction of diffusion (word relation)

higher concentration → lower concentration

Diffusion always runs down the concentration gradient, from where particles are more crowded to where they are less crowded, driven only by the particles' own kinetic energy.

Making a diluted solution

$$C_1V_1 = C_2V_2$$

Used to calculate the volume of a stock solution needed to make a specified volume of a more dilute solution, where C_1 , V_1 are the concentration and volume of the stock and C_2 , V_2 are the concentration and volume required.

KEY CONCEPTS

- **Definition of active transport:** Active transport is the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration (against a concentration gradient), using *energy released by respiration*.
- **Definition of diffusion:** Diffusion is the *net* movement of particles from a region of their higher concentration to a region of their lower concentration (down a concentration gradient), as a result of their *random* movement. It needs no membrane and no energy from the cell.
- **Definition of osmosis:** Osmosis is the net movement of water molecules from a region of higher water concentration (a dilute solution) to a region of lower water concentration (a more concentrated solution), through a *partially permeable membrane*. Only water moves; like diffusion it is *passive* and needs no energy from the cell.
- **Diffusion and gas exchange at a respiring cell:** Aerobic respiration continuously uses up oxygen and produces carbon dioxide inside a cell, keeping oxygen concentration *lower* inside the cell than in the blood and carbon dioxide *higher* inside than in the blood. Diffusion always runs from high to low concentration, so oxygen diffuses *into* the respiring cell and carbon dioxide diffuses *out* of it.
- **Osmosis in animal cells:** An animal cell such as a red blood cell has no cell wall. In a solution of higher water concentration than its contents, water enters and the cell *bursts*. In a solution of lower water concentration, water leaves and the cell *shrinks and shrivels*. In a solution of equal water concentration, there is no net movement and the cell keeps its normal shape.
- **Osmosis in plant cells:** A plant cell's rigid cellulose *cell wall* resists the pressure of entering water, so in a solution of higher water concentration the cell becomes *swollen and firm* rather than bursting. In a very concentrated solution, so much water leaves that the membrane *pulls away from the cell wall*, leaving a visible gap; the wall itself does not shrink.

- **Water concentration versus solute concentration:** A *concentrated* solution has a *high solute* concentration but a *low water* concentration; a *dilute* solution has a *low solute* concentration but a *high water* concentration. Water always moves toward the concentrated (solute) side, which is the same as moving toward the region of lower water concentration.
- **Which substances cross the membrane by diffusion:** Small, uncharged molecules such as *oxygen* and *carbon dioxide* diffuse across the cell membrane easily. Large molecules and charged particles (ions) cross far less readily and usually need a carrier protein or active transport. Dialysis (Visking) tubing models this: its pores let small molecules such as glucose through but hold back large molecules such as starch.
- **Net movement versus random motion at equilibrium:** At equilibrium, particles do not stop moving. They continue to move randomly at the same speed, but equal numbers now cross in each direction, so there is no further *net* movement. "Diffusion stops at equilibrium" is inaccurate; "net diffusion stops at equilibrium" is correct.
- **Water as the body's solvent:** Most of the chemistry of life happens in solution. Water is the solvent that carries dissolved substances such as glucose and mineral ions around an organism, in blood plasma in animals and in sap in plants; a substance must usually be dissolved before it can be transported.
- **Waterlogged soil and reduced active transport:** *Waterlogged soil* contains very little oxygen, which slows aerobic respiration in root cells, releasing less energy. Since active transport depends on that energy, less active transport happens and the plant absorbs *fewer* mineral ions, even though the ions are still present in the soil.

EXAM TIPS

TIP Diffusion moves particles *down* the gradient and needs *no* energy. Active transport moves particles *against* the gradient and needs energy from respiration. Whenever a question pairs "against the gradient" with "uses energy", the answer is active transport.

TIP Osmosis, like all diffusion, is a *passive* process powered by the random motion of water molecules, never by respiration. A statement pairing water movement with "uses energy" or "against the gradient" describes active transport, not osmosis.

TIP If a cell is placed in a solution with the same water concentration as its contents, water molecules still cross the membrane in both directions at equal rates; there is simply no *net* movement, so the cell's mass and shape stay unchanged.

14 Organisation of the organism

KEY FORMULAS

Actual size from image size and magnification

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

Rearrangement of the magnification formula. Use whenever an image size and a magnification are given and the real, physical size is needed. Image size always goes on top of the fraction.

Magnification

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

Magnification is a ratio of two lengths in the *same* units, so it has no units of its own. Use to find how many times larger (or smaller) an image is than the real specimen.

Converting millimetres to micrometres

$$1 \text{ mm} = 1000 \mu\text{m}$$

To express a millimetre answer in micrometres, multiply by 1000. Do the magnification division first, entirely in millimetres, and convert to micrometres only as the final step.

Image size from actual size and magnification

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

The third rearrangement of the magnification formula. Use when the actual size and the magnification are known and the size of the image needs to be predicted or checked.

KEY CONCEPTS

- **Animal cell structures and functions:** Every animal cell has five structures. *Cell membrane*: partially permeable boundary that controls which substances enter and leave. *Cytoplasm*: jelly like substance where chemical reactions occur. *Nucleus*: contains the genetic material and controls the cell's activities. *Mitochondria*: site of aerobic respiration, releasing energy from glucose. *Ribosomes*: site of protein synthesis.
- **Bacterial cell structure:** A bacterial cell has a cell wall, a cell membrane, cytoplasm, ribosomes, and a single loop of circular DNA lying free in the cytoplasm. It has no nucleus, no mitochondria, no chloroplasts, and no permanent vacuole; respiration reactions occur directly in the cytoplasm and across the membrane instead.
- **Cell theory:** All living organisms are composed of cells. The cell is the basic unit of structure and function in living organisms. New cells are produced only by the division of existing cells; no cell is ever built from raw chemicals.
- **Cell, tissue, organ, organ system, organism:** A *cell* is the basic structural and functional unit. A *tissue* is a group of similar cells working together for one function. An *organ* is made of several different tissues working together for one overall function. An *organ system* is a group of organs working together for a broad function. An *organism* is a complete, independent living thing.
- **Eukaryotic and prokaryotic cells:** *Eukaryotic* cells (animal, plant) have their genetic material enclosed inside a nuclear membrane, forming a true nucleus. *Prokaryotic* cells (bacterial) have no nuclear membrane; their genetic material lies free in the cytoplasm as a single circular loop.
- **Plant cell: the three extra structures:** A plant cell has every animal cell structure plus three extras. *Cell wall*: rigid cellulose layer giving fixed shape and support, freely permeable. *Chloroplasts*: contain

chlorophyll and are the site of photosynthesis; not every plant cell has them. *Permanent vacuole*: fluid filled sac containing cell sap; its outward turgor pressure keeps the cell firm.

- **Six specialised cells and their jobs:** *Ciliated cell*: lines the trachea and bronchi; beating cilia sweep mucus and trapped particles out of the airways. *Root hair cell*: long thin extension increases surface area for absorbing water and mineral ions. *Palisade mesophyll cell*: packed with chloroplasts for photosynthesis near the leaf surface. *Neurone*: long axon conducts electrical impulses over long distances. *Red blood cell*: no nucleus and packed with haemoglobin to carry oxygen. *Sperm and egg cell*: sperm is small with a flagellum and many mitochondria for swimming; the egg is large with food reserves for early development.
- **New cells come only from division:** New cells are produced only by the division of existing cells, never built from raw chemicals. Division produces two daughter cells genetically identical to the parent, each with a faithful copy of the original DNA, which is essential for growth and tissue repair.

EXAM TIPS

TIP Glance at whether the magnification is above or below 1 before dividing. Magnification greater than 1: the actual size is *smaller* than the image size. Magnification less than 1: the actual size is *larger* than the image size, as with a shrunk photograph. If the answer goes the wrong way, the division has been done backwards.

TIP On an unlabelled diagram, check for a membrane bound nucleus first. No visible nucleus means the cell is prokaryotic (bacterial). A clear nucleus means the cell is eukaryotic (plant or animal); then check for a cell wall plus chloroplasts to decide plant versus animal.

TIP Before answering a comparison question, sort every named structure into *shared* (cell membrane, cytoplasm, nucleus, mitochondria, ribosomes; found in plant and animal cells), *plant only* (cell wall, chloroplasts, permanent vacuole), or *bacterial only* (circular DNA, unenclosed). Most wrong options mix a structure from the wrong bucket into an otherwise correct pair.

TIP Not every plant cell contains chloroplasts (root cells, for instance, have none), so testing for a *cell wall* is a more reliable way to identify a plant cell than testing for chloroplasts.

TIP An organ (for example the stomach, built from several tissues) and the organ system it belongs to (for example the digestive system, built from several organs) are two different levels. Naming one when the question means the other is a common source of lost marks.

TIP A bacterial cell still has genetic material, its single circular chromosome; it is simply not wrapped in a nuclear membrane. Writing "bacteria have no genetic material" instead of "bacteria have no nucleus" is a costly slip.

15 Organisms and their environment

KEY CONCEPTS

- **Carbon cycle processes:** Photosynthesis removes carbon dioxide from the atmosphere and fixes its carbon into organic molecules. Respiration, by every living organism, returns carbon dioxide to the atmosphere. Feeding passes carbon along food chains. Decomposition, by bacteria and fungi feeding on dead material, returns carbon dioxide to the air. Combustion of fossil fuels or wood also returns carbon dioxide, releasing carbon that had been locked away for millions of years.
- **Energy flow through an ecosystem:** Once chemical energy is locked into a producer, it passes from organism to organism along a food chain, always starting with a producer because only a producer can capture new energy from outside the living world. Energy is lost at every step, mainly as heat from respiration, and eventually leaves the ecosystem entirely; unlike carbon, energy is never recycled.
- **Energy flows, carbon cycles:** Energy flows through an ecosystem in one direction and is eventually lost as heat, so the Sun must constantly resupply it. Carbon, by contrast, is recycled: the same atoms are used again and again, moving between carbon dioxide in the air and organic molecules in living things.
- **Factors affecting population size:** A population's rate of growth is affected by food supply (more food, faster growth), competition for limited resources, predation (more predators lowers the prey population), disease (spreads faster in a large crowded population), and human activity such as overfishing, hunting, pollution or habitat destruction.
- **Population, community and ecosystem:** A population is a group of organisms of one species living in the same area at the same time. A community is all the populations of different species living together. An ecosystem is a unit containing the community of organisms and their non-living environment, interacting together.
- **Principal source of energy:** The principal source of energy input to biological systems is the Sun. Light energy falls on green plants, algae and some bacteria, and a small fraction is captured during photosynthesis and converted into chemical energy stored in glucose and other organic molecules.
- **Producer, consumer, herbivore, carnivore, decomposer:** A producer makes its own organic nutrients, usually by photosynthesis. A consumer gets its energy by feeding on other organisms. A herbivore eats plants; a carnivore eats other animals. A decomposer gets its energy from dead or waste organic material; the main decomposers are bacteria and fungi. An organism that eats both plants and animals has no single label and must be classified by what it is eating in each specific feeding link.
- **Pyramid of numbers and pyramid of biomass:** An ecological pyramid stacks one bar per trophic level, producer at the bottom. A pyramid of numbers has bar width proportional to the number of organisms; it can be inverted when one large organism supports many small ones. A pyramid of biomass has bar width proportional to the mass of living material; because it accounts for size, it is almost always a true pyramid shape.
- **Trophic levels and consumer names:** A trophic level is an organism's position in a food chain, food web or pyramid. Trophic level 1 is the producer; trophic level 2 is the primary consumer (a herbivore); trophic level 3 is the secondary consumer; trophic level 4 is the tertiary consumer; trophic level 5, where a chain runs this far, is the quaternary consumer.
- **The sigmoid population growth curve:** When a population grows with limited resources, its numbers trace an S-shaped curve with three phases. The lag phase is a slow start while few individuals establish and begin reproducing. The exponential (log) phase is rapid, accelerating growth while resources are still plentiful. The stationary phase levels off at the carrying capacity, the maximum sustainable population size.
- **Why a pyramid of biomass is usually preferred:** A pyramid of numbers only counts heads, so it cannot tell a giant tree from a tiny bacterium and can be misleadingly inverted. A pyramid of biomass measures the total mass of living material at each level, a much better proxy for the energy and resource that level represents, so it is far less often inverted and gives a more realistic picture.

EXAM TIPS

TIP Every arrow in a food chain represents the transfer of energy and points from the organism being eaten to the organism doing the eating. "Grass to grasshopper" means the grasshopper gains the energy. Drawing an arrow backwards, from predator to prey, is the single most common food-chain error.

TIP "Principal source of energy" always means the Sun, however the question phrases it (light energy, solar energy, sunlight). Photosynthesis is the process a producer uses to capture that energy, not the source itself.

TIP To decide whether a change speeds up or slows down population growth, ask whether it gives the population more of something it needs (food, space) or removes individuals (predation, disease, human activity). More resources mean faster growth; more removals mean slower growth or decline.

TIP Photosynthesis removes carbon dioxide and happens only in the light, only in organisms with chlorophyll. Respiration returns carbon dioxide and happens all the time, in every living organism, day and night, including plants.

TIP Both axes must be labelled with the quantity and units. The scale must let the bars fill most of the grid. For grouped continuous data, such as depth ranges, bars are drawn with no gaps between them. Missing labels or a poorly chosen scale can lose marks even when every bar height is correct.

TIP A food web is a network of interconnected food chains. If a predator is removed, the species it ate tend to increase; if a prey species declines (naturally or through human activity such as pesticides, hunting or habitat destruction), its predators must switch prey or decline too. Human impact questions use the same arrow-tracing logic as any other food-web question.

16 Plant nutrition

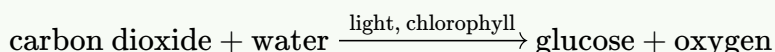
KEY FORMULAS

Rate of photosynthesis by bubble count

$$\text{rate (bubbles/min)} = \frac{\text{number of bubbles counted}}{\text{time taken (min)}}$$

Used to standardise gas bubble counts from an aquatic plant taken over different time intervals, so results at different light intensities or carbon dioxide concentrations can be compared fairly.

Word equation for photosynthesis



Reactants (carbon dioxide, water) sit on the left; products (glucose, oxygen) sit on the right. Light and chlorophyll are written above the arrow because neither is chemically consumed.

Percentage change (for comparing rates)

$$\text{percentage change} = \frac{\text{change}}{\text{original value}} \times 100$$

Used to express a rise or fall in bubble count, gas volume or any measured rate as a percentage; state which reading is the "original" (the denominator) before calculating.

KEY CONCEPTS

- **Chlorophyll's location and role:** Chlorophyll is a green pigment held inside *chloroplasts*, found in large numbers in leaf cells (mainly palisade mesophyll). It transfers light energy into chemical energy for the synthesis of carbohydrates; it is not itself used up and does not "make food" directly.
- **Definition of photosynthesis:** Photosynthesis is the manufacture of carbohydrates from the raw materials carbon dioxide and water, using energy from light. A plant is *autotrophic* because it makes its own organic food from inorganic raw materials, unlike the *heterotrophic* animals and fungi that take in ready-made food.
- **Destarching and the four-step starch test:** Destarching (24 to 48 hours in the dark) removes existing starch so any starch found afterwards was made during the experiment. The starch test: boil the leaf in water (kills cells), boil in ethanol in a water bath with the Bunsen off (removes chlorophyll), dip in warm water (softens), add iodine solution (orange-brown to blue-black shows starch).
- **Fates of the glucose made in photosynthesis:** Glucose is used in respiration for energy, converted to insoluble *starch* for storage, converted to soluble *sucrose* for transport in the phloem, built into *cellulose* for new cell walls, or combined with nitrate ions to make amino acids and proteins.
- **Limiting factors: light, carbon dioxide, temperature:** Whichever of light intensity, carbon dioxide concentration or temperature is in shortest supply holds the rate down (the *limiting factor*). Light and carbon dioxide graphs rise then plateau as another factor takes over; the temperature graph rises to an optimum then falls as enzymes denature.
- **Magnesium ions and chlorophyll:** Magnesium ions are needed to make chlorophyll. A plant lacking magnesium cannot build enough chlorophyll, so its leaves yellow (chlorosis) and it photosynthesises poorly.
- **Nitrate ions and protein synthesis:** Nitrate ions supply nitrogen, which combines with glucose to make amino acids and hence proteins, needed for growth and new cells. A plant lacking nitrate shows stunted (poor) growth.
- **Tissue layers of a dicotyledonous leaf, top to bottom:** From the upper surface downward: waxy cuticle, upper epidermis (no chloroplasts), palisade mesophyll (tall, chloroplast-packed), spongy mesophyll (loosely packed, large air spaces), lower epidermis (most stomata), with a vascular bundle (xylem above, phloem below) running through the middle.

- **Hydrogencarbonate indicator and gas exchange:** Hydrogencarbonate indicator is orange-red in ordinary air. It turns purple when carbon dioxide is removed (net photosynthesis exceeds respiration in bright light) and yellow when carbon dioxide increases (net respiration only, in darkness). A tube with indicator but no plant is the control.
- **Leaf shape: broad, flat and thin:** A broad, flat blade gives a large surface area to absorb light and carbon dioxide. A thin blade shortens the diffusion distance for carbon dioxide and lets light penetrate to all photosynthesising cells.

EXAM TIPS

TIP To prove a factor (chlorophyll, light or carbon dioxide) is necessary, change only that one factor and keep everything else the same, including a control region or leaf where the factor is present. Without a control the result cannot be attributed to that one factor.

TIP Photosynthesis builds glucose and stores energy, and happens only in the light. Respiration breaks down glucose and releases energy, and happens constantly. A description mentioning "releasing energy" or "using oxygen" is respiration, not photosynthesis.

TIP Enzymes are not alive, so heat cannot kill them; high temperature denatures them, so the active site changes shape and stops working. This applies only above the optimum temperature; at low temperature enzymes simply work slowly.

TIP Nitrate deficiency stunts growth (too little protein for new tissue); magnesium deficiency yellows the leaves (too little chlorophyll). Yellow leaves point to magnesium; poor growth with normal colour points to nitrate.

TIP Glucose is made and respired; starch is the insoluble storage carbohydrate; sucrose is the soluble form transported in phloem; cellulose builds new cell walls. Swapping any two of these roles is a common dropped mark.

17 Reproduction

KEY FORMULAS

Fertilisation as a word equation

male gamete nucleus + female gamete nucleus → zygote

A general form of the fertilisation event that applies to both animal gametes (sperm and egg) and plant gametes (pollen nucleus and egg-cell nucleus). Used to state precisely what fertilisation is, rather than describing whole cells joining.

Pollination direction

anther → stigma

The direction pollen grains travel during pollination. Fertilisation happens later and elsewhere, in the ovule, once a pollen tube has grown down through the style.

Direction of exchange at the placenta: useful substances

mother's blood → fetus's blood

Useful substances such as food and oxygen pass from the mother's blood to the fetus's blood across the placenta.

KEY CONCEPTS

- **Definition of asexual reproduction:** Asexual reproduction is the process resulting in the production of *genetically identical* offspring from *one parent*. There is no fusion of gametes, so the offspring are clones of the parent: same genotype, same phenotype barring environmental differences.
- **Definition of fertilisation:** Fertilisation is the *fusion of the nuclei of two gametes*. The precise word examiners require is *nuclei*: writing "the sperm and egg join" or "the cells merge" without naming the nuclei loses the mark, because it is specifically the nuclei, carrying the genetic material, that fuse.
- **Definition of sexual reproduction:** Sexual reproduction is the process involving the *fusion of the nuclei of two gametes* (sex cells) to form a zygote, and the production of offspring that are *genetically different* from each other. The two anchor phrases are "fusion of gamete nuclei" and "genetically different offspring".
- **Egg cell: adaptive features:** An egg cell is *large*, with cytoplasm containing food stores for the zygote before implantation. Its membrane or jelly coat *changes* immediately after one sperm enters, stopping any other sperm getting in. Eggs are produced in small numbers, usually one per cycle.
- **Female reproductive system: parts and functions:** The *ovary* produces egg cells and the hormone oestrogen. The *oviduct* carries the egg towards the uterus, and fertilisation normally happens here. The *uterus* is where the fetus develops. The *cervix* is a ring of muscle at the base of the uterus that keeps it closed during pregnancy. The *vagina* receives the penis and semen and is the birth canal.
- **Flower structure: stamen and carpel:** The *stamen* is the male part of a flower, made of the *anther* (produces and releases pollen grains) and the *filament* (holds the anther in position). The *carpel* is the female part, made of the *stigma* (receives pollen), the *style* (connects stigma to ovary) and the *ovary* (contains the ovule, which becomes the seed after fertilisation).
- **Male reproductive system: parts and functions:** The *testis* produces sperm and the hormone testosterone. The *scrotum* holds the testes outside the body, keeping them slightly cooler than body temperature. The *sperm duct* carries sperm from the testis towards the urethra. The *prostate gland* adds fluid to the sperm to form semen. The *urethra* carries semen, and separately urine, out through the *penis*.
- **Pollination defined and distinguished from fertilisation:** Pollination is the *transfer of pollen grains from an anther to a stigma*. That is the entire definition, anther to stigma. It is not fertilisation and not the pollen reaching the ovule; keeping pollination (transfer) separate from fertilisation (nuclei fusing) is the single most tested distinction in this topic.

- **Sperm cell: adaptive features:** A sperm cell has a *tail* to swim towards the egg, many *mitochondria* in the mid-piece to release the energy needed for swimming, and an *acrosome* (an enzyme-containing cap on the tip) to digest through the egg's outer layers. Sperm are small and produced in huge numbers, increasing the chance one reaches the egg.
- **STI and HIV, leading to AIDS:** A sexually transmitted infection (STI) is transmitted through sexual contact. *HIV* is a virus that causes an STI; it attacks and destroys *lymphocytes*, the white blood cells the immune system uses to fight infection. As these are lost, the immune system weakens until the person can no longer fight off other infections; this stage is *AIDS*.
- **Testosterone and oestrogen:** *Testosterone* is the main male sex hormone, produced by the testes; it drives facial and body hair, a deeper voice, muscle development and the start of sperm production. *Oestrogen* is the main female sex hormone, produced by the ovaries; it drives breast growth, wider hips, body hair growth and the start of the menstrual cycle.
- **Control methods and the routes they block:** Using *condoms* blocks the exchange of sexual fluids. *Not sharing needles* blocks blood-to-blood transmission. *Screening donated blood* removes infected blood before transfusion. *Testing and treating* infected people, including contact tracing, stops them passing the infection on; some bacterial STIs, such as gonorrhoea, can be treated with antibiotics. *Education* informs people how STIs spread and how to prevent them.
- **From fertilisation to a developing fetus:** Fertilisation happens in the *oviduct*, forming a *zygote*. The zygote divides as it travels down the oviduct, becoming a ball of cells called an *embryo*. The embryo implants into the thick, blood-rich lining of the uterus, and continues to develop into a *fetus*.
- **Insect versus wind pollination:** An insect-pollinated flower has large coloured, scented petals, nectaries, anthers and a sticky stigma held inside, and a small amount of large, sticky or spiky pollen. A wind-pollinated flower has small or absent, dull petals, no nectaries, anthers and feathery stigmas hanging outside, and a large amount of small, smooth, light pollen. An insect is a precise courier that the flower attracts and rewards; wind is a random courier, so the flower makes masses of light pollen and dangles its parts into the airflow instead.
- **Oestrogen and progesterone act on the uterus lining:** *Oestrogen*, from the ovary, repairs and thickens the uterus lining in the first half of the cycle. *Progesterone*, from the ovary, maintains the thick lining in the second half. When progesterone falls, the lining can no longer be maintained and breaks down, causing menstruation.
- **Placenta: exchange without blood mixing:** The *placenta* is a disc-shaped structure attached to the uterus wall that lets substances pass between the mother's blood and the fetus's blood without the two bloods ever mixing. The *umbilical cord* connects the fetus to the placenta and carries the fetus's blood to and from it so the exchange can happen there.
- **Recognising asexual reproduction from an example:** Examiners test asexual reproduction by naming an unfamiliar organism and asking you to classify it. The tell is always *one parent, no gametes, identical offspring*: bacteria dividing into two, a potato producing new plants from tubers, strawberry or spider plants from runners, Hydra budding, and fungi producing spores.
- **Self- versus cross-pollination:** *Self-pollination* is the transfer of pollen from the anther to the stigma of the same flower, or a different flower on the same plant. *Cross-pollination* is the transfer of pollen from the anther of one flower to the stigma of a flower on a different plant of the same species.
- **The menstrual cycle by uterus lining:** The menstrual cycle is a roughly 28-day cycle. Days 1 to 5 are *menstruation*: the uterus lining breaks down and is lost. Days 6 to 13 are repair and thickening: the lining is rebuilt and an egg matures. Around day 14 is *ovulation*: an egg is released from the ovary. Days 15 to 28 are maintenance: the lining stays thick, ready to receive a fertilised egg.
- **Transmission routes of HIV:** HIV is passed on through unprotected sexual intercourse with an infected person, through infected blood (sharing needles, or a transfusion of untested infected blood), and from mother to child across the placenta, during birth, or through breast milk.

EXAM TIPS

TIP Growth of the sexual organs happens under *both* testosterone and oestrogen, one of the few secondary sexual characteristics that is not sex specific. Questions sometimes ask which characteristic develops in both males and females, and this is the expected answer.

TIP HIV is passed on through unprotected sexual intercourse, infected blood (for example sharing needles or an untested transfusion), and from mother to child. Hugging and sharing plates or cups do *not* transmit it, because no blood, sexual fluids or breast milk are exchanged.

TIP The *urethra* in the male carries both urine and semen, at different times, but the *sperm duct* carries only sperm, from the testis towards the urethra. Mixing up "sperm duct" and "urethra" is a classic lost mark.

TIP Confirming asexual reproduction needs both parts of the definition, not just one: *one parent involved* and *no fusion of gamete nuclei*. A process with only one parent but that still involves gametes would not be asexual.

TIP Seeds germinate only when *water*, *oxygen* and a suitable warm *temperature* are all present. Investigating each condition means removing only that one variable (for example dry cotton wool to test water, or boiled water sealed under oil to exclude oxygen) while keeping everything else, including a control with all conditions present, the same.

TIP The examiners' precise wording is that the *nuclei* of two gametes fuse at fertilisation, not that "the sperm and egg join" or "the cells merge". Writing about whole cells joining, rather than their nuclei, costs the definition mark even when the rest of the answer is correct.

TIP Some pathogens, for example HIV, and toxins, for example nicotine and alcohol, can cross the placenta from the mother to the fetus and harm its development. This is why pregnant people are advised not to smoke or drink alcohol.

18 Respiration

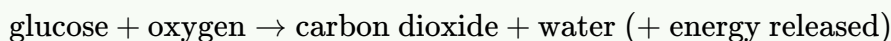
KEY FORMULAS

Rate of gas production

$$\text{rate} = \frac{\text{quantity produced}}{\text{time taken}}$$

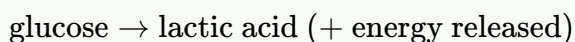
Use to calculate bubbles per minute, or volume of gas per minute, from a count and a time. Round to the number of significant figures appropriate to the measurement, not to the raw calculator output.

Word equation for aerobic respiration



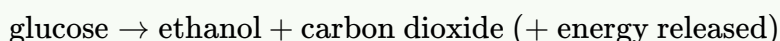
Two reactants combine to form two products, with energy released as an outcome of the reaction rather than a listed product. Learn as a fixed sequence for fill the gap questions.

Word equation for anaerobic respiration in muscle



Only one product, lactic acid, and critically no carbon dioxide. This is the pathway muscle cells switch to when they cannot obtain enough oxygen fast enough during vigorous exercise.

Word equation for anaerobic respiration in yeast



No oxygen appears anywhere in this equation, the fastest check that the pathway is anaerobic. This reaction is the basis of brewing (the ethanol produced) and baking (the carbon dioxide produced).

Volume of stock solution needed for a dilution

$$\text{volume of stock} = \frac{\text{target concentration}}{\text{stock concentration}} \times \text{total final volume}$$

Use to make a weaker glucose solution from a stronger stock solution. The rest of the total volume is made up with distilled water; the amount of glucose stays the same, only the volume it is dissolved in changes.

KEY CONCEPTS

- **Aerobic respiration definition:** *Aerobic respiration* releases a relatively large amount of energy by breaking down glucose using oxygen. It is the pathway a cell runs whenever oxygen is available, and it takes place mainly in the mitochondria.
- **Anaerobic respiration definition:** *Anaerobic respiration* releases a relatively small amount of energy by breaking down glucose without using oxygen. A cell falls back on it when oxygen is absent, or not available fast enough.
- **Definition of respiration:** *Respiration* is the chemical reactions in cells that break down nutrient molecules, usually glucose, and release energy. It happens inside every living cell of every living organism, continuously, whether or not the organism breathes.
- **Energy comparison: aerobic releases far more energy than anaerobic:** Anaerobic respiration releases roughly twenty times less energy per glucose molecule than aerobic respiration. Aerobic respiration breaks glucose all the way down to carbon dioxide and water; anaerobic respiration stops early, at ethanol or lactic acid, both still energy rich.
- **Four uses of energy released by respiration:** *Movement* (muscle contraction), *active transport* (moving substances against a concentration gradient), *synthesis of large molecules* (proteins and

DNA, needed for growth and cell division), and, in mammals and birds, *maintaining a constant body temperature*.

- **Identifying variables in the yeast investigation:** The *independent variable* is whichever condition is deliberately changed between tubes, usually temperature or glucose concentration. The *dependent variable* is the outcome measured, rate of gas production or height risen. Every other variable (volume and concentration of yeast suspension, volume and concentration of glucose solution, reaction time) must be *controlled*.
- **Fermentation in brewing and baking:** Humans have exploited yeast's anaerobic pathway for thousands of years. *Brewing* uses the ethanol produced (the alcohol in beer and wine); *baking* uses the carbon dioxide produced (it makes bread dough rise), while the small amount of ethanol produced evaporates off during baking.
- **Site of aerobic respiration: mitochondria:** Aerobic respiration takes place mainly in the *mitochondria*. Cells with a high, sustained energy demand, muscle cells and sperm cells for example, contain unusually large numbers of mitochondria.
- **Testing for carbon dioxide:** The gas produced by respiring yeast is carbon dioxide, confirmed with the standard test: bubbling the gas through *limewater*, which turns from clear to *milky* (cloudy white). An equivalent test uses *hydrogencarbonate indicator*, which is orange red in normal air and turns *yellow* as carbon dioxide concentration rises.

EXAM TIPS

TIP Carbon dioxide and water are shared with several other reactions this course covers. The reliable check for "is this aerobic respiration" is whether oxygen appears as a *reactant*, alongside glucose.

TIP *Breathing* is the mechanical movement of air into and out of the lungs, one process in one organ system of air breathing animals. *Respiration* is a chemical process in every cell of every organism, plants and bacteria included, none of which breathe.

TIP Mixing up which organism produces which anaerobic product is one of the most common errors in this chapter. Anchor on application: brewing and baking use yeast's ethanol and carbon dioxide; lactic acid is the "muscle burn" substance, and cannot be detected with the limewater test.

TIP Naming "growth" alone as a use of energy earns little credit. State the mechanism: growth means building new cells, which means synthesising new proteins and new DNA, both energy expensive processes.

TIP Aerobic respiration consumes oxygen and glucose and produces carbon dioxide and water; photosynthesis consumes carbon dioxide and water and produces glucose and oxygen. Naming the correct substances is only half the mark; getting the direction (reactant versus product) right is the other half.

TIP "Anaerobic" does not mean the cell has stopped respiring; it means the cell has switched to a different pathway that does not need oxygen. Anaerobic respiration continues, releasing less energy per glucose molecule than aerobic respiration would, but it continues.

19 Transport in animals

KEY FORMULAS

Full route of blood through the heart

vena cava → right atrium → right ventricle → pulmonary artery → lungs →
pulmonary vein → left atrium → left ventricle → aorta

Use to answer "trace one drop of blood" questions. Blood always arrives in an atrium and always leaves from a ventricle; deoxygenated blood is pumped to the lungs before oxygenated blood is pumped to the body.

Heart rate increase

$\Delta\text{heart rate} = \text{heart rate after} - \text{heart rate before}$

Use to calculate the rise in heart rate caused by exercise. This is a simple subtraction, not a percentage or a ratio, unless the question specifically asks for one of those instead.

Heart rate (bpm)

$\text{heart rate (bpm)} = \frac{\text{number of beats}}{\text{time (minutes)}}$

The general definition behind "beats per minute". Use it to convert a count of beats over any timed interval into a rate.

Pressure decreases along the route

$P_{\text{artery}} > P_{\text{capillary}} > P_{\text{vein}}$

Blood pressure falls steadily as blood moves away from the heart through the vessel network; this pressure difference is the reason artery, capillary and vein walls are built so differently.

KEY CONCEPTS

- **Arteries vs veins: the direction rule:** *Arteries* carry blood away from the heart; *veins* carry blood towards the heart. This rule applies with no exceptions in naming, regardless of whether the blood inside is oxygenated or deoxygenated.
- **Artery structure:** *Arteries* carry blood away from the heart at high pressure, so they have a *thick wall* and a *narrow lumen*, able to withstand the surge of pressure from each heartbeat.
- **Capillary function: built for exchange:** Capillaries are the only vessels where exchange between blood and tissues happens. Oxygen and glucose diffuse out of capillary blood into the surrounding cells; carbon dioxide and other waste diffuse the other way.
- **Capillary structure:** *Capillaries* have a wall only *one cell thick* and a very narrow lumen, just wide enough for red blood cells to pass through roughly in single file.
- **Circulatory system: vessels, pump and valves:** A circulatory system is built from three parts working together: *blood vessels* (the pipework that carries blood around the body), a *pump* (the heart, which provides the force to move it), and *valves* (which ensure that force only ever pushes blood in one direction). Removing any one of the three makes the system fail.
- **Coronary heart disease: cause and risk factors:** *Coronary heart disease* develops when the coronary arteries become narrowed by fatty deposits building up on their inner walls, restricting the blood supply to the heart muscle. Known risk factors are a diet high in saturated fat, smoking, and a lack of exercise.
- **Distinguishing red vs white blood cells by nucleus:** A *red blood cell* is a small, biconcave disc with *no nucleus* once mature. A *white blood cell* is larger than a red blood cell and keeps a clear *nucleus*. A *platelet* is a very small cell fragment, smaller than either, with no nucleus.

- **Effect of exercise on heart rate:** Heart rate rises as soon as physical activity begins, because exercising muscles respire faster and need oxygen and glucose delivered at a faster rate; the heart beats faster to meet that demand.
- **Four components of blood:** Blood is made of four components: *red blood cells*, *white blood cells*, *platelets*, and *plasma*, the pale liquid that carries all three cell types and everything dissolved in the blood.
- **Four heart chambers: atria receive, ventricles pump:** The mammalian heart has four chambers. The two upper *atria* (singular atrium) receive blood arriving at the heart; the two lower *ventricles* pump blood out of the heart. The right side handles deoxygenated blood, the left side oxygenated blood.
- **Function of valves:** A valve is a flap of tissue that opens when blood pushes it the correct way and closes if blood starts to flow backwards. Valves are the structure that *ensures blood flows in one direction only*; vessel walls and the pump itself do not have this one-way property on their own.
- **Functions of blood components:** *Red blood cells* transport oxygen, carried by *haemoglobin*. *Plasma* transports dissolved substances such as glucose, urea and hormones. *White blood cells* defend the body by making antibodies and by engulfing pathogens (phagocytosis). *Platelets* help the blood to clot.
- **Single circulation (fish):** A fish has a *single circulation*: blood passes through the heart only *once* for each complete circuit of the body, travelling heart to gills to body and back to the heart.
- **Vein structure:** *Veins* carry blood back towards the heart at much lower pressure, so they have a comparatively *thin wall*, a *large lumen* (offering little resistance to slow-moving blood), and *valves* to stop the low-pressure blood flowing backwards.
- **Blood clotting: two roles:** Blood clotting does two jobs at once at a wound site: it stops blood loss, and it blocks the entry point pathogens would otherwise use to enter the body.
- **Double circulation (mammal):** A mammal has a *double circulation*: blood passes through the heart *twice* for each complete circuit of the body, once through the *pulmonary circulation* (heart to lungs and back) and once through the *systemic circulation* (heart to the rest of the body and back). Both loops start and finish at the heart.
- **Monitoring heart activity via pulse:** The heart's activity can be monitored by feeling the *pulse*: the physical surge of pressure felt in an artery, commonly at the wrist, each time the heart contracts, giving a direct measure of heart rate.
- **Named vessels: pulmonary artery/vein, renal artery/vein:** The *pulmonary artery* carries deoxygenated blood from the heart to the lungs; the *pulmonary vein* returns oxygenated blood from the lungs to the heart. The *renal artery* supplies the kidney with oxygenated blood; the *renal vein* carries blood away from the kidney back towards the heart.

EXAM TIPS

TIP A capillary's narrow lumen looks like a disadvantage at first, since it seems that less blood could get through, but it is a deliberate feature that *slows* blood flow and gives more time for diffusion. Never describe a narrow capillary lumen as a weakness.

TIP In any "identify the labelled cell" question, check the nucleus first: no nucleus and full disc size means a red blood cell; no nucleus and tiny fragment size means a platelet; a visible nucleus means a white blood cell.

TIP Eating less saturated fat reduces the fatty deposits that narrow the coronary arteries, and regular exercise helps keep the heart and blood vessels healthy; both genuinely lower the risk of coronary heart disease.

TIP "Single" and "double" circulation describe how many times blood passes through the heart per complete circuit of the body, not how many chambers the heart has. Trace the full loop and count re-entries to the heart before answering.

TIP The *pulmonary artery* carries deoxygenated blood and the *pulmonary vein* carries oxygenated blood, the reverse of most other arteries and veins. The classification "artery vs vein" always tracks direction relative to the heart, never oxygenation.

TIP "Increase" in a heart-rate question means a straightforward subtraction (after minus before), not a percentage or a ratio. Always check the command word before choosing which operation to use.

20 Transport in plants

KEY FORMULAS

Rate of water uptake from a potometer

$$\text{rate} = \frac{\text{distance moved by air bubble}}{\text{time taken}}$$

Used whenever a potometer investigation gives a distance and a time and asks for a rate. The result is a rate of water uptake, used as a proxy for the rate of transpiration, not an exact measure of it.

Percentage change in transpiration rate between two conditions

$$\% \text{ change} = \frac{\text{new rate} - \text{old rate}}{\text{old rate}} \times 100$$

Used whenever a question gives the rate under two different conditions, for example two temperatures or two wind speeds, and asks for the percentage increase or decrease between them.

Rearranging the rate equation for distance or time

$$\text{distance} = \text{rate} \times \text{time} \quad \text{time} = \frac{\text{distance}}{\text{rate}}$$

Used when a question gives a known rate and asks how far a bubble will travel in a stated time, or how long a bubble takes to travel a stated distance, rather than asking for the rate itself.

KEY CONCEPTS

- **Definition of transpiration: two steps:** Transpiration is the loss of water vapour from a plant, mainly from the leaves. Step 1: water evaporates from the moist surfaces of mesophyll cells inside the leaf into the internal air spaces. Step 2: that water vapour diffuses out of the leaf through the stomata. Naming only one step drops marks.
- **Factors increasing transpiration rate: temperature and wind speed:** Raising temperature speeds up evaporation from mesophyll cells and steepens the water vapour concentration gradient out through the stomata, so transpiration rate increases. Moving air continuously sweeps away the humid air layer around the stomata, keeping the gradient steep, so transpiration rate also increases with wind speed.
- **Functions of xylem and phloem:** Xylem transports water and dissolved mineral ions, always in one direction, from the roots up to the stem and leaves. Phloem transports sucrose and amino acids. Name the substances, never write "food" or "nutrients" for phloem, examiners specifically penalise the vague word.
- **Root hair cell structure and surface area:** A root hair cell grows a single, long, thin tubular extension into the soil. This shape dramatically increases the cell's surface area in contact with soil water without a matching increase in volume, and since both water and mineral ion uptake happen across the cell's surface, more surface area means faster uptake.
- **Xylem's second job: support:** Xylem vessel walls are thickened with lignin, a tough, woody material. Beyond the strength needed to carry water, this rigidity gives the whole plant mechanical support, helping stems and trunks stay upright. Phloem has no comparable structural role, so "support" is a xylem-specific answer, never a phloem one.
- **Location of xylem and phloem in roots, stems and leaves:** Root: xylem forms a central, star-shaped column, with phloem in separate patches between the arms; root hairs are outer-surface projections, never part of the vascular tissue. Dicotyledonous stem: vascular bundles form a single ring near the edge, xylem toward the inside. Monocotyledonous stem: bundles are scattered throughout the cross-section. Leaf vein: xylem lies toward the upper epidermis, phloem toward the lower epidermis.
- **The pathway of water through the plant:** Water follows a continuous pathway: root hair cell, then root cortex cells, then the central xylem of the root, then the xylem of the stem, then the xylem of the

leaf vein, then mesophyll cells of the leaf, where most of it is eventually lost by transpiration. Any option that inserts phloem into this sequence, or reverses the direction, describes the wrong tissue or the wrong direction.

- **What a potometer measures:** A potometer is a sealed apparatus holding a leafy shoot, connected to a water filled capillary tube with a single air bubble. The distance the bubble moves per unit time is used as a proxy for the volume of water taken up by the shoot, which closely matches, but is not identical to, the volume of water lost by transpiration.

EXAM TIPS

TIP Transpiration is a loss of water vapour, a gas, not liquid water. Evaporation happens at the mesophyll cell surface, inside the leaf; diffusion is what happens at the stomata. Writing "water evaporates out of the stomata" conflates the two steps and is usually only given partial credit.

TIP "Explain why X increases the rate of uptake" answers want the full chain: shape leads to increased surface area, which leads to faster absorption across that surface. Writing only "it has more surface area" on its own drops the final link and loses marks.

TIP If two shoots are compared at different temperatures, every other condition that could independently affect transpiration rate, humidity, wind speed, light intensity, and the size and species of the shoot, must be kept the same. Naming the controlled variables explicitly is worth marks on its own.

TIP "Scattered throughout the cross-section" describes a monocot stem. "Arranged in a ring near the edge" describes a dicot stem. If a question gives a cross-section description rather than a picture, extract this one phrase before anything else.

21 Variation and selection

KEY CONCEPTS

- **Adaptive feature:** An adaptive feature is an inherited feature that helps an organism to survive and reproduce in its environment. Both halves of the definition are required for marks: the feature must be inherited, and it must give a stated survival or reproductive benefit.
- **Continuous variation:** Continuous variation produces a range of phenotypes between two extremes, with every intermediate value possible (e.g. body mass, height). It is caused by many genes acting together, modified by the environment, and plots as a smooth curve.
- **Discontinuous variation:** Discontinuous variation results in a limited number of distinct phenotypes with no intermediates (e.g. ABO blood group, tongue-rolling, pea seed shape). It is caused by one gene, or a small number of genes, with little or no environmental influence, and plots as a bar chart.
- **Genetic variation and environmental variation:** Genetic variation is caused by differences in the alleles individuals inherit and is heritable. Environmental variation is caused by conditions experienced during life (diet, climate, injury) and is not passed on. Many features, such as height, are shaped by both.
- **Mutagens:** A mutagen is a factor that increases the rate at which mutation occurs. The Core syllabus names two: ionising radiation (e.g. ultraviolet light, X-rays, radiation from radioactive substances) and certain chemicals (e.g. compounds in tobacco smoke).
- **Mutation: the source of new alleles:** A mutation is a genetic change, a change in the genetic material of a cell. Mutation is the way in which new alleles are formed, making it the ultimate source of all genetic variation.
- **Natural selection:** Natural selection proceeds in five steps: (1) variation exists within a population, some of it inherited; (2) organisms produce more offspring than the environment can support, so there is a struggle for survival; (3) individuals whose variations make them better adapted are more likely to survive; (4) survivors reproduce, passing on the advantageous alleles; (5) over many generations the advantageous alleles become more common and the population becomes better adapted.
- **Selective breeding:** Selective breeding (artificial selection) is the process by which humans choose which organisms reproduce, in order to develop populations with features useful to people. The cycle is: select individuals with the most desirable form of the feature, breed them, select again from the offspring, and repeat over many generations.
- **Variation:** Variation is the differences that exist between individuals of the same species. It is the raw material that selection acts on; without differences between individuals there would be nothing for the environment to select between.
- **Inherited features versus acquired characteristics:** An adaptive feature must be inherited (passed on through the genes). An acquired characteristic, such as a learned behaviour or muscle built through exercise, is gained during an individual's life and is not passed on, so it cannot be an adaptive feature.
- **Investigating variation:** Investigating variation means measuring or recording a feature across a large sample, tallying the values or categories, and plotting the result. A smooth curve of frequencies indicates continuous variation; a bar chart of distinct categories indicates discontinuous variation. A large sample is needed before the pattern becomes clear.
- **Selective breeding targets:** Crop plants are selectively bred for higher yield, larger fruits or grains, disease resistance and drought tolerance. Domesticated animals are bred for more meat or milk, faster growth, and disease resistance. Changing an organism's environment (more food, water, warmth) is not selective breeding, because it does not change which alleles are passed on.

EXAM TIPS

TIP An organism does not change itself during its life and pass the change on. State instead that variation already existed by chance, the better-adapted individuals survived and reproduced, and the advantageous allele became more common over generations. Never write that an organism "changed to suit" its environment.

TIP A feature that is inherited but gives no stated benefit is not an adaptive feature. Check every candidate feature against both halves of the definition: is it inherited, and does it help this organism survive or reproduce in this environment?

TIP Full marks for describing selective breeding require three elements: select the individuals with the desired feature, breed them together, and repeat over many generations. Omitting "repeat over many generations" is the most common way candidates lose the final mark.

TIP To sort a feature as continuous or discontinuous, ask only one question: can an individual have an in-between value? If yes, it is continuous; if no, it is discontinuous. Do not judge by how many categories exist; ABO blood group has four categories and is still discontinuous.

TIP Never classify a whole organism as "showing continuous variation". Variation type belongs to a feature. The same plant can show continuous variation in one feature and discontinuous variation in another at the same time; always name the feature being classified.



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