



Biology (0610)

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Standard Cheat Sheet

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1 Biological molecules

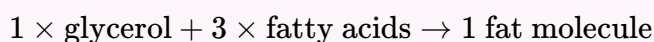
KEY FORMULAS

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.

Complementary base-pairing rule



A always pairs with T (adenine with thymine); C always pairs with G (cytosine with guanine). Knowing the sequence on one DNA strand fixes the sequence on the other, base by base.

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 build muscle, form enzymes, make antibodies and carry oxygen (as haemoglobin) from only twenty building blocks.
- **DNA is a double helix held together by paired bases:** A DNA molecule is made of two strands twisted around each other into a *double helix*, held together by cross-links, each a pair of chemical units called *bases*. There are four bases, A, T, C and G, and they pair in a fixed, complementary way: A always with T, C always with G.
- **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. Nucleic acids such as DNA also carry nitrogen, so a purified nitrogen-containing substance is a protein or a nucleic acid, never a pure carbohydrate or a pure fat.
- **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 or a nucleic acid, never a pure carbohydrate or a pure fat. Carbohydrates and fats share the same three elements (carbon, hydrogen, oxygen); only protein and DNA add 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.

TIP Because A always pairs with T and C always pairs with G, the percentage of A in a DNA sample always equals the percentage of T, and the percentage of C always equals the percentage of G. A question stating "30% of the bases are A" fixes T at 30% as well.

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, harnessed for two different products depending on which one is collected.

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 the mass of a GM crop grown, rises from one value to another. Always divide by the *original* (starting) value.

Combined growth formula

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

A single-line combination of the two steps above, where t is the total time elapsed and d is the time for one division.

Number of divisions in a given time

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

Find n first whenever a division time and a total elapsed time are given, then substitute into 2^n .

KEY CONCEPTS

- **Bread-making: the carbon dioxide is wanted:** 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.
- **Definition of genetic modification:** *Genetic modification (genetic engineering)* changes the genetic material of an organism, usually by inserting a gene from another organism, so it gains a new characteristic. The genetic code is universal, so a human gene put into a bacterium is read correctly and builds the human protein.
- **Fermenters grow microorganisms at scale:** A *fermenter* is a large, sterile, stainless-steel vessel used to grow an enormous population of microorganisms, for example *Penicillium*, the fungus that makes the antibiotic *penicillin*.
- **Genetic modification is not selective breeding:** *Selective breeding* chooses which existing individuals of the *same species* reproduce, over many generations, and cannot move a gene between species. *Genetic modification* transfers a *specific* gene, often between *different* species, in a single controlled step.
- **Lactase makes lactose-free milk:** *Lactose* is the sugar naturally in milk. People who are lactose intolerant lack enough *lactase* to digest it. Treating milk with lactase before sale breaks lactose down

in advance into *glucose and galactose*, which are absorbed easily, producing lactose-free milk.

- **Ligase forms recombinant DNA:** *Ligase* is the molecular glue that joins (seals) a gene into a cut plasmid, forming a single continuous loop of DNA. Because this loop contains DNA from two sources, it is called *recombinant DNA*, and the plasmid carrying it acts as a *vector*.
- **Lower temperature cleaning has a limit:** Because the enzymes chemically attack stains, biological powders clean effectively at *lower temperatures* (around 30 to 40 °C), saving energy. But each enzyme has an *optimum temperature*; wash too hot and the enzymes *denature*, so a very hot wash cleans *worse*, not better.
- **Pectinase breaks down pectin in fruit pulp:** Crushed fruit pulp contains *pectin*, a carbohydrate that thickens the pulp and traps juice, also clouding the liquid. *Pectinase* is the enzyme that breaks pectin down.
- **Plasmids act as vectors:** A *plasmid* is a small, circular loop of DNA in a bacterium, separate from its single main chromosome. A plasmid can be removed, cut open, given a new gene, and returned to the cell, where the bacterium follows the inserted gene's instructions as if it were its own. This makes the plasmid a *vector*, the vehicle that delivers a new gene into a cell.
- **Proteases and lipases in biological washing powders:** Biological washing powders contain enzymes that digest stain molecules into small, soluble products. *Proteases* digest protein-based stains (blood, egg, grass, sweat) into amino acids; *lipases* digest fat-based stains (grease, oil, butter) into fatty acids and glycerol.
- **Restriction enzymes cut DNA leaving sticky ends:** *Restriction enzymes* are molecular scissors that cut DNA at specific points. Many cut in a staggered way, leaving short single-stranded overhangs called *sticky ends*. The same restriction enzyme, used on two different pieces of DNA, leaves *complementary* sticky ends that can pair up.
- **Temperature is controlled by a water jacket:** Respiration and the industrial reactions release heat. A *water jacket*, a double wall around the tank through which cooling water flows, removes excess heat and keeps the temperature at the optimum for the organism's enzymes.
- **The five steps of insulin production:** (1) The *human insulin gene* is cut from human DNA using a restriction enzyme. (2) A *bacterial plasmid* is cut open with the *same* restriction enzyme. (3) The gene is joined into the plasmid by *ligase*, forming *recombinant DNA*. (4) The recombinant plasmid is inserted into *bacteria*. (5) The bacteria are grown, usually in a *fermenter*, reproduce rapidly, and each cell reads the gene and makes human insulin.
- **Three properties that make bacteria ideal:** Bacteria are the standard organism for biotechnology and genetic modification because of three properties: a *rapid reproduction rate* (binary fission every 20 to 60 minutes, so a population grows exponentially), the *ability to make complex molecules* such as proteins, and the *presence of plasmids* that can carry a new gene into the cell.
- **Three traits given to GM crops:** *Herbicide resistance*: the crop is unharmed by a weedkiller, so a field can be sprayed to kill weeds without harming the crop. *Insect (pest) resistance*: the crop makes its own protein toxic to pests (often from *Bacillus thuringiensis*), reducing damage and chemical insecticide use. *Improved nutritional content*: a gene is added so the crop makes a nutrient it normally lacks, for example *golden rice*, engineered to make *beta-carotene*.
- **Why gas is bubbled through the culture:** *Penicillium* respire *aerobically*, so it needs a continuous supply of *oxygen*. Air is bubbled up through the culture from the base to keep the whole liquid oxygenated; the stirrer keeps cells, nutrients and bubbles evenly mixed.
- **Advantages of GM crops:** Higher *yield* from the same land; *pest resistance* reduces crop losses and chemical insecticide use; *herbicide resistance* makes weed control easier; *improved nutrition* can tackle deficiency diseases where a population relies on one staple crop.
- **Biofuel: the ethanol is wanted:** 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, the reverse of the roles in bread-making.
- **Disadvantages and concerns about GM crops:** *Cross-pollination* can spread the introduced gene to nearby wild or non-GM plants; the crop's toxin may harm *non-target organisms* such as butterflies and bees; widespread planting of one variety can *reduce biodiversity*; GM seed is often more *costly*, and some raise ethical or long-term-safety concerns.
- **Two benefits of adding pectinase before pressing:** Breaking down pectin releases juice trapped in the pulp, which *increases the volume (yield) of juice*, and removes the substance that would otherwise cloud the liquid, so the juice is also *clearer*.
- **Why dough is kept warm, not hot:** Yeast's respiration is controlled by enzymes. Too cold and the enzymes work too slowly for the dough to rise in reasonable time; too hot and the enzymes *denature* and the yeast dies, so dough is left in a *warm*, not a hot, place.

EXAM TIPS

- TIP** Using *one* restriction enzyme to cut both the gene and the plasmid guarantees their sticky ends are complementary, so they pair up and ligase can seal the join. Different restriction enzymes on the gene and plasmid leave non-matching sticky ends, so no recombinant DNA forms.
- TIP** Do not confuse penicillin production (*aerobic*, oxygen bubbled *in*) with the yeast processes (*anaerobic*, carbon dioxide produced and released). The organism and the type of respiration decide which direction the gas moves.
- TIP** A hotter wash cleaning *worse* with a biological powder is a favourite exam trap. Anchor an answer on the words *optimum* and *denature*, and link denaturing to the *active site changing shape*, not to the enzyme "dying" (enzymes are molecules, not organisms).
- TIP** A useful sentence frame for a balanced-view mark: "This is an advantage because... however, a valid concern is... so an overall judgement depends on..." Writing that frame guarantees both halves of the mark scheme are addressed.
- TIP** "State conditions that must be controlled in a fermenter" is a very common question. Keep a mental checklist, *temperature*, *pH*, *nutrients*, *sterility (aseptic conditions)*, and pair each one with a *reason*; a bare one-word list rarely scores full marks.
- TIP** A common item names a microorganism used in *both* bread-making and biofuel production. The organism is always *yeast*, the process is always *anaerobic respiration*, and the two products are always *carbon dioxide* and *ethanol*, whichever one is being collected in that context.
- TIP** Phrases that flag genetic modification: "a gene from another organism", "inserted into", "restriction enzyme", "plasmid", "different species". Phrases that flag selective breeding: "chosen the best", "bred together over many generations", "same species".

KEY CONCEPTS

- **Classification and natural classification reflect shared ancestry:** Organisms are placed in the same group because they share features. A *natural classification* goes further, aiming for groups that reflect *evolutionary relationships*: members of a small group inherited their shared features from a recent common ancestor. The smaller the group two organisms share, the more features they have in common and the more closely related they are.
- **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.
- **DNA and protein sequence evidence for relatedness:** The more recently two species shared a common ancestor, the less time there has been for their DNA base sequences (and the amino acid sequences of shared proteins) to diverge, so the more similar those sequences are. Sequence comparison gives appearance-independent evidence of relationship, unlike outward looks, which can mislead (a dolphin resembles a shark but is a mammal).
- **Ferns versus flowering plants, monocots versus dicots:** *Ferns* have roots, stems and leaves (fronds) but no flowers or seeds; they reproduce by spores. *Flowering plants* reproduce using flowers, which produce seeds. Flowering plants split into *monocotyledons* (one cotyledon, parallel leaf veins, flower parts usually in threes) and *dicotyledons* (two cotyledons, net-like branching leaf veins, flower parts usually in fours or fives).
- **The arthropod groups and their defining features:** All arthropods have an exoskeleton, a segmented body and jointed legs. *Insects*: three body parts, three pairs of legs, one pair of antennae, usually wings. *Arachnids*: two body parts (cephalothorax and abdomen), four pairs of legs, no wings or antennae. *Crustaceans*: more than four pairs of legs, two pairs of antennae, usually gills. *Myriapods*: many similar segments, each with one or two pairs of legs, one pair of antennae.
- **The binomial naming system:** Every species has a unique two part scientific name devised under the binomial system. 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. A lion is *Panthera leo* and a tiger is *Panthera tigris*; sharing the genus *Panthera* shows they are closely related.
- **The five 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, often chloroplasts, make their own food by photosynthesis. *Fungi*: cell wall made of chitin, no chlorophyll, feed by releasing enzymes onto food and absorbing the digested products (saprophytic or parasitic nutrition). *Prokaryotes* (bacteria): single celled, no true nucleus, DNA a free circular loop. *Protoctists*: mostly single celled eukaryotes (a true nucleus) that do not fit the animal, plant or fungus kingdoms, such as *Amoeba* and algae.
- **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*; mimicking one or two, as a car moving and burning fuel does, 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 by an increase in cell number, cell size, or both. *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.
- **The vertebrate groups and their defining features:** A vertebrate has an internal skeleton with a backbone. *Fish*: wet scales, gills, fins, soft eggs in water, ectothermic. *Amphibians*: moist skin, young breathe with gills in water, adults have lungs on land, soft eggs in water. *Reptiles*: dry scaly skin, lungs, soft shelled eggs on land, ectothermic. *Birds*: feathers, beak, wings, hard shelled eggs, endothermic. *Mammals*: fur or hair, mammary glands producing milk, mostly live young, endothermic.
- **Virus structure and why viruses fit no kingdom:** A virus has only two components: a core of genetic material (DNA or RNA) surrounded by an outer protein coat. It has no cytoplasm, nucleus, cell membrane or organelles, so it is not made of cells at all, which excludes it from every kingdom

(all five kingdoms are made of cells). A virus can only reproduce by entering a host cell and hijacking that cell's machinery.

- **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. Each choice either names the organism or sends the user to another step; each either/or question halves the number of remaining possibilities.
- **Deciding a kingdom: check the nucleus first, then wall and chloroplasts:** The fastest first check when placing any organism is the nucleus question. No true nucleus means prokaryote. A true nucleus means the organism is one of the other four kingdoms, so check next for a cell wall and its material, then for chloroplasts, then for whether the organism is multicellular, to decide between animal, plant, fungus and protist.

EXAM TIPS

TIP Excretion removes waste made by the body's own metabolism, carbon dioxide from respiration and urea from breaking down excess amino acids. Egestion removes undigested food (faeces), which was never absorbed into cells and never took part in a metabolic reaction. Anchor the distinction on the word *metabolism*.

TIP "Permanent" excludes temporary swelling: a wilted plant that takes up water and stiffens reverses the moment it loses that water again. "Dry mass" is used because water content fluctuates hour to hour; real growth means the organism has built more permanent material, shown as a rise in dry mass.

TIP The single most examined arthropod distinction is insect versus arachnid. Insect equals six legs and three body parts; arachnid equals eight legs and two body parts. If a question describes eight legs, the animal cannot be an insect no matter how insect-like it looks.

TIP A well designed dichotomous key can identify one organism out of many possibilities in only a handful of steps, because each two-way choice halves the number that remain. Features chosen must be visible and unambiguous; a feature that depends on judgement, such as "large" or "small", makes an unreliable key.

TIP If two organisms mate and produce living offspring, that alone does not make them the same species; the offspring must themselves be fertile. Sterile hybrids, the mule from horse times donkey or the liger from lion times tiger, are living proof that two organisms can interbreed and still belong to different species.

TIP Digestion, absorption, photosynthesis, transpiration and circulation are real biological processes, but none of them is itself a member of the seven-characteristic list. They are components of the seven: digestion and photosynthesis sit under nutrition, circulation supports respiration and excretion. A question that slips one of these into a list of "characteristics" is testing this distinction.

4 Coordination and response

KEY CONCEPTS

- **Accommodation:** Accommodation is the change in the shape of the lens that focuses light from objects at different distances sharply onto the retina, controlled by the ciliary muscle acting through the suspensory ligaments. For a near object the ciliary muscle contracts, the suspensory ligaments slacken, and the lens becomes fatter, refracting light more. For a distant object the ciliary muscle relaxes, the ligaments become taut, and the lens is pulled thin, refracting light less.
- **Adrenaline:** Adrenaline is produced by the adrenal glands, one on top of each kidney. It is released in situations of fear, stress or excitement, the fight or flight response, and it increases the heart rate and depth of breathing, and increases the blood glucose concentration by causing stored glycogen in the liver to be broken down into glucose, giving the muscles more fuel and oxygen for a sudden burst of activity.
- **Blood glucose control: insulin and glucagon:** Two hormones from the pancreas act on the liver to control blood glucose. When blood glucose is too high, the pancreas releases insulin, which causes the liver to convert excess glucose into glycogen for storage, so blood glucose falls. When blood glucose is too low, the pancreas releases glucagon, which causes the liver to convert stored glycogen back into glucose, so blood glucose rises.
- **CNS and PNS:** The central nervous system (CNS) is the brain and spinal cord; it is the coordinator, deciding which effectors to activate. The peripheral nervous system (PNS) is all the nerves that carry impulses to the CNS from receptors and from the CNS out to effectors.
- **Homeostasis definition:** Homeostasis is the maintenance of a constant internal environment. Cells only work properly within a narrow range of conditions, temperature, water content, and the concentrations of substances such as glucose, so the body must continually detect and correct any drift away from the ideal.
- **Hormone definition:** A hormone is a chemical substance, produced by a gland and carried by the blood, which alters the activity of one or more specific target organs. The glands that make hormones form the endocrine system.
- **Negative feedback:** Negative feedback is the mechanism homeostasis uses: a change is detected, an effector produces a response in the opposite direction to the change, and the factor returns toward its set point. The response then switches off once the set point is restored.
- **Phototropism and auxin:** A shoot grows towards light, positive phototropism, which brings its leaves more light for photosynthesis. The response is controlled chemically by a plant growth substance called auxin, made in the shoot tip, which moves to the shaded side of the shoot and makes the cells there elongate more than those on the lit side, so the shoot bends towards the light.
- **Receptors, coordinators and effectors:** A receptor detects a stimulus, a change in the environment, and converts it into an electrical impulse. A coordinator, usually the CNS, receives impulses from receptors and sends out impulses to the correct effectors. An effector carries out the response; effectors are muscles (which contract) or glands (which secrete a substance).
- **Reflex action:** A reflex action is a fast, automatic response to a stimulus that does not involve conscious thought. In a spinal reflex the spinal cord, not the brain, is the coordinator, which is why a hand can move before the sensation of pain is even felt; impulses still travel up to the brain afterwards so the person becomes aware of what happened.
- **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: sensory senses the stimulus and carries the signal in; motor moves the effector and carries the signal out.
- **The eye's structures:** The cornea refracts most of the light entering the eye. The iris controls the size of the pupil, and so how much light enters. The lens, a transparent flexible biconvex disc, fine-tunes the focusing of light onto the retina. The retina, at the back of the eye, contains the receptor cells (rods and cones) that detect light and start impulses; the fovea, on the light axis, is packed with cones and gives the most detailed vision. The optic nerve carries electrical impulses from the retina to the brain.
- **The pupil reflex and antagonistic iris muscles:** The iris contains two sets of muscle that work as an antagonistic pair: circular muscles run in rings around the pupil, and when they contract the pupil gets smaller; radial muscles run outward like spokes, and when they contract the pupil gets larger. In bright light the circular muscles contract and the radial muscles relax, so the pupil constricts. In dim light the reverse happens, so the pupil dilates.

- **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 the direction of light.
- **Comparing nervous and hormonal control:** Nervous control uses an electrical impulse, transported by neurones, acting very fast with a precise target and a short-lived effect. Hormonal control uses a chemical hormone, transported by the bloodstream, acting more slowly on a more widespread target but with a longer-lasting effect. The body uses the nervous system for anything that must happen now, and the hormonal system for anything that must be sustained.
- **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.
- **How an impulse crosses a synapse:** An electrical impulse arrives at the end of the first neurone, stimulating vesicles to release neurotransmitter into the synaptic gap. The neurotransmitter diffuses across the gap, down a concentration gradient, needing no energy, then binds to receptor molecules on the second neurone, stimulating a new electrical impulse there. Because vesicles are only in the first neurone and receptors are only on the second, transmission can only run one way.
- **Job-sort framework for the eye:** Sort every eye-structure question into one of three jobs: refracting (cornea does most, lens is adjustable), controlling light in (iris and pupil), or detecting (retina, with the fovea as the high-detail spot). Most eye questions are really asking which job a part does.
- **Synapse structure:** Neurones do not touch; the junction between them is a synapse. Vesicles are small sacs inside the swollen ending of the first neurone, each storing molecules of a chemical called a neurotransmitter. The synaptic gap is the small space between the two neurones. Receptors are protein molecules on the membrane of the second neurone that the neurotransmitter can bind to.
- **Temperature control by the skin:** When the body is too hot, sweating cools it as the sweat evaporates and takes heat energy from the body, and vasodilation widens the arterioles supplying the skin capillaries, so more warm blood flows near the surface and more heat is lost. When the body is too cold, shivering releases heat through the respiration that fuels rapid muscle contraction, vasoconstriction narrows those arterioles so less heat is lost, and hair erector muscles raise hairs to trap an insulating layer of air.
- **The reflex arc:** The pathway an impulse follows in a reflex is the reflex arc: stimulus, receptor, sensory neurone, relay neurone (in the spinal cord), motor neurone, effector, response. The reflex arc is the physical wiring; the reflex action is what it produces.
- **Type 1 diabetes:** In Type 1 diabetes the pancreas does not produce enough insulin, so after a meal the blood glucose concentration rises and is not brought back down. It is treated by injecting insulin and by monitoring and controlling the diet, managing carbohydrate intake.

EXAM TIPS

TIP A "compare" question always wants both systems addressed, even if it is phrased around just one of them. Give at least two paired contrasts, for example "nervous control is electrical and fast, whereas hormonal control is chemical and slower", rather than describing only one side.

TIP Two precise points win marks on auxin questions: auxin promotes (increases) cell elongation, it does not destroy cells; and it accumulates on the shaded side of a shoot, not the lit side. Getting either point backwards is the classic error the exam tests for.

TIP The two hormones are endlessly confused. Fix them with the initial-letter trick: insulin puts glucose into store (glucose to glycogen, glucose down). Glucagon is then simply its opposite (glycogen to glucose, glucose up). Get insulin right and glucagon follows.

TIP The pupil reflex and accommodation are different reflexes controlled by different muscles. The iris muscles (circular and radial) control the pupil size in response to light intensity; the ciliary muscle controls the lens shape in response to object distance. If a question is about brightness, think iris; if it is about near versus far focusing, think ciliary.

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

- **Active immunity: the body's own antibodies, and memory cells:** *Active immunity* is defence by antibodies the body makes *itself*, gained after an infection or by vaccination. The first response also produces *memory cells*, which remain after the pathogen is gone; on a second exposure they recognise the antigen and drive antibody production quickly and in large amounts (the secondary response), so active immunity is *long-term*.
- **Antigens and antibodies: the complementary-shape fit:** An *antigen* is a molecule on the surface of a pathogen, with a shape specific to that pathogen. An *antibody* is a protein made by lymphocytes with a shape *complementary* to one specific antigen only, binding it exactly as one key fits one lock. An antibody raised against one pathogen will not bind a differently-shaped antigen on another.
- **Chemical barrier: stomach acid:** *Stomach acid* (hydrochloric acid) kills pathogens swallowed in food and drink, before they can infect the gut. It is the star example of a *chemical* barrier: it destroys pathogens rather than trapping them.
- **Cholera's toxin chain: from bacterium to watery diarrhoea:** *Vibrio cholerae*, a bacterium transmitted indirectly in contaminated water, multiplies in the small intestine and releases a *toxin*. The toxin makes the gut lining secrete *chloride ions* into the gut, which *lowers the water potential* of the gut contents; water then moves out of the blood into the gut *by osmosis*, causing severe watery diarrhoea and dangerous loss of water and ions.
- **Direct transmission: person to person, nothing in between:** *Direct transmission* passes a pathogen straight from one person to another. Routes: direct contact with infected skin; infected body fluids (a shared needle, a blood transfusion); across the placenta or in breast milk, mother to baby.
- **Herd immunity: protection through the population:** When a large proportion of a population is immune (through vaccination), a pathogen finds very few susceptible hosts to spread to, so the chain of transmission breaks. This is *herd immunity*, and it protects even people who are not immune, such as newborn babies too young to be vaccinated, because the pathogen rarely reaches them.
- **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 (how cholera spreads); contaminated surfaces or objects; airborne droplets from coughs and sneezes; animal vectors (a mosquito carrying malaria, a housefly carrying pathogens onto food).
- **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 incoming air; *mucus* in the airways, trapping particles for removal (a trapping action, so mechanical).
- **Oral rehydration therapy and cholera prevention:** *Oral rehydration therapy* is a drink of water, salts (ions) and glucose: water replaces lost fluid, salts replace lost ions and restore the body's water balance, and glucose aids the uptake of ions and water and gives energy. Prevention targets the transmission route: clean treated drinking water, sewage treatment and sanitation, and good hygiene.
- **Passive immunity: borrowed, short-term protection:** *Passive immunity* is short-term defence from antibodies made by *another individual* and received ready-made, across the placenta or in breast milk. Because the body's own lymphocytes were never stimulated, *no memory cells* form, so the borrowed antibodies are not replaced as they break down and protection fades within weeks.
- **Pathogen: the exact definition:** A *pathogen* is a disease-causing organism. The four groups to name with an example each: *bacteria* (*Vibrio cholerae*, tuberculosis), *viruses* (influenza, measles, HIV), *fungi* (athlete's foot) and *protocista* (*Plasmodium*, malaria).
- **Phagocytes engulf; lymphocytes make antibodies:** If a pathogen breaches the barriers, *phagocytes* (white blood cells) carry out *phagocytosis*: they move towards the pathogen, engulf it into a vacuole, and enzymes inside digest it. This defence is *non-specific*, attacking anything foreign. *Lymphocytes*, the other white blood cell, produce antibodies instead (*specific*, see below).
- **Three ways a bound antibody destroys a pathogen:** Once an antibody binds its antigen, it can *mark the pathogen for phagocytosis* (phagocytes then engulf it more easily), cause *agglutination* (clumping many pathogens together), or *neutralise toxins* by acting as an antitoxin. Underneath every specific response, *memory cells* are also produced for long-term immunity.
- **Transmissible disease versus a non-pathogen condition:** A *transmissible disease* (communicable or infectious disease) is one in which the pathogen can be passed from one host to

another. Conditions such as type-1 diabetes or a vitamin deficiency have no pathogen and cannot be caught, however similar the symptoms might sound.

- **Vaccination: active immunity without the illness:** A *vaccine* of weakened or inactivated pathogens (or their antigens) stimulates lymphocytes to make antibodies and *memory cells*, without the person suffering the disease first. If the real pathogen enters later, the memory cells drive a fast, large secondary response that destroys it before it causes disease. Because the person's own lymphocytes did the work, vaccination gives *active*, long-term immunity.
- **Why agglutination helps beyond just clumping:** Agglutination sticks many pathogens together into a clump, which both slows their spread through the body and lets a single phagocyte engulf several pathogens in one bulk engulfing event, rather than tracking each one down separately.

EXAM TIPS

TIP The *antigen* is the marker *on the pathogen*; the *antibody* is the protein the *body makes* to match it. Because the two words look alike, questions deliberately offer swapped versions; check which one is on the pathogen and which one the body produces.

TIP The commonest error in the chapter: *phagocytes engulf* (phago = "eating"); *lymphocytes make antibodies*. Writing either job against the wrong cell reverses the two and loses the mark.

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 Ask: whose lymphocytes made the antibodies? The patient's own (after infection or vaccination) means *active* and long-term; someone else's, handed over ready-made, means *passive* and short-term.

TIP Herd immunity protects the unvaccinated by *stopping the pathogen spreading* through a mostly-immune population, never by giving them antibodies. Do not write that vaccinated people "pass on" their immunity to the unvaccinated; no antibodies are transferred.

TIP *Treatment* means oral rehydration, replacing water, ions and glucose to keep an already-infected patient alive. *Prevention* means clean water, sanitation and hygiene, to break the transmission route before anyone is infected. A question about reducing new cases wants prevention; a question about helping a current patient wants treatment.

TIP A full-mark active/passive comparison names all four contrasts: (1) own antibodies versus received antibodies; (2) made by the body's own lymphocytes versus from another individual; (3) memory cells produced versus not produced; (4) long-term versus short-term.

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 three load bearing parts: the substance must be *taken into the body* (swallowed, inhaled, injected, absorbed); it must *modify or affect* something, not merely pass through unchanged; and the change must be to *chemical reactions in the body*, its biochemistry.
- **How resistance arises: the four-step natural-selection sequence:** Resistance is not something a bacterium decides to develop; it arises by natural selection. (1) Within a large population there is variation: by chance mutation, a few bacteria already carry a resistance gene before the antibiotic is ever used. (2) The antibiotic kills the non-resistant bacteria. (3) The resistant survivors reproduce, passing on the resistance gene. (4) Over time the proportion of resistant bacteria rises until the whole population is resistant, producing a strain such as MRSA. The antibiotic is the selection pressure; it does not create the resistance.
- **The wide definition captures caffeine, alcohol and nicotine too:** Because the definition says nothing about benefit, it captures far more than medicines. Caffeine (in coffee, tea and energy drinks), nicotine (in tobacco) and alcohol (ethanol in drinks) are all drugs, because each one enters the body and alters a chemical reaction, caffeine speeds up transmission at nerve cells, alcohol slows it. Whether a drug is helpful, harmful, legal or illegal is a social judgement layered on top of the biology.
- **What an antibiotic does to bacteria:** An antibiotic is a drug used to treat *bacterial* infections: it either kills the bacteria or stops them multiplying, allowing the body's immune system to clear the remainder. 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 several different antibiotics before finding one that still works, if one exists at all.
- **Why antibiotics work on bacteria but not on viruses:** A bacterium is a living cell with its own cell wall, cell membrane, ribosomes and metabolism, structures and processes an antibiotic can attack, for example by stopping cell wall construction so the cell bursts, or jamming its ribosomes. A virus is not a cell at all: it has no cell wall, no ribosomes and no metabolism of its own, and it reproduces only by hijacking a host body cell from the inside. Because a virus has none of the structures an antibiotic targets, there is nothing for the drug to attack; human cells also differ enough (no cell wall, different ribosomes) that the antibiotic damages the bacterium without seriously harming the patient.
- **Why essential-only use slows the rise of resistance:** Every use of an antibiotic kills the non-resistant bacteria and hands a survival advantage to any resistant ones, so the more often antibiotics are used, including for infections where they are not needed, the more selection pressure is applied and the faster resistant strains spread. Using antibiotics only when they are essential, and always completing the full prescribed course, applies that selection pressure less often and slows the development and spread of resistant strains such as MRSA.

EXAM TIPS

TIP The two most tempting wrong answers always narrow the definition down to "illegal substance" or "medicine". If an option adds the words "illegal", "harmful" or "medicine only", it is almost certainly the distractor, not the syllabus definition, which is deliberately broad.

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

TIP Whenever a question mentions penicillin or "an antibiotic", the first mental note should be the pair of facts, *kills bacteria, no effect on viruses*. Half the marks in this chapter fall straight out of that single line.

TIP In any "few survive and multiply" data question, the marking points are almost always the same four: variation, a few resistant individuals already present by chance; the antibiotic kills the non-

resistant bacteria; the resistant survive; and the survivors reproduce and pass on resistance. Writing all four in order banks full marks.

7 Enzymes

KEY FORMULAS

Converting millimetres to centimetres before substituting

$$1 \text{ cm} = 10 \text{ mm}$$

Convert the diameter and height to centimetres before substituting into $V = \pi r^2 h$, so the answer is already in cm^3 and no separate division at the end is needed. Converting the final volume instead, by dividing by 1000, gives the same answer but is more error prone if a length is forgotten.

Enzyme-substrate reaction sequence



The full four stage cycle of enzyme action. The enzyme leaves the right hand side chemically identical to how it entered the left hand side, so it is immediately available to repeat the cycle.

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. Convert every length to the same unit, normally centimetres, before substituting.

KEY CONCEPTS

- **Active site and substrate:** The *active site* is the region on an enzyme's surface, folded into a precise three dimensional 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 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. Its folded shape is held together by many weak bonds between different parts of the amino acid chain; this shape creates the active site and is exactly what heat and extreme pH destroy, which is why enzymes are damaged by conditions that leave many non protein catalysts unaffected.
- **Enzyme-substrate complex:** When a substrate binds a complementary active site, the temporary combined structure formed is the *enzyme-substrate complex*. This complex forms and breaks apart every time a substrate molecule is processed: the enzyme itself is never used up, but a fresh complex forms on every cycle, which is how a small concentration of enzyme can process a large amount of substrate over time.
- **Specificity:** *Specificity* is the term for an enzyme normally catalysing only one reaction, acting on only one substrate or a small group of closely related substrates, because only that substrate has the complementary shape needed to fit its active site. This is why a cell needs thousands of different enzymes rather than one general purpose enzyme.

- **Why every organism depends on enzymes:** Without enzymes, the reactions of *metabolism*, digesting food, releasing energy, building new molecules, copying genetic material, would proceed far too slowly at normal body temperature to sustain life. Enzymes lower the energy needed for a reaction to get started, so metabolism runs fast enough to support life without the cell raising its own temperature.
- **Explaining the effect of pH:** Extreme pH changes the concentration of hydrogen ions around an enzyme, and these ions interfere with the ionic and hydrogen bonds holding the protein's folded shape together, distorting the active site. Different enzymes have very different optimum pH values matched to where they normally work; pepsin in the stomach has an acidic optimum of around pH 2, while small intestine enzymes have a neutral to slightly alkaline optimum.
- **Explaining the effect of temperature using kinetic theory and denaturation:** As temperature rises towards the optimum, particles have more kinetic energy and collide more often and more successfully, so enzyme-substrate complexes form faster and activity increases. Beyond the optimum, heat instead breaks the weak bonds holding the enzyme's shape together, distorting the active site; this is *denaturation*, and it is permanent.
- **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, the time for a colour change, or the volume of juice produced. Every other condition, enzyme concentration, substrate concentration, volumes used, reaction time before measuring, must be a *controlled variable*.
- **Metabolism:** *Metabolism* is the collective term for the chemical reactions that keep an organism alive. Enzymes control the great majority of these reactions; every one of the seven characteristics of living organisms depends, directly or indirectly, on enzyme controlled reactions running fast enough to sustain life.

EXAM TIPS

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.

TIP Below the optimum temperature, rising kinetic energy causes more successful collisions and a faster reaction. Above the optimum, denaturation distorts the active site and the reaction slows, eventually to zero. Never explain the falling half of the curve using kinetic theory, and never explain the rising half using denaturation.

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.

TIP A result of no activity at all at an extreme pH or temperature should be explained as complete denaturation, the active site destroyed beyond use. It is never correct to explain a zero result as the enzyme working too fast to detect.

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 (chemical reactions in cells), together with substances in excess of requirements. *Egestion*, the removal of undigested food as faeces, is not excretion, because that material passed through the gut but was never absorbed and never took part in the body's metabolism.
- **The kidney's two regions: cortex and medulla:** A kidney cut in longitudinal section shows an outer *cortex*, with a darker granular appearance, and an inner *medulla*, made up of cone-shaped areas with a striped appearance. Urine collects centrally before draining into the ureter.
- **The lungs excrete carbon dioxide; the kidneys excrete urea, excess water and excess ions:** Aerobic respiration in every cell produces *carbon dioxide*, carried in the blood to the *lungs* and breathed out. The *kidneys* remove *urea, excess water and excess ions* from the blood and expel them dissolved in water as *urine*. Urea is a genuine toxic waste made by the liver; excess water and ions are a managed surplus.
- **The nephron: filtering unit of the kidney:** Each kidney contains about a million microscopic *nephrons*. Blood enters via the *afferent arteriole* and reaches the *glomerulus*, a knot of capillaries sitting inside the cup-shaped *renal (Bowman's) capsule*, both in the cortex; blood leaves via the narrower *efferent arteriole*. A long *tubule* leads away from the capsule, loops into the medulla, and drains into a collecting duct, wrapped along its length by a *capillary network* that returns reabsorbed substances to the blood.
- **The urinary system: kidneys, ureters, bladder, urethra:** The *kidneys* (a pair) filter the blood and make urine, receiving blood through the *renal artery* and returning it through the *renal vein*. The *ureters* (one per kidney) carry urine down to the *bladder*, a muscular sac that stores it. The *urethra* carries urine from the bladder out of the body.
- **Urea is made in the liver but excreted by the kidneys:** The single most important sentence in this chapter: absorbed excess amino acids are deaminated in the *liver*, which converts their nitrogen-containing part into *urea*; the urea then travels in the blood to the *kidneys*, which remove it. Different organ makes it, different organ excretes it.
- **Urine is formed by filtration then selective reabsorption:** At the glomerulus, high blood pressure forces water, glucose, ions and urea out of the blood into the tubule as *filtrate*; blood cells and large plasma proteins are too big to be filtered and stay in the blood. Along the tubule, useful substances (all the glucose, most of the water, needed ions) are *selectively reabsorbed* back into the blood, leaving urea and the true excess behind as urine.
- **Assimilation builds proteins up; deamination breaks excess amino acids down:** *Assimilation* is the process in which absorbed amino acids are used by cells to build the body's own proteins, such as enzymes and plasma proteins that help blood clot. Because the body cannot store excess amino acids, any surplus is instead broken down by *deamination*: the liver removes the nitrogen-containing part, converting it into urea, while the remaining carbon-based part can be used in respiration or stored as carbohydrate or fat.
- **What is filtered, what is reabsorbed, what stays in the urine:** At the glomerulus, water, glucose, ions and urea are all filtered into the tubule. Along the tubule, all the glucose and most of the water and needed ions are reabsorbed back into the blood, but urea, excess water and excess ions are not reabsorbed and pass on as urine. Healthy urine is therefore water, urea and excess ions, with no glucose and no protein.
- **Why continuous removal of carbon dioxide matters:** Dissolved carbon dioxide forms carbonic acid in the blood, lowering blood pH; enzymes work only within a narrow pH range. A build-up of carbon dioxide would make the blood too acidic and disrupt enzyme-controlled reactions throughout the body, so continuous removal by the lungs keeps blood pH within safe limits.
- **Why urea's removal matters: toxicity:** Urea is toxic if allowed to accumulate: at high concentrations it poisons cells and disrupts the body's normal functioning, which is eventually life-threatening. The kidneys' continuous removal of urea keeps its blood concentration low enough to be safe, exactly as the lungs' removal of carbon dioxide keeps blood pH safe.

EXAM TIPS

TIP Keep each of the four urinary organs tied to exactly one verb: kidney *filters*, ureter *carries* (kidney to bladder), bladder *stores*, urethra *carries* (bladder to outside). The bladder is never the

correct answer to "which organ excretes X?"; its only job is storage.

TIP "Excreted by the kidneys" is not the same as "filtered by the kidneys". Glucose *is* filtered out of the blood at the glomerulus but it is *not* excreted, because it is entirely reabsorbed and kept. Read the exact wording of a question: excreted means it ends up leaving the body in the urine.

TIP Fix the pair with a simple hook: there are two ur-*E*ters (*E*ntering the bladder, two of them) and one ure*THRA* (the single tube out *THR*ough to the outside). Cortex is on the outer cover; medulla is the middle, and is not to be confused with the medulla of the brain.

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 per minute 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.

Pressure-volume inverse relationship

$$\text{volume} \uparrow \Rightarrow \text{pressure} \downarrow ; \quad \text{volume} \downarrow \Rightarrow \text{pressure} \uparrow$$

For a fixed amount of gas, increasing the volume of a space lowers the pressure inside it, and decreasing the volume raises it. This is the pressure-volume rule that drives ventilation; air then flows from high pressure to low pressure.

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 between two plotted data points, such as 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 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 change is a subtraction; a "how many times" question needs a division.

KEY CONCEPTS

- **Alveoli structure and adaptations:** Each of the hundreds of millions of *alveoli* has a wall one cell thick, is wrapped in capillaries whose walls are also one cell thick, and has a moist lining, giving the lungs roughly 70 m² of exchange surface.
- **Ciliated cells sweep mucus:** *Ciliated cells* have *cilia* that beat in a coordinated, wave-like rhythm, sweeping the mucus, with everything trapped in it, upwards towards the throat, where it is swallowed. This continuous upward conveyor is the *mucociliary escalator*.
- **Definition of a gas exchange surface:** A *gas exchange surface* is any surface across which oxygen and carbon dioxide are exchanged between an organism and its environment. Whether it is the alveolus, the villus or a flattened body surface, an efficient surface always shows the same four features.
- **Diaphragm contraction and relaxation:** The *diaphragm* is a dome-shaped sheet of muscle below the lungs. When it contracts it flattens and moves down; when it relaxes it springs back up into its dome shape. The ribs are bones and are moved by the intercostal muscles, not on their own.

- **Diffusion directions and gradient reasoning:** 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, kept steep by ventilation and circulation.
- **Exercise increases both rate and depth:** During exercise, muscles respire faster and need more oxygen while producing more carbon dioxide, increasing both the *rate* (breaths per minute) and the *depth* (volume per breath) of breathing.
- **External versus internal intercostal muscles:** There are two antagonistic sets of intercostal muscles between each pair of ribs. The *external* intercostal muscles contract to pull the ribs upwards and outwards (breathing in); the *internal* intercostal muscles contract to pull the ribs downwards and inwards (forced breathing out).
- **Full inspiration sequence:** External intercostal muscles contract (ribs up and out) and the diaphragm contracts (flattens and moves down), increasing the volume of the thorax. This lowers the air pressure inside the lungs below atmospheric pressure, so air flows in until the pressures equalise.
- **Goblet cells secrete mucus:** *Goblet cells* in the airway lining secrete *mucus*, a sticky fluid. As air passes over the lining, dust and pathogens get trapped in the mucus instead of reaching the alveoli.
- **Order of structures and the role of each:** Air passes *nose* → *larynx* → *trachea* → *bronchi* → *bronchioles* → *alveoli*. The trachea and bronchi are held open by cartilage; the alveoli are the gas exchange surface; the diaphragm and intercostal muscles, outside the airway, drive ventilation.
- **Table of composition changes:** Compared with inspired air, expired air has *less oxygen* (~21% to ~16%), *more carbon dioxide* (~0.04% to ~4%), *more water vapour* and is *warmer*; *nitrogen* stays at ~78% because the body neither uses nor produces it.
- **The carbon-dioxide detection control chain:** Activity raises respiration, which raises the carbon dioxide concentration in the blood. The *brain detects* this rise and sends more nerve impulses to the breathing muscles, which contract more strongly and more often, increasing the rate and depth of breathing.
- **The four features of an efficient exchange surface:** A *large surface area* lets more molecules cross per second; a *thin wall* gives a short diffusion distance; a *good blood supply* maintains a steep concentration gradient; a *moist, well-ventilated surface* dissolves oxygen and keeps replacing the air side of the gradient with fresh air.
- **Forced expiration:** Quiet expiration is passive, needing no muscle contraction of its own. *Forced* expiration (coughing, blowing up a balloon, exercise) adds an active step: the internal intercostal muscles contract to pull the ribs down and in more strongly, pushing air out faster.
- **Full (quiet) expiration sequence:** The external intercostal muscles relax, so the ribs fall under their own weight and elastic recoil, and the diaphragm relaxes, springing back up into its dome. Both movements decrease the volume of the thorax, raising the pressure inside above atmospheric pressure, so air flows out.
- **Function of cartilage rings:** The trachea and bronchi contain firm, C-shaped rings of *cartilage*. Their function is to hold the airway open and stop it collapsing when the pressure inside falls during a deep, fast breath in. The gap in the C-shape lets the oesophagus behind bulge into it when swallowing.
- **Oxygen debt and recovery:** During hard exercise the muscles cannot get enough oxygen and build up an *oxygen debt* along with extra carbon dioxide. Breathing stays fast and deep after exercise stops to remove the excess carbon dioxide and repay the oxygen debt; a trained athlete recovers faster because of more efficient gas exchange and circulation.
- **Respiration is the cause, and the limewater apparatus:** Aerobic respiration uses oxygen and produces carbon dioxide, which is why expired air has less oxygen and more carbon dioxide. The rise in carbon dioxide is shown with *limewater*: expired air turns a tube of limewater milky faster than inspired air, provided the volume and concentration of limewater and the volume of air passed through are kept the same in each tube.

EXAM TIPS

TIP A frequent lost mark is writing that "cilia trap the dust". Cilia do not trap anything; the *mucus* traps particles, and the *cilia move* the mucus. Keep the two jobs separate: goblet cells make the mucus that traps, ciliated cells sweep the mucus that carries particles away.

TIP "External" and "internal" intercostals are the most common mix-up in this topic. Fix it with a phrase: EXternal for EXpand the chest (breathing in); internal for forced breathing out.

TIP Even though carbon dioxide rises a hundredfold in relative terms, it is still only ~4% of expired air. Nitrogen (~78%) is unchanged and remains the single biggest gas in both inspired and expired air.

TIP "Explain how the alveoli are adapted for efficient gas exchange" wants each feature named *and* paired with its effect on diffusion, e.g. large surface area lets more diffusion happen at once, thin wall shortens the diffusion distance, good blood supply maintains a steep gradient. A feature named without its consequence usually scores half the marks.

TIP The *oesophagus* (gullet) runs next to the trachea but is part of the digestive system, leading to the stomach. On a diagram, the trachea is the tube held open by visible cartilage rings and leading towards the lungs; the oesophagus has no cartilage.

TIP Do not say the alveoli "breathe" or "absorb" gases as if they were active. Every gas movement across the alveolar wall is passive diffusion down a concentration gradient; ventilation and circulation keep the gradients steep, but do not power the crossing itself.

TIP The lungs are passive; they are inflated by the incoming air. The correct causal order is muscles contract, volume increases, pressure falls, air flows in. State it in that order for the marks.

TIP If a graph of lung volume is rising, the person is breathing in: the diaphragm and external intercostals are contracting. If it is falling, they are breathing out: both are relaxing. The slope of the graph tells you the muscle states directly.

TIP Respiration in cells produces carbon dioxide, which is carried by the blood to the alveoli, diffuses into the alveolar air, and is breathed out. Naming *respiration* as the source is the mark that separates a describe answer from an explain answer.

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 more or less indefinitely. Plastics are the classic non-biodegradable pollutant, entangling or being swallowed by animals and slowly fragmenting into microplastics.
- **Biodiversity: definition:** Biodiversity is the number of different species present in an area, and the genetic variety within them. Habitat destruction removes food and shelter for many species at once, and losing one species can cause the decline of others that depended on it.
- **Carbon dioxide and methane: sources:** Carbon dioxide is released by the combustion of fossil fuels in power stations, vehicles and industry, and by deforestation, burning and decay of felled trees plus the loss of photosynthesis that removed it. Methane is released from cattle as a by-product of digestion, from rice paddy fields, and from decaying waste in landfill; molecule for molecule it is a far more powerful greenhouse gas than carbon dioxide, though present in much smaller amounts.
- **Deforestation: definition:** Deforestation is the large-scale removal of forest, usually to obtain timber or to clear land for farming, mining or building.
- **Eutrophication: the six-step chain:** Fertiliser or untreated sewage adds nitrate and phosphate ions to the water. Extra nutrients cause explosive growth of algae and water plants, an algal bloom. The bloom blocks light from plants growing below the surface. Deprived of light, those plants cannot photosynthesise and die. Decomposing bacteria feed on the dead material and multiply rapidly, respiring aerobically. The huge population of respiring bacteria uses up the dissolved oxygen, so fish and other aquatic animals suffocate and die.
- **Four undesirable effects of deforestation:** Deforestation causes loss of habitat and biodiversity, because vast numbers of species lose food and shelter at once; soil erosion, because roots no longer bind the soil and rain washes away the fertile topsoil, with mineral ions leaching downward out of reach of roots; disruption of the water cycle, because less transpiration means less rainfall while faster surface run-off increases flooding and later drought; and contribution to climate change, because trees stop removing carbon dioxide and burning or rotting timber releases the carbon they had stored.
- **Genetic diversity risk in small populations:** A small population contains only a small sample of the alleles that once existed in the species. Breeding within such a small group leads to inbreeding, breeding between close relatives, which increases the chance that offspring inherit two copies of the same harmful recessive allele. Low genetic variation also leaves the population unable to adapt if the environment changes, because there is little variety for natural selection to act on.
- **Greenhouse effect and enhanced greenhouse effect:** The greenhouse effect keeps Earth warm: gases including carbon dioxide and methane absorb long-wave 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, average global temperatures rise, and weather patterns shift, climate change.
- **Habitat destruction: three reasons plus overfishing:** Humans destroy habitats through increased land use for food production, housing and industry; extraction of natural resources such as mining, quarrying and felling timber; and pollution. Overfishing, removing so many individuals of a species that the marine food web is disrupted, is a specific form of habitat destruction even though no land is cleared.
- **Intensive livestock production: advantages and disadvantages:** Intensive livestock production keeps large numbers of animals in a small, closely controlled space. Advantages: more food produced from a given quantity of feed and land, because less energy is lost to movement and heat; lower costs; easier control of diet, health and breeding. Disadvantages: little of the land is left as natural habitat, and disease spreads very easily through the crowded population.
- **Methods of increasing food production:** Humans raise food production using monocultures, chemical fertilisers, insecticides and herbicides, intensive livestock production, and modern agricultural machinery and technology. Each raises yield, and every one has a cost: monocultures are vulnerable to disease, fertilisers wash into waterways and cause eutrophication, and intensive livestock relies on routine antibiotics that drive resistance.
- **Monoculture: advantages and disadvantages:** A monoculture is growing a single crop species, usually a single genetic variety, over a large area. The advantages flow from uniformity and scale: very high yield per unit area, efficient use of machinery, and lower labour costs. The disadvantages flow from the lack of variety: a field of genetically near-identical plants offers a disease no resistant

individuals to slow it down, and monocultures support very few other species and deplete the soil of the specific mineral ions one 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 fertilisers washed off farmland.
- **Reasons for conservation:** Species are conserved to maintain biodiversity and the balance of ecosystems, because species are interdependent; to protect potential future resources such as medicines, foods and materials that come from wild species; to maintain a reservoir of genetic variation that may be needed to breed disease resistance or new traits into crops and livestock; and for ethical, cultural and economic reasons such as ecotourism.
- **Routine antibiotic use and antibiotic resistance:** Animals kept close together in large numbers allow disease to spread very easily, so antibiotics are given routinely, often to the whole herd or flock, to prevent outbreaks and promote faster growth. This kills susceptible bacteria and leaves resistant ones to survive and multiply, natural selection, and resistant bacteria or their resistance genes can pass to bacteria that infect humans.
- **Sustainable resource: forests and fish stocks:** A sustainable resource is one that is removed and used in such a way that it is replaced and does not run out. Forests are managed sustainably by felling only mature trees and replanting a new tree for every one felled. Fish stocks are managed sustainably using quotas, net mesh-size limits that let young fish escape to breed, closed seasons, and protected areas.
- **Assisted reproduction: AI, IVF, studbooks and frozen zoos:** Studbooks and coordinated breeding across zoos ensure the most unrelated individuals are bred together, spreading available genes widely. Artificial insemination transfers collected sperm from a genetically valuable male to a female elsewhere without moving or risking the animals. In vitro fertilisation and embryo transfer fertilise collected eggs outside the body and implant the embryo into a surrogate, allowing breeding even when the valuable individuals cannot mate naturally. Frozen zoos store sperm, eggs and embryos as a long-term reservoir of genetic variation.
- **Conservation methods: habitats, laws, education, seed banks, captive breeding:** Protected habitats such as national parks and marine protected areas conserve whole communities at once and are the most effective method. Laws against hunting and trade in endangered species, and education encouraging sustainable behaviour, support this. Seed banks preserve plant genetic diversity as dried, frozen seeds. Captive breeding programmes breed endangered animals with a view to reintroduction.
- **Disruption of the water cycle by deforestation:** Trees take up water through their roots and return large amounts to the atmosphere by transpiration. Removing them means less water is returned to the air, so local rainfall can fall, while without roots to absorb water and slow run-off, rain runs straight off the land, increasing both flooding and, later, drought.
- **Microplastics accumulate up a food chain:** Once eaten, microplastics and any attached toxins can be passed along a food chain from prey to predator. Each small animal eats many fragments; a small fish eats many small animals, taking in all their accumulated plastic; a large predator eats many of those fish, so the concentration builds up at each stage and is highest in the top predator.
- **Why confinement raises meat yield:** Restricting an animal's movement and keeping it warm means less energy is lost as heat and in muscular activity, so more of the energy in its food goes into growth, and it converts feed to body mass more efficiently.
- **Why disease spreads through a monoculture:** Every plant in a monoculture is the same variety, so all plants are genetically identical or nearly so, sharing exactly the same susceptibility to a new disease with no resistant individual anywhere to act as a barrier. The plants also grow close together, so spores spread easily from plant to plant, and the infection passes through the whole crop.

EXAM TIPS

TIP Biodiversity is the number of different species, not the number of individuals. A field with a million wheat plants and almost nothing else has a huge population but very low biodiversity. Writing "biodiversity means lots of organisms" instead of "lots of different species" is a recurring error the mark scheme penalises.

TIP A fertiliser feeds the crop by supplying mineral ions and does nothing to weeds. A herbicide kills weeds. An insecticide kills insect pests. Attributing a herbicide's job to a fertiliser is one of the most common single-mark losses in this topic.

TIP The oxygen is used up by decomposing bacteria respiring, not by the algae or plants "breathing it in". Writing "the algae use up all the oxygen" scores nothing for this step. Name the decomposers, and say they respire aerobically and therefore remove dissolved oxygen.

TIP The classic error on "state three effects of deforestation" is giving three versions of the same effect, such as "animals die", "plants die" and "species lost", which are all the single idea of lost biodiversity. A well-marked answer names three genuinely different effects from the list of four.

TIP The enhanced greenhouse effect, carbon dioxide and methane trapping heat, is different from the destruction of the ozone layer, caused by a separate set of chemicals that let through harmful ultraviolet radiation. The 0610 syllabus focuses on the greenhouse gases and climate change, not the ozone layer.

TIP "Why does disease spread so easily through a monoculture?" is answered with two linked ideas every time: the plants are genetically identical, so they are all equally susceptible; and they are close together, so the pathogen spreads easily between them. Give both for full marks.

11 Human nutrition

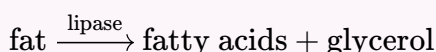
KEY FORMULAS

Comparing an amount eaten against a recommended daily allowance (RDA)

$$\text{shortfall or surplus} = \text{amount eaten} - \text{RDA}$$

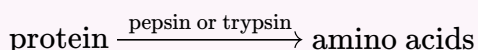
Used when a table gives an RDA and an amount eaten for several nutrients. Calculate this difference for every nutrient individually before deciding which deficiency disease, if any, is at risk.

Fat digestion by lipase



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

Protein digestion by pepsin and trypsin



Used to state what the two proteases do to protein. Pepsin is made and acts in the stomach (optimum around pH 2); trypsin is made in the pancreas and acts in the small intestine (alkaline optimum).

Starch digestion: starch to maltose to glucose



Used to state the full starch-digestion pathway. Amylase (salivary glands and pancreas) produces maltose; maltase, bound to the small intestine's lining, then converts maltose to glucose right at the point of absorption.

Surface-area increase from villi and microvilli

$$\text{surface area factor} = \frac{30 \text{ m}^2}{0.3 \text{ m}^2} = 100$$

Used to express how many times villi and microvilli multiply the small intestine's absorbing surface area, without the gut becoming any longer.

KEY CONCEPTS

- **Balanced diet:** A *balanced diet* contains all the nutrients the body needs, in the right proportions and in enough quantity to keep the body healthy, neither too much nor too little of any one nutrient.
- **Bile emulsifies fat:** *Bile*, made by the liver and stored in the gall bladder, emulsifies fat: it breaks large fat droplets into many smaller droplets in the small intestine, massively increasing the surface area of fat exposed to lipase, without changing any fat molecule chemically.
- **Bile neutralises acidic food entering the duodenum:** Stomach contents arrive in the duodenum still strongly acidic, but the pancreas's enzymes have alkaline optima. *Bile neutralises* this acidic food, raising its pH so trypsin, lipase, and pancreatic amylase can work efficiently, a separate job from emulsification.
- **Capillaries absorb water-soluble products; the lacteal absorbs fat products:** A dense network of *blood capillaries* beneath a villus's epithelium absorbs glucose, amino acids, water, vitamins, and mineral ions. A single central *lacteal*, part of the lymphatic system, absorbs the fatty acids and glycerol from fat digestion.
- **Chemical digestion breaks large insoluble molecules into small soluble ones:** *Chemical digestion* uses enzymes to break large, insoluble food molecules into small, soluble molecules, so

that they can be absorbed. Physical digestion changes only size and shape; chemical digestion breaks actual chemical bonds.

- **Digestive organs and their main functions:** Food travels mouth, oesophagus, stomach, small intestine (duodenum then ileum), large intestine/colon, rectum, anus. The liver makes bile; the gall bladder stores it; the pancreas makes amylase, trypsin, and lipase, 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.
- **Functions of hydrochloric acid:** The stomach lining releases hydrochloric acid, which kills many pathogens taken in with food and provides the optimum acidic pH for pepsin to work at its best.
- **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 or lymph), and *egestion* (passing undigested food out as faeces).
- **Physical digestion increases surface area:** *Physical digestion* breaks food into smaller pieces by mechanical means without changing the food molecules. Its purpose, stated directly in the syllabus, is to increase the surface area of food, which increases the rate at which enzymes can act on it.
- **Rickets:** *Rickets* is caused by a lack of vitamin D, needed for the body to absorb and use calcium. Without enough vitamin D, too little calcium reaches the bones, which 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, needed for healthy connective tissue and wound healing. Connective tissue weakens throughout the body, most visibly as swollen, bleeding gums, and wounds heal unusually slowly.
- **The small intestine is the main site of absorption:** *Absorption* is the movement of small, soluble digested molecules out of the gut into the blood or lymph. The small intestine, with its enormous internal surface area, is the main site of absorption.
- **Villi and microvilli increase surface area:** The small intestine's lining is folded into millions of finger-like *villi*, and each villus's epithelial cells are further folded into *microvilli*. Both structures increase the surface area available for absorption without increasing the gut's length.
- **Assimilation:** *Assimilation* is the separate, later step in which absorbed nutrients are actually taken up and used by the body's cells, for example a muscle cell respiring absorbed glucose. Absorption gets a molecule into the blood; assimilation is cells using it.
- **Bile's two separate roles:** Bile has two distinct jobs: it *emulsifies* fat (a physical role, increasing surface area for lipase) and it *neutralises* acidic food entering the duodenum (a chemical-conditions role, giving the small intestine's enzymes their optimum alkaline pH). Bile itself contains no enzymes.
- **Stomach churning as 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 (pepsin, HCl) also happening there.
- **Tooth structure:** Every tooth has the same four layers: *enamel* (hard 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 *cement* (covers the root, anchoring it in the jawbone).
- **Water absorption and the distinction between absorption and assimilation:** Most water is absorbed in the small intestine, with some further water absorbed in the colon. Absorption (molecules entering the blood or lymph) and assimilation (cells then using those molecules) are two distinct, separately tested steps.

EXAM TIPS

TIP The liver makes bile and the gall bladder stores it. Bile has two separate jobs, covered later in this chapter, but it never itself catalyses a chemical reaction; it is not an enzyme.

TIP "Bile digests fat" is a common but incorrect shorthand. Bile is not an enzyme and breaks no chemical bond in a fat molecule; it only breaks large droplets into smaller ones. The enzyme *lipase* carries out the actual chemical breakdown afterwards.

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

TIP Rickets is really a *calcium-use* problem caused by a vitamin D shortage: vitamin D controls how much dietary calcium is actually absorbed. Read deficiency questions for which nutrient is reported as low before naming the disease.

TIP Pepsin and trypsin catalyse the same type of reaction but work in very different environments. No single enzyme has an optimum pH spanning both the highly acidic stomach and the alkaline small intestine, which is why the body needs two separate proteases.

12 Inheritance

KEY FORMULAS

Complementary base pairing

$$A \leftrightarrow T, \quad C \leftrightarrow G$$

Use to work out the complementary strand of a DNA molecule from a given base sequence, keeping the bases in the same left-to-right order. Adenine always pairs with thymine; cytosine always pairs with guanine.

Fertilisation restores the diploid number

$$\text{haploid gamete} + \text{haploid gamete} \rightarrow \text{diploid zygote}$$

Two haploid gametes (23 chromosomes each in humans) fuse at fertilisation to restore the full diploid number (46). This is why gametes must be haploid, otherwise the chromosome number would double every generation.

Two-heterozygote cross ratio

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

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

Codominant heterozygote cross ratio

$$C^R C^W \times C^R C^W \rightarrow 1 C^R C^R : 2 C^R C^W : 1 C^W C^W \Rightarrow 1 \text{ red} : 2 \text{ roan} : 1 \text{ white}$$

Use for a cross between two heterozygotes at a codominant locus. The phenotype ratio is 1:2:1, not 3:1, because the heterozygote has its own distinct phenotype rather than looking like one of the homozygotes.

Probability from a Punnett square

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

For a two-heterozygote cross there are always 4 boxes, so probabilities come in quarters. Read the question carefully to see whether it asks for a probability among all offspring or only among one sex.

KEY CONCEPTS

- **Chromosome, gene and allele: the size hierarchy:** A *chromosome* is a thread-like structure made of DNA, carrying genes in a fixed linear order. A *gene* is a length of DNA that codes for a particular protein. An *allele* is an alternative version of a gene.
- **DNA controls the cell by controlling proteins:** DNA controls how a cell works by controlling which proteins the cell makes. The sequence of bases in a gene determines the sequence of amino acids in a protein, and the amino acid sequence determines how the protein folds and what it does.
- **Dominant and recessive alleles:** 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, since a dominant allele would otherwise mask it.
- **Genotype, phenotype, homozygous, heterozygous:** *Genotype* is the alleles an organism has (for example Tt); *phenotype* is its observable characteristics (for example "tall"). *Homozygous* means two identical alleles (TT , tt); *heterozygous* means two different alleles (Tt).
- **Haploid and diploid:** A *diploid* nucleus contains two sets of chromosomes, present in pairs; body cells are diploid. A *haploid* nucleus contains one set of chromosomes, unpaired; gametes are haploid. In humans, a diploid body cell has 46 chromosomes (23 pairs); a haploid gamete has 23.

- **Meiosis is a reduction division producing variation:** *Meiosis* is nuclear division that produces cells with half the number of chromosomes of the parent cell (a reduction division), used to make gametes. The cells it produces are genetically different from each other and from the parent cell.
- **Mitosis produces identical daughter cells:** *Mitosis* is nuclear division that produces two genetically identical daughter cells, each with the same number of chromosomes as the parent cell. Each chromosome is copied exactly before division, and one copy of each goes to each daughter cell.
- **Protein synthesis: DNA to protein:** The base sequence of a gene is copied in the nucleus to make *mRNA*, which carries the copied code out of the nucleus to a *ribosome* in the cytoplasm, where it is used to join amino acids in the correct order. Flow of information: DNA (gene) → mRNA → ribosome → protein.
- **Roles of mitosis:** Mitosis is responsible for *growth* (producing new cells identical to existing ones), *repair* of damaged tissue, *replacement* of worn-out cells, and *asexual reproduction* in organisms that reproduce this way.
- **Same genes, different cells: gene expression:** Every body cell of an organism contains the same complete set of genes, but only some of the genes in a given cell are switched on (expressed). Cells differ because different genes are expressed in them, not because they contain different genes.
- **ABO blood groups: three alleles:** The human ABO blood group gene has three alleles: I^A and I^B are codominant with each other, and I^O is recessive to both. A person with genotype $I^A I^B$ has blood group AB, showing both antigens A and B together.
- **Codominance: both alleles expressed together:** In *codominance*, both alleles in a heterozygote are fully expressed in the phenotype, rather than one masking the other. In cattle, a red allele and a white allele are codominant, and a heterozygote is roan, showing red hairs and white hairs together.
- **Mitosis and meiosis contrasted:** Mitosis gives 2 daughter cells, same chromosome number as the parent, genetically identical; its roles are growth, repair, replacement and asexual reproduction. Meiosis gives 4 daughter cells, half the chromosome number, genetically different; its role is producing gametes for sexual reproduction.
- **Sex determination by sperm type:** Females are XX, males are XY. All eggs carry an X; sperm carry an X or a Y in roughly equal numbers. X-sperm with an egg gives XX (female); Y-sperm with an egg gives XY (male), giving an expected 1:1 ratio of girls to boys.
- **Sex-linked inheritance:** A *sex-linked characteristic* is controlled by a gene carried on the X chromosome. Because males have only one X, a recessive allele on it is expressed even with a single copy, so sex-linked recessive conditions such as red-green colour blindness are far more common in males than females.
- **Stem cells divide by mitosis:** A *stem cell* is an unspecialised cell that divides, by mitosis, to produce daughter cells that can become specialised. Sources include red bone marrow in adults and the early embryo, both dividing by mitosis to supply new cells that then specialise.
- **Why gametes must be made by meiosis, not mitosis:** If gametes were made by mitosis they would be diploid, and fertilisation would double the chromosome number every generation. Meiosis halves the number first, so fertilisation restores exactly the diploid number, and it also shuffles alleles into new combinations.

EXAM TIPS

TIP If a question describes a division that halves the chromosome number, produces gametes, or produces genetically varied cells, it is meiosis. If it describes cells that are genetically identical, that is mitosis, never meiosis.

TIP Genes code directly for proteins such as enzymes, haemoglobin, collagen and antibodies. Carbohydrates (starch, glycogen, glucose) and fats are not proteins and are not coded for directly by a gene; DNA only controls them indirectly, via the enzymes that build them.

TIP Crossing an unknown-genotype individual with a homozygous recessive lets the offspring phenotypes reveal the unknown parent's alleles directly. If even one recessive-phenotype offspring appears, the unknown parent must be heterozygous.

TIP Nucleus, chromosome, gene, DNA: the nucleus contains chromosomes, a chromosome is made of DNA, and a gene is a length of that DNA. Almost every one-mark definition question tests whether a term is placed at the correct level of this hierarchy.

TIP A common exam trap offers "half the parent's chromosome number" as a tempting wrong answer for mitosis. Mitosis keeps the chromosome number the *same* as the parent; only meiosis halves 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 using carrier proteins powered by energy from respiration; this is the opposite direction to diffusion and osmosis.

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. The concentration at which percentage change crosses zero is the concentration with the same water potential as the potato cell sap.

Predicting direction of water movement from water potential values

$-50 \text{ kPa} > -200 \text{ kPa} \implies$ water moves from -50 to -200 kPa

Compare two water potentials on a number line. Water always moves from the higher (less negative) value toward the lower (more negative) value, down the water potential gradient.

Surface-area-to-volume ratio of a cube

$$SA : V = \frac{6L^2}{L^3} = \frac{6}{L}$$

For a cube of side L , surface area is $6L^2$ and volume is L^3 . As L increases, $6/L$ falls, so a larger cube (or cell) has a smaller surface area relative to its volume.

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 *carrier proteins* powered by *energy from 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 requires no membrane and no energy input from the cell.
- **Definition of osmosis:** Osmosis is the net movement of water molecules from a region of higher water potential (a dilute solution) to a region of lower water potential (a concentrated solution), through a *partially permeable membrane*. Pure water has the highest (zero) water potential; dissolving solute lowers it.
- **Diffusion and gas exchange at a respiring cell:** Aerobic respiration continuously uses up oxygen and produces carbon dioxide, keeping oxygen concentration lower and carbon dioxide concentration higher inside a respiring cell than in the blood. Oxygen therefore diffuses in and carbon dioxide diffuses out, both down their own gradients.
- **Factors affecting rate of diffusion:** Diffusion is faster with a *larger surface area*, a *steeper concentration gradient*, a *shorter distance*, a *higher temperature*, and *smaller, non-polar* molecules. Each factor acts independently; a real exchange surface is built to maximise several at once.
- **Osmosis in animal cells:** In pure or dilute water, water enters an animal cell by osmosis and, with no wall to resist, the cell swells and *bursts (lysis)*. In a concentrated solution, water leaves and the cell shrinks and shrivels (*crenation*). In a solution of equal water potential, there is no net movement.
- **Surface-area-to-volume ratio and the limits of diffusion:** As an object gets larger, its volume grows faster than its surface area, so its surface-area-to-volume ratio (SA:V) *falls*. A large object

therefore has too little surface, relative to its bulk, to be supplied by diffusion alone, which is why large, active organisms need specialised exchange surfaces and a transport system.

- **The feature unique to active transport:** Some facilitated diffusion also uses carrier proteins, so "uses a carrier protein" alone does not identify active transport. The feature unique to active transport is moving substances *against* the concentration gradient using *energy from respiration*.
- **Turgid, flaccid and plasmolysed plant cells:** In a solution of higher water potential, a plant cell takes in water and becomes *turgid* (firm, wall under pressure). Losing some water makes it *flaccid* (soft). In a solution of much lower water potential, so much water leaves that the membrane pulls away from the wall: the cell is *plasmolysed*.
- **Water potential versus water and solute concentration:** A concentrated solution has a *low* water potential; a dilute solution has a *high* water potential. Water always moves from higher to lower water potential, which is the same rule as moving from higher to lower water concentration, expressed in the Extended vocabulary.
- **Why membranes let some substances diffuse and not others:** The cell membrane is largely a *lipid* layer, so small, *non-polar (lipid-soluble)* molecules such as oxygen and carbon dioxide diffuse across it easily. Large molecules and charged ions cross far less readily and often need a carrier protein or active transport.
- **Glucose absorption in the small intestine:** Most glucose is absorbed from the gut by diffusion while its concentration there is high, but toward the end of digestion the gut glucose concentration can fall below that in the blood. The intestine lining then uses *active transport* to absorb the remaining glucose against the gradient.
- **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. "Net diffusion stops at equilibrium" is the accurate statement.
- **Root hair cells: mineral ion uptake and mitochondria:** Soil water is often dilute in mineral ions, yet a root hair cell's own ion concentration is already higher, so the cell must use active transport, not diffusion, to take up more. This is why root hair cells contain *many mitochondria*, to supply the energy the carrier proteins need.
- **Water as the body's solvent:** Water is the solvent that dissolves glucose, mineral ions, amino acids and urea so they can be transported in blood plasma or in xylem and phloem sap. A substance must usually be dissolved before it can be transported or take part in reactions.

EXAM TIPS

TIP Living systems have negative water potentials; pure water is the zero maximum. "Higher water potential" means *closer to zero* (for example -50 kPa is higher than -200 kPa). Water still moves from the higher (less negative) value to the lower (more negative) value.

TIP Diffusion happens equally in open air, in a liquid, and across a membrane. Building "across a partially permeable membrane" into a definition of diffusion has accidentally defined *osmosis* instead; keep the general definition membrane-free.

TIP Diffusion and osmosis are passive and move substances *down* a gradient with no energy cost. Active transport moves substances *against* a gradient and *always* costs energy from respiration; a respiratory poison stops active transport but does not stop diffusion or osmosis.

TIP Osmosis, like all diffusion, is a *passive* process. A statement pairing water movement with "uses energy from respiration" or "against the water potential gradient" is describing active transport, not osmosis.

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. Convert both lengths to the same unit before dividing.

Converting between millimetres and micrometres

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

There are 1000 micrometres in one millimetre. Multiply by 1000 to convert millimetres to micrometres; divide by 1000 to convert micrometres to millimetres. Extended candidates are examined on both directions.

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.

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, including plasmids:** A bacterial cell has a cell wall, a cell membrane, cytoplasm, ribosomes, a single loop of circular DNA lying free in the cytoplasm, and usually one or more *plasmids*, small separate circular loops of DNA that can carry extra genes such as antibiotic resistance. It has no nucleus, no mitochondria, no chloroplasts, and no permanent vacuole.
- **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, an acrosome, 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, plasmids; 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 If the image size and the actual size are given in different units, centimetres and micrometres for example, convert both to the *same* unit before applying the magnification formula. Dividing mismatched units gives an answer that is out by a factor of 10, 1000, or worse, with no warning that anything has gone wrong.

TIP A bacterial cell still has genetic material, its single circular chromosome and any plasmids; 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 FORMULAS

Energy transferred to the next trophic level

$$E_{\text{next level}} = E_{\text{this level}} \times \frac{10}{100}$$

Use once per step up the food chain. On average about 10% of the energy at one trophic level is transferred to the level above it; the rest is lost, mainly as heat.

Compounding energy transfer across n trophic levels

$$E_n = E_0 \times \left(\frac{10}{100} \right)^n$$

Use when a consumer is n trophic levels above the producer (E_0). Apply the 10% transfer once for every step; each extra level multiplies the remaining energy by another 10%.

Percentage ecological efficiency of a transfer

$$\text{efficiency (\%)} = \frac{\text{energy transferred to next level}}{\text{energy available at current level}} \times 100$$

The general definition behind the "10%" teaching average; measured efficiencies for real transfers range from under 1% to over 25% depending on the organisms involved.

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 is one way, unlike nutrient cycling:** Energy passes from organism to organism along a food chain, getting smaller at every handover, and eventually leaves the ecosystem as heat. Unlike carbon or nitrogen atoms, energy is never recycled, so the Sun must constantly resupply it; this one-way loss is the reason food chains are short and ecological pyramids behave the way they do.
- **Four factors affecting population size:** A population's rate of growth is affected by food supply (more food supports faster growth), competition for limited resources (which intensifies as the population grows), predation (more predators lowers the prey population), and disease (which spreads more easily in a large, crowded population). These factors are strongly density-dependent, which is why populations level off rather than growing forever.
- **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 and the energy sequence:** The principal source of energy input to biological systems is the Sun. A producer absorbs light energy and, by photosynthesis, converts it into chemical energy stored in glucose and other organic molecules; that chemical energy is then passed to a consumer when the consumer feeds.
- **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. The primary consumer eats the producer, the secondary consumer eats the primary consumer, and so on up the chain.

- **The 10% rule and why energy is lost between trophic levels:** On average only about 10% of the energy in one trophic level is transferred to the next; roughly 90% is lost, through respiration (released as heat), movement (also ending as heat), undigested waste egested as faeces, and nitrogen-containing waste lost in excretion. Because the energy remaining shrinks by about ten times at every step, food chains rarely reach more than four or five trophic levels: eventually there is too little energy left to support another level.
- **The four bacteria groups of the nitrogen cycle:** Neither plants nor animals can use nitrogen gas directly. Nitrogen-fixing bacteria (free in the soil and in legume root nodules) convert nitrogen gas into nitrogen compounds plants can absorb. Plants build proteins from absorbed nitrate; decomposers break dead protein and waste down into ammonium ions. Nitrifying bacteria convert ammonium into nitrate, needing oxygen. Denitrifying bacteria convert nitrate back into nitrogen gas in waterlogged, oxygen-poor soil, removing usable nitrogen.
- **Three kinds of ecological pyramid:** A pyramid of numbers has bar width proportional to the number of organisms at each trophic level; it can be inverted when one large organism supports many small ones. A pyramid of biomass has bar width proportional to the dry mass of living material; it is almost always a true pyramid. A pyramid of energy has bar width proportional to the energy flowing through each level per unit area per year; because energy always decreases up the chain, it is never inverted.
- **The sigmoid growth curve and what causes each phase:** The lag phase is slow because there are too few breeding individuals. The exponential (log) phase is fast because resources are plentiful and competition, predation and disease are all low, so nearly all offspring survive. The stationary phase levels off specifically because food and space become limiting and competition, predation and disease increase in the crowded population, so the birth rate falls until it equals the death rate.
- **Why a pyramid of energy is never inverted:** Because energy always decreases from one trophic level to the next, every energy bar is smaller than the one below it, so a pyramid of energy is always a true, right-way-up shape regardless of the sizes or numbers of organisms involved. It is also the most accurate measure, because it is based on the rate energy flows through each level rather than a single snapshot of numbers or mass.
- **Why eating crops directly is more energy-efficient than eating livestock:** A food chain with fewer steps wastes less energy. Eating crop plants directly is a one-step chain, so the human trophic level receives roughly 10% of the crop's energy. Feeding the crop to livestock first adds a step, so only about 10% of 10% (about 1%) of the crop's original energy reaches the human, because roughly 90% is lost in the livestock's respiration, movement, body heat and waste. A given area of farmland can therefore feed more people on a plant diet than on a meat diet.

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 Fixation takes nitrogen gas in, from the atmosphere into soil compounds. Nitrification turns ammonium into nitrate within the soil. Denitrification sends nitrogen gas back out, from soil nitrate to the atmosphere. Mixing up the direction each process moves nitrogen is the single biggest source of lost marks in this topic.

TIP A very common slip is stopping after a single 10% step and quoting the primary consumers' energy as the answer for a higher level. Count how many transfers separate the level asked about from the producer, and apply the 10% that many times.

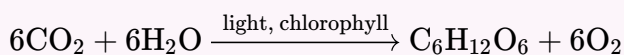
TIP Name the form of energy precisely: light energy before it reaches the producer, chemical energy once stored in food, and heat energy once lost to the surroundings. Vague terms such as "food energy" or "Sun energy" throw away easy marks.

TIP In the stationary phase the population is not dead and organisms are not failing to reproduce; births and deaths are both happening, but at equal rates, so the total stays constant. Describing it as "the population stops reproducing" loses the mark; the correct idea is a balance between birth rate and death rate.

16 Plant nutrition

KEY FORMULAS

Balanced chemical equation for photosynthesis



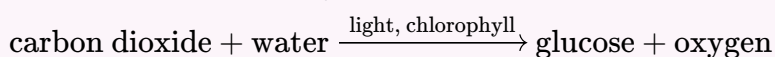
Required at Extended tier alongside the word equation. Check the balance atom by atom: 6 carbon, 18 oxygen and 12 hydrogen on each side.

Rate of photosynthesis by bubble count

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

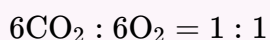
Standardises gas bubble counts from an aquatic plant taken over different time intervals so results at different light intensities, carbon dioxide concentrations or temperatures can be compared.

Word equation for photosynthesis



Reactants on the left, products on the right; light and chlorophyll sit above the arrow because neither is chemically consumed.

The 1:1 ratio of carbon dioxide used to oxygen released



Read directly from the balanced equation; explains why the leaf-disc and hydrogencarbonate-indicator experiments can track photosynthesis by following either gas.

KEY CONCEPTS

- **Chlorophyll: location, role and catalyst-like behaviour:** Chlorophyll is held on the internal membranes of chloroplasts. It transfers light energy into chemical energy for building carbohydrates, absorbing mainly red and blue light and reflecting green. It is not used up; it behaves like a catalyst, regenerated to capture light again.
- **Definition of photosynthesis:** Photosynthesis is the manufacture of carbohydrates from carbon dioxide and water, using light energy. A plant is *autotrophic*, making its own organic food from inorganic raw materials, unlike *heterotrophic* animals and fungi.
- **Destarching and controlled-experiment logic:** Destarching (24 to 48 hours in darkness) removes existing starch so any starch found afterwards was made during the experiment. Every requirement experiment changes only one factor and includes a control with that factor present.
- **Fates of the glucose made in photosynthesis:** Glucose is respired for energy, converted to insoluble starch for storage, converted to soluble sucrose for transport in phloem, built into cellulose for cell walls, combined with nitrate ions to make amino acids and proteins, or stored as lipids in some seeds.
- **Limiting factors: explaining the graph shapes:** Light and carbon dioxide graphs rise (that factor limiting) then plateau (a different factor now limiting); the plateau height depends on the level of the held-constant factor. The temperature graph rises to an optimum then falls sharply as the enzymes controlling photosynthesis denature.
- **Mineral ions: nitrate and magnesium:** Nitrate ions supply nitrogen for amino acids and proteins; deficiency stunts growth. Magnesium ions are needed to make chlorophyll; deficiency causes yellowing between the leaf veins (chlorosis) and slower photosynthesis.

- **The four-step starch test:** Boil the leaf in water (kills cells, stops reactions), 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 present).
- **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 (large air spaces), lower epidermis (most stomata, guard cells), with a vascular bundle (xylem delivering water, phloem carrying sucrose away) running through the middle.
- **Using limiting factors: glasshouse growers:** Growers raise light (lamps), temperature (heaters) and carbon dioxide (enrichment) to push the rate of photosynthesis higher. Raising a factor that is not currently limiting wastes money for no extra yield; identify the limiting factor first.
- **Broad, flat and thin: overall leaf-shape adaptations:** A broad, flat blade gives a large surface area for absorbing light and carbon dioxide. A thin blade shortens the diffusion distance for carbon dioxide and lets light penetrate to every photosynthesising cell.

EXAM TIPS

TIP Every "is X needed?" experiment must destarch first, vary only the one factor under test, and include a control that has the factor present. Missing the control means the result cannot be attributed to that factor alone.

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

TIP Enzymes are not alive, so heat cannot kill them; high temperature denatures them, changing the active site's shape so it stops working. This applies only above the optimum; below it enzymes simply work more slowly.

TIP In a glasshouse question, whichever factor you raise that produces no change was not limiting; the factor that, when raised, makes the rate jump was the limiting one. A cold but sunny day usually points to temperature.

TIP Glucose is made and respired; starch is the insoluble storage carbohydrate; sucrose is transported in phloem; cellulose builds cell walls; lipids are an energy-dense store in some seeds. Swapping any two roles is a common dropped mark.

17 Reproduction

KEY FORMULAS

Direction of exchange at the placenta: useful substances

oxygen, glucose, amino acids : mother's blood → fetus's blood

Useful substances diffuse from the mother's blood to the fetus's blood across the placenta, each moving down its own concentration gradient, because the fetus continuously uses oxygen and nutrients.

Pollination direction

anther → stigma

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

Restoring the diploid number at fertilisation

$n + n \rightarrow 2n$

A haploid gamete nucleus (n chromosomes) fuses with another haploid gamete nucleus (n chromosomes) to form a diploid zygote ($2n$ chromosomes). This keeps the chromosome number constant from generation to generation.

Direction of exchange at the placenta: waste products

carbon dioxide, urea : fetus's blood → mother's blood

Waste products diffuse from the fetus's blood to the mother's blood across the placenta, down their own concentration gradient, so the mother can remove them.

The hormonal control chain of the menstrual cycle

FSH → egg matures, oestrogen produced → LH → ovulation → progesterone maintains lining

FSH causes an egg to mature and stimulates oestrogen production, which thickens the lining and triggers a surge leading to LH, which causes ovulation; progesterone from the corpus luteum then maintains the thickened lining.

KEY CONCEPTS

- **Definition of asexual reproduction:** Asexual reproduction is the process resulting in the production of *genetically identical* offspring from *one parent*. Because there is only one parent and no fusion of gametes, the offspring inherit an exact copy of the parent's DNA by mitosis, so they are clones: same genotype, same phenotype barring environmental differences.
- **Definition of sexual reproduction and fertilisation:** Sexual reproduction is the process involving the *fusion of the nuclei of two gametes* to form a zygote, and the production of offspring that are *genetically different* from each other. Fertilisation is defined precisely as the fusion of the nuclei of two gametes; the precise word examiners require is *nuclei*, not "the sperm and egg join".
- **Egg cell: adaptive features:** An egg cell is *large*, with cytoplasm containing food stores for the zygote before implantation. Its membrane *changes* immediately after one sperm enters, stopping any other sperm getting in and preventing extra chromosomes. Eggs are produced in small numbers, usually one per cycle.
- **Female reproductive system: parts and functions:** The *ovary* produces egg cells and the hormones oestrogen and progesterone. 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).
- **FSH and LH: the pituitary hormones controlling the ovary:** *FSH* (follicle-stimulating hormone), from the pituitary gland, causes an egg to mature in the ovary and stimulates the ovary to produce oestrogen. *LH* (luteinising hormone), also from the pituitary gland, causes ovulation, the release of the egg, at about day 14.
- **Haploid gametes, diploid zygote:** Every ordinary body cell is *diploid*, carrying two full sets of chromosomes. If two diploid gametes fused, the offspring would have double the chromosomes, doubling again every generation. To prevent that, gametes are *haploid*, carrying one set of chromosomes; fusing two haploid gamete nuclei restores the diploid number in the zygote.
- **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*. It is not fertilisation, and it is not the pollen reaching the ovule; keeping pollination (transfer) separate from fertilisation (nuclei fusing in the ovule) 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 by aerobic respiration, 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.
- **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 a main female sex hormone, produced by the ovaries; it drives breast growth, wider hips, body hair growth and the start of the menstrual cycle.
- **Advantages and disadvantages of asexual reproduction:** *Advantages:* only one parent is needed, so it is fast and reliable, can colonise an area quickly, and every offspring inherits the parent's already successful genotype. *Disadvantages:* there is no genetic variation, so if the environment changes, for example a new disease appears, the whole population shares the same weakness and could be wiped out together.
- **Advantages and disadvantages of sexual reproduction:** *Advantages:* sexual reproduction produces *genetic variation* among offspring, since two parents' alleles are shuffled and combined, and variation means some offspring may survive a changing environment. *Disadvantages:* it needs two parents (or at least two gametes), is usually slower, and produces fewer offspring per parent.
- **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 units before they reach a transfusion recipient. *Testing and treating* infected people, including contact tracing, stops them passing the infection on; some bacterial STIs, such as gonorrhoea, can be cured 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 diploid *zygote*. The zygote divides by mitosis 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.
- **Menstrual cycle stages by uterus lining:** Days 1 to 5 are *menstruation*: the lining breaks down and is lost. Days 6 to 13 are repair and thickening, while an egg matures in an ovary. Around day 14 is

ovulation: an egg is released into the oviduct. Days 15 to 28 are maintenance, with the lining kept thick ready for a fertilised egg.

- **Self- and cross-pollination and their genetic consequence:** *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; using one parent's alleles only, it produces *less genetic variation*. *Cross-pollination* is the transfer of pollen to a flower on a different plant of the same species; bringing together alleles from two parents, it produces *more genetic variation*.
- **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 HIV is passed on through unprotected sexual intercourse, infected blood (for example sharing needles or an untested transfusion), and from mother to child across the placenta, during birth, or through breast milk. Hugging, shaking hands and sharing cups or plates do *not* transmit it.

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 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 the same.

TIP Whenever a question mentions a *changing environment*, a *new disease*, or *long-term survival* of a species, the expected advantage is variation from sexual reproduction. Whenever it mentions *speed*, *one parent*, or *keeping a good variety*, the expected advantage is asexual reproduction.

TIP The "monoculture wiped out by one disease" scenario is the examiners' favourite disadvantage. If a question describes a whole field of genetically identical crops, the expected answer is: no variation, so if one plant is susceptible to a disease, all are, and the entire crop can be lost.

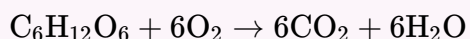
TIP Progesterone *maintains* the uterus lining; when progesterone *drops*, because the corpus luteum breaks down without a pregnancy, the lining can no longer be maintained and breaks down. Almost every menstrual-cycle data question is really testing whether this one relationship can be applied to a graph.

TIP The placenta is not a perfect barrier. Some pathogens, for example HIV and rubella virus, and toxins, for example nicotine and alcohol, can cross the placenta from the mother to the fetus and harm its development.

18 Respiration

KEY FORMULAS

Balanced chemical equation for aerobic respiration



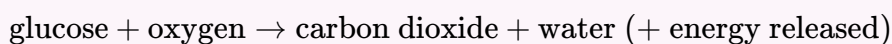
Extended only. Expresses the same reaction as the word equation using molecular formulae and exact molecule ratios: one glucose molecule reacts with six oxygen molecules to produce six carbon dioxide and six water molecules (ratio 1 : 6 : 6 : 6).

Rate of gas production

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

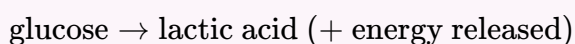
Use to calculate bubbles per minute, or volume of gas per minute, from a count and a time. Round to the number of significant figures appropriate to the measurement, not to the raw calculator output.

Word equation for aerobic respiration



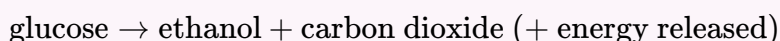
Two reactants combine to form two products, with energy released as an outcome of the reaction rather than a listed product. Learn as a fixed sequence for fill the gap questions.

Word equation for anaerobic respiration in muscle



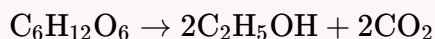
Only one product, lactic acid, and critically no carbon dioxide. This is the pathway muscle cells switch to when they cannot obtain enough oxygen fast enough during vigorous exercise.

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).

Balanced chemical equation for anaerobic respiration in yeast



One molecule of glucose produces two molecules of ethanol and two molecules of carbon dioxide (ratio 1 : 2 : 2). Scale every coefficient by the same factor to find the yield from a different starting quantity of glucose.

KEY CONCEPTS

- **Aerobic respiration definition:** *Aerobic respiration* releases a relatively large amount of energy by breaking down glucose using oxygen. It breaks glucose down completely, extracting close to the maximum energy available, and is the pathway most cells run whenever oxygen is available.
- **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 for metabolism. 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 much less energy per glucose molecule than aerobic respiration, commonly quoted as around twenty to twenty five times less. Aerobic respiration breaks glucose all the way down to carbon dioxide and water; anaerobic respiration stops early, at lactic acid or ethanol, both still energy rich.
- **Four uses of energy released by respiration:** *Movement* (muscle contraction, cytoplasmic streaming in some cells), *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, usually bubbles per minute or volume of gas per minute. Every other variable (volume and concentration of yeast suspension, volume and concentration of glucose solution, reaction time) must be *controlled*.
- **What an oxygen debt is:** An *oxygen debt* is the extra oxygen the body needs after exercise to break down the lactic acid that built up in the muscles during anaerobic respiration. It is "repaid" once oxygen is available again, through continued fast, deep breathing.
- **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, sperm cells, and liver 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 red in normal air, turns *yellow* as carbon dioxide concentration rises, and turns purple or violet if carbon dioxide concentration falls below atmospheric level.
- **Where the oxygen debt is repaid: the liver:** Lactic acid diffuses out of the working muscle into the bloodstream, is transported to the *liver*, and is broken down there using the extra oxygen supplied by continued fast, deep breathing. Removal happens at the liver, not back in the muscle where the lactic acid was produced.

EXAM TIPS

TIP Carbon dioxide and water are shared with the aerobic equation only; anaerobic respiration in muscle produces lactic acid with no carbon dioxide at all. The reliable check for "which pathway is this" is whether oxygen appears as a *reactant*: present means aerobic, absent means anaerobic.

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 is a breaking down (catabolic) process that consumes oxygen and glucose and produces carbon dioxide and water; photosynthesis is a building up (anabolic) process that

consumes carbon dioxide and water and produces glucose and oxygen. Sharing the same four substances does not make the two equations identical.

TIP Both pathways run simultaneously in working muscle during vigorous exercise, with the balance shifting toward anaerobic as intensity rises. Never write that aerobic respiration "stops" during exercise.

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.

TIP Both aerobic and anaerobic respiration in yeast produce carbon dioxide, so a positive limewater result alone does not identify which pathway is running. Distinguishing them requires comparing the *rate* of carbon dioxide production with and without oxygen, or testing specifically for ethanol.

TIP If a question states the precision used elsewhere in a results table, that is a direct instruction for your own answer's precision, not background colour. Always match it rather than reporting a raw calculator output.

TIP Glucose contributes 6 carbon, 12 hydrogen, 6 oxygen atoms. Six O_2 molecules contribute 12 more oxygen atoms. Six CO_2 contributes 6 carbon and 12 oxygen; six H_2O contributes 12 hydrogen and 6 oxygen. Both sides total 6 carbon, 12 hydrogen, 18 oxygen, confirming the equation is balanced.

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.

Left ventricle wall thickness vs right ventricle

$\text{thickness}_{\text{LV}} \approx 3 \times \text{thickness}_{\text{RV}}$

The left ventricle wall is roughly three times thicker than the right ventricle wall. More muscle allows a greater contraction force, generating the higher pressure needed to pump blood all the way around the whole body, rather than just the short distance to the nearby lungs.

Heart rate from a timed pulse count

$\text{heart rate (bpm)} = \text{count} \times \frac{60}{\text{window length (s)}}$

Scale a short timed pulse count up to a per-minute rate. Write the scale-up factor down explicitly before multiplying; a 15 s window uses $\times 4$, a 20 s window uses $\times 3$, and so on.

Lumen diameter from external diameter and wall thickness

$\text{lumen diameter} = \text{external diameter} - 2 \times \text{wall thickness}$

The wall runs all the way round the lumen, so it reduces the diameter *twice*, once on each side. Always subtract twice the stated (single-side) wall thickness from the external diameter, not the wall thickness once.

KEY CONCEPTS

- **Advantages of a double circulation:** Because blood is re-pumped by the heart after leaving the lungs, it reaches the body at *high pressure*, delivering oxygen quickly. Because the two loops are kept apart by the heart's two-sided structure, oxygenated and deoxygenated blood are *kept separate*, so the body only ever receives fully oxygenated blood.
- **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: thick elastic wall, narrow lumen:** *Arteries* carry blood away from the heart at high pressure, so they have a *thick wall containing muscle and elastic tissue* and a *narrow lumen*. The elastic tissue stretches as each pressure surge passes and recoils afterwards, squeezing the blood onward and keeping pressure from dropping too far between beats.
- **Atrioventricular valves vs semilunar valves:** *Atrioventricular valves* sit between each atrium and the ventricle below it; *semilunar valves* sit at the base of the aorta and the pulmonary artery. Both stop backflow, but at different points in the heartbeat cycle and at different locations.

- **Capillary structure: three features built for exchange:** *Capillaries* have a wall only *one cell thick* (shortest diffusion distance), a *narrow lumen* (slows blood, giving more time for exchange), and form *dense, branching networks* (large total surface area for exchange).
- **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, which branch off the aorta to supply the heart muscle, become narrowed or blocked by fatty deposits. Risk factors include a diet high in saturated fat or salt, smoking, high stress, and physical inactivity.
- **Distinguishing blood cell types by nucleus:** A *red blood cell* is a biconcave disc with *no nucleus*. A *phagocyte* has a distinctive *lobed* nucleus and grainy cytoplasm. A *lymphocyte* has a *large, round* nucleus filling most of the cell. A *platelet* is a tiny cell fragment with no nucleus.
- **Double circulation (mammal): pulmonary and systemic loops:** A mammal has a *double circulation*: blood passes through the heart *twice* for each complete circuit of the body. The *pulmonary circulation* carries blood between the heart and the lungs; the *systemic circulation* carries blood between the heart and the rest of the body. Both loops start and finish at the heart.
- **Four components of blood:** Blood is made of four components: *red blood cells*, *white blood cells* (of which lymphocytes and phagocytes are the two named types), *platelets*, and *plasma*, the pale liquid that carries all three cell types and everything dissolved in the blood.
- **Four heart chambers and the septum:** The heart has four chambers: two upper *atria*, which receive blood, and two lower *ventricles*, which pump blood out. The *septum*, a thick muscular wall down the centre, keeps the left (oxygenated) and right (deoxygenated) sides completely separate.
- **Functions of the blood components:** *Red blood cells* transport oxygen using haemoglobin. *Lymphocytes* produce *antibodies*. *Phagocytes* carry out *phagocytosis*, engulfing pathogens directly. *Platelets* help the blood to clot. *Plasma* transports dissolved substances such as glucose, urea and hormones.
- **Heart rate rises with exercise:** During exercise, muscles respire faster, so they need oxygen and glucose delivered faster and carbon dioxide removed faster. The heart beats faster, helped by the hormone *adrenaline*, to meet that demand.
- **Lymphocytes vs phagocytes: two different tactics:** A *phagocyte* works directly: it moves to a pathogen, engulfs it, and digests it inside the cell. A *lymphocyte* works indirectly: it releases soluble *antibodies* into the plasma, which attach specifically to a matching pathogen and mark it for destruction.
- **Oxygen debt: why heart rate stays high after exercise:** If exercise is intense enough that muscles respire anaerobically, lactic acid builds up, creating an *oxygen debt*. Heart rate stays elevated after exercise stops specifically to keep delivering the extra oxygen needed to break down that lactic acid, only falling back to resting rate once the debt is cleared.
- **Pulse vs ECG: what each measures:** A *pulse* is the physical pressure surge felt in an artery each time the heart contracts, giving heart rate. An *electrocardiogram (ECG)* instead records the *electrical activity* that triggers each contraction, revealing rate, timing and rhythm, information a pulse count alone cannot give.
- **Role 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, sealing the vessel or chamber shut against the wrong-way pressure. Valves appear at every point in the system where backflow would otherwise be a risk.
- **Single circulation (fish): route and pressure:** A fish has a *single circulation*: blood passes through the heart only *once* for each complete circuit of the body, travelling heart to gills (gas exchange) to the rest of the body and back to the heart. Blood loses pressure crossing the gill capillaries, so it reaches the body slowly, at low pressure.
- **Vein structure: thin wall, large lumen, valves:** *Veins* carry blood back towards the heart at much lower pressure, so they have a comparatively *thin wall*, a *large lumen* (low resistance to slow-moving blood), and *valves* to stop the low-pressure blood flowing backwards.
- **Blood clotting mechanism: fibrinogen to fibrin:** At a wound, platelets clump together and release chemicals that trigger the conversion of the soluble plasma protein *fibrinogen* into insoluble *fibrin* threads, which form a mesh that traps blood cells and seals the wound, stopping blood loss and blocking pathogen entry.
- **Named vessels: pulmonary and renal:** The *pulmonary artery* carries deoxygenated blood from the right ventricle to the lungs; the *pulmonary vein* returns oxygenated blood to the left atrium, an

exception to "arteries carry oxygenated blood". The *renal artery* supplies the kidney; the *renal vein* carries filtered blood away.

- **The heartbeat cycle: contraction, relaxation and valve action:** A heartbeat is a two-phase cycle of muscle contraction paired with valve action. Ventricular contraction raises pressure sharply, closing the atrioventricular valves and opening the semilunar valves. Ventricular relaxation lowers pressure, closing the semilunar valves and opening the atrioventricular valves as the atria push blood down.
- **The liver's unique double blood supply:** The liver is unusual in having *two* vessels bringing blood in: the *hepatic artery* (oxygenated blood, as any organ needs) and the *hepatic portal vein* (blood rich in absorbed food, arriving directly from the small intestine), and one vessel, the *hepatic vein*, taking blood away.

EXAM TIPS

TIP When the ventricles *contract*, rising pressure forces the atrioventricular valves *shut* and the semilunar valves *open*. When the ventricles *relax and fill*, the semilunar valves *shut* and the atrioventricular valves *open*.

TIP Run the checklist in order: (1) is there a nucleus at all, if not it is a red blood cell or a platelet; (2) if no nucleus, is it a full disc (red blood cell) or a tiny fragment (platelet); (3) if there is a nucleus, is it large and round (lymphocyte) or small and lobed (phagocyte).

TIP "Single circulation" and "double circulation" describe how many times blood passes through the heart per complete circuit of the body, not the number of chambers or vessels involved. Trace the loop and count re-entries to the heart, not the chambers.

TIP Eating less saturated fat and salt reduces the fatty deposits that narrow the coronary arteries in the first place, and regular exercise strengthens the heart muscle and helps keep body mass and blood pressure in a healthy range, both lowering overall risk.

TIP The hepatic portal vein is the one vessel in this chapter that breaks the simple "veins go straight to the heart" pattern, it runs between two organs (gut and liver) instead. Learn it explicitly as the named exception rather than forcing it into the general vein rule.

TIP The most common error in a lumen-diameter calculation is subtracting the wall thickness only once. Sanity-check that the final lumen size is smaller than the external diameter but still a sensible fraction of it, and convert mm to μm by multiplying by 1000 if the question asks for micrometres.

TIP State X's normal job in one sentence, then state what fails to happen without it, then state the practical consequence. Skipping straight to the consequence without the mechanism in between usually loses the explanation mark even when the final answer is correct.

TIP Answer with both halves: (1) blood is re-pumped after the lungs, so pressure to the body is high; (2) the heart's two sides keep oxygenated and deoxygenated blood apart. Most mark schemes reward both halves, worded in the context the question gives.

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, two humidities or two wind speeds, and asks for the percentage increase or decrease between them.

Volume of a xylem vessel modelled as a cylinder

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

Used when a xylem vessel is modelled as a cylinder and a question gives its length and diameter. Halve the diameter to get the radius before squaring it, then multiply by the length and by π . A common error is squaring the diameter instead of the radius, which gives an answer four times too large.

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 affecting transpiration rate: temperature, humidity, wind speed:** All three factors act on the same underlying variable, the steepness of the water vapour concentration gradient between the leaf's internal air spaces and the air outside the stomata. Higher temperature and higher wind speed both increase transpiration rate; higher humidity decreases it, since it reduces the gradient driving diffusion out of the leaf.
- **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, and also provides mechanical support through lignified walls. Phloem transports sucrose and amino acids from a source to a sink, and, unlike xylem, its direction of flow is not fixed. Name the substances, never write "food" for phloem.
- **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, so a cell with more surface area exposed to soil water absorbs water and mineral ions faster.
- **Translocation: sucrose and amino acids in phloem:** Translocation is the movement of sucrose and amino acids through the phloem, in either direction, from wherever they are produced or stored (a source) to wherever they are needed (a sink). It is a genuinely separate transport system from the water and mineral ion pathway carried in xylem, different tissue, different cargo, and not restricted to a single fixed direction.
- **Xylem's second job: support:** Xylem vessel walls are thickened with lignin, a tough, woody material. Beyond the strength needed to withstand the tension created as water is pulled up through them, this rigidity gives the whole plant mechanical support. Phloem has no comparable structural role, its sieve tube walls stay thin and unligified because the tissue must stay alive.
- **Internal leaf surface area and stomatal distribution:** The spongy mesophyll has large, air filled spaces between loosely packed cells, giving the leaf's interior a very large surface area of moist cell wall exposed to internal air, which is why evaporation can keep pace with diffusion out through the

stomata. Stomata are typically far more numerous on the lower leaf surface, which reduces water loss on the sun facing upper surface while still allowing efficient gas exchange.

- **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 (adaxial) side, phloem toward the lower (abaxial) side.
- **Sieve tube elements and companion cells:** Phloem tissue is built from living sieve tube elements, joined end to end by perforated sieve plates that allow sugar solution to flow between adjacent cells. Each sieve tube element is closely associated with a living companion cell, which carries out the active loading and metabolic work that the sieve tube element, having lost its nucleus at maturity, cannot perform unaided. This is why phloem, unlike xylem, must remain living.
- **Sources and sinks:** A source is any part of the plant producing or releasing sucrose into the phloem, most commonly a photosynthesising leaf. A sink is any part of the plant using or storing sucrose delivered by the phloem, such as a growing root tip or a developing fruit. The same organ can switch role between source and sink at different times of year, since the terms describe a current functional state, not a permanent anatomical category.
- **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.
- **The structure of a mature xylem vessel:** A mature xylem vessel is dead, having lost its cytoplasm and nucleus, so it offers no resistance to water flow and needs no metabolic upkeep. The end walls between adjacent cells break down completely, fusing a column of cells into one continuous, unobstructed tube. The remaining walls are thickened with lignin, deposited in rings, spirals, or a continuous pitted layer, which resists collapse under tension and stops water leaking sideways.
- **The transpiration pull (cohesion-tension mechanism):** Water molecules cohere to one another through hydrogen bonds, so the water inside a xylem vessel behaves as a single, continuous, unbroken thread from root to leaf. As water evaporates from mesophyll cells at the top of this column, it creates a tension transmitted down the whole column, drawing more water up to replace what was lost, entirely passively, with no pump anywhere in the plant.

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 diffusion or absorption across that surface. Writing only "it has more surface area" on its own drops the final link and loses marks.

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.

TIP Xylem always carries water and mineral ions in a single fixed direction, root to leaf. Phloem carries sucrose and amino acids from source to sink, and which organs act as source and which act as sink can change, so the direction of flow in a particular section of phloem is not permanently fixed.

KEY CONCEPTS

- **Adaptation versus adaptive feature:** An adaptive feature is the inherited structure or function itself. Adaptation is the long-term process, driven by natural selection over many generations, by which a species comes to possess adaptive features. Adaptive features are the product; adaptation is the process that produced them.
- **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: the feature must be inherited, and it must give a stated survival or reproductive benefit in that specific environment.
- **Antibiotic resistance: natural selection in bacteria:** A chance mutation gives a bacterium resistance before an antibiotic is ever used. The antibiotic kills the non-resistant bacteria; the resistant survivors reproduce rapidly, passing on the resistance allele. Over time the population becomes mostly resistant. Overuse of antibiotics speeds this by applying the selection pressure more often.
- **Continuous variation:** Continuous variation produces a range of phenotypes between two extremes, with every intermediate value present (e.g. height, body mass). It is caused by many genes acting together (polygenic inheritance), modified by the environment, and plots as a smooth, bell-shaped 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.
- **Gene mutation: a random change in the base sequence of DNA:** A gene mutation is a random change in the base sequence of DNA. The bases (A, T, C, G) are the letters genes are written in; changing one can change the allele. Mutation is the way in which new alleles are formed, making it the ultimate source of all genetic variation.
- **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 and is not passed on. Most visible features, such as height, are shaped by both.
- **Hydrophyte adaptations:** A hydrophyte is a plant adapted to live in or on water, where the problems are floating, gas exchange and support rather than water loss. Features include large air spaces for buoyancy and gas transport, stomata on the upper surface only in floating leaves, and a thin or absent cuticle, since water conservation is unnecessary.
- **Mutagens:** A mutagen is a factor that increases the rate at which mutation occurs. The syllabus names two: ionising radiation (e.g. ultraviolet light, X-rays, radiation from radioactive substances) and certain chemicals (e.g. compounds in tobacco smoke).
- **Natural selection:** Natural selection proceeds in five steps: (1) heritable variation exists within a population; (2) organisms produce more offspring than the environment can support, causing 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. This drives adaptation and all evolution.
- **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.
- **Three sources of genetic variation:** The sources of genetic variation in a population are mutation, meiosis and random fertilisation. Mutation is the only one that creates a genuinely new allele; meiosis (shuffling alleles into gametes) and random fertilisation (combining two randomly assorted sets of alleles) only generate new combinations of alleles that already exist.
- **Variation:** Variation is the differences that exist between individuals of the same species. It is the raw material that natural and artificial selection act on; without heritable differences there would be nothing to select between.
- **Xerophyte adaptations:** A xerophyte is a plant adapted to survive in very dry conditions, where the problem is conserving water. Features include a thick waxy cuticle, reduced or rolled leaves (or leaves reduced to spines, with photosynthesis moved to a water-storing stem), sunken or enclosed stomata, surface hairs, and extensive roots, each reducing water loss or improving water capture.

- **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 true shape of the spread becomes clear.
- **Natural selection versus artificial selection:** Both processes select among pre-existing inherited variation, and neither creates new alleles, only mutation does that. In natural selection the environment selects for survival, usually slowly over many generations. In artificial selection humans select for features useful to people, usually faster because the choice is deliberate and strong each generation.
- **Selective breeding targets:** Crop plants are selectively bred for higher yield, larger fruits or grains, disease resistance, and tolerance of drought or cold. Domesticated animals are bred for more meat or milk, faster growth to maturity, docile temperament, 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. "Survival of the fittest" means best-suited to the environment, not strongest.

TIP A feature that is inherited but has 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 If a question asks for the ultimate or original source of genetic variation, the answer is mutation. If it asks for sources that produce new combinations without creating anything new, the answer is meiosis and random fertilisation.

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, because it is the repetition that shifts the population.

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. The number of categories is irrelevant; ABO blood group has four categories and is still discontinuous.

TIP The antibiotic does not cause the resistance mutation and does not make bacteria resistant. It selects: it kills the non-resistant bacteria, leaving the already-resistant ones to multiply. Say "resistance arose by chance mutation, and the antibiotic selected for it", not "the antibiotic caused the bacteria to mutate".

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

TIP A typical land plant has most stomata on the lower leaf surface, to reduce water loss. Do not "correct" a floating leaf to this pattern: for a water lily, the upper surface is the only one touching the air, so that is the only surface where stomata can function.



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