Combined Science (0653)

IGCSE • Core • CAIE

Comprehensive Cheat Sheet

The Practice Book
www.thepracticebook.org

1 Acids, bases and salts

KEY FORMULAS

Neutralisation as an ionic equation

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Use to summarise any acid and alkali reaction: the hydrogen ion from the acid and the hydroxide ion from the alkali combine to form water. This single equation underlies every salt-and-water reaction; the remaining ions form the salt in solution.

Acid and metal: magnesium with dilute hydrochloric acid

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

Use as the model for any acid and metal reaction, which gives a salt and hydrogen. Magnesium forms Mg^{2+}, so two hydrochloric acid molecules are needed to balance the two chloride ions in $MgCl_2$; a common error is writing $MgCl$.

Neutralisation by a base: copper(II) oxide with sulfuric acid

$$CuO(s) + H_2SO_4(aq) \rightarrow CuSO_4(aq) + H_2O(l)$$

Use as the model for an acid and base neutralisation, which gives a salt and water with no gas. The salt takes the *metal from the base* and the *acid part from the acid*, so copper(II) oxide and sulfuric acid give copper(II) sulfate.

Acid and carbonate: magnesium carbonate with hydrochloric acid

$$MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$$

Use as the model for any acid and carbonate reaction, which gives a salt, water and carbon dioxide. Two HCl are needed so the two chlorides balance the Mg^{2+}; the coefficient of 2 in front of the acid is the balancing detail most often tested.

Precipitation equation: barium sulfate

$$BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$$

Use as the model for a precipitation reaction, where two soluble solutions swap partners to give an insoluble salt. Barium sulfate is the insoluble product with state symbol (s); the soluble sodium chloride stays dissolved and is washed away as a spectator by-product.

KEY CONCEPTS

- **Acid, base and alkali defined**: An *acid* is a substance whose aqueous solution has a pH below 7 and turns litmus red; its formula almost always begins with hydrogen, as in HCl, H_2SO_4 and HNO_3. A *base* is an oxide or hydroxide of a metal that reacts with an acid to form a salt and water. An *alkali* is a base that is soluble in water, such as sodium hydroxide, potassium hydroxide or aqueous ammonia; every alkali is a base, but not every base is an alkali.
- **Classifying an oxide as acidic or basic**: An oxide is classified from the character of the element joined to the oxygen. *Basic oxides* are the oxides of *metals*, such as CuO, CaO and Na_2O; they react with acids to form a salt and water. *Acidic oxides* are the oxides of *non-metals*, such as SO_2 and CO_2 ; they dissolve in water to give an acidic solution and react with bases. The single question is whether the element is a metal or a non-metal.
- **Indicators and the pH scale**: An *indicator* shows a different colour in an acid than in an alkali. Litmus is *red* in acid and *blue* in alkali. To read an actual value, *universal indicator* is matched to a

colour chart giving a pH: below 7 is acidic, exactly 7 is neutral (green), and above 7 is alkaline. The lower the pH the more strongly acidic, and the higher the pH the more strongly alkaline.

- **The master decision: soluble or insoluble**: How a salt is made is decided by one question: is the target salt *soluble* or *insoluble* in water? A *soluble* salt is made by reacting a dilute acid with a suitable reactant, then crystallising the salt from the filtrate. An *insoluble* salt is made by *precipitation*: mixing two soluble solutions so the salt forms as a solid, which is filtered, washed and dried.
- **The three characteristic reactions of a dilute acid**: A dilute acid reacts in three ways, each giving a salt. With a *metal* it gives a salt and *hydrogen*, which pops with a lit splint; calcium and dilute hydrochloric acid react this way to give calcium chloride and hydrogen. With a *base* it gives a salt and *water* only, with no gas. With a *carbonate* it gives a salt, *water* and *carbon dioxide*, which turns limewater milky. Only the metal and carbonate reactions release a gas, and the two gases are different.
- **Base versus alkali**: Every alkali is a base, but only a base that is *soluble* in water is an alkali. Sodium hydroxide, potassium hydroxide and aqueous ammonia dissolve, so they are alkalis; copper(II) oxide does not dissolve, so it is a base but not an alkali. An insoluble base still neutralises an acid, but it cannot form an alkaline *solution*, so it will not turn litmus in a beaker of water blue.
- **Soluble salt from an alkali: titration**: If the base is a soluble alkali, there is no excess solid to filter off, so titration is used instead. Add an indicator and run acid in from a burette until the exact neutralisation volume is found. Then repeat with the same volumes but no indicator, so no coloured dye contaminates the salt, and crystallise that solution.
- **Soluble salt from an insoluble reactant: the excess-solid method**: When the acid reacts with an insoluble metal, base or carbonate, add the solid *in excess* so all the acid is used up. The acid is exhausted when solid remains undissolved, and for a metal or carbonate, when fizzing stops. Then *filter* off the leftover excess solid to leave a solution of the pure salt, before evaporating and crystallising.
- **Insoluble salt: precipitation**: An insoluble salt cannot be crystallised from solution, so it is made by *precipitation*. Mix two *soluble* solutions, one supplying the metal ion and the other the non-metal ion of the target salt; the insoluble salt forms at once as a solid precipitate. *Filter* to collect it, *wash* the residue with distilled water to remove soluble impurities, then leave it to dry.
- **Screening for an oxide's class from the element's character**: To classify the oxide of an unnamed element, decide first whether the element itself is a metal or a non-metal. An element in Group 14 that shows *non-metallic* character forms an *acidic* oxide, which reacts with a base to form a salt and water; the same reasoning applied to a metallic element would instead give a basic oxide. The element's character, not its group number or position, fixes the oxide's class.

EXAM TIPS

TIP If the base, carbonate or metal is *insoluble*, add it in excess to the acid and filter off the leftover solid. If the base is a soluble *alkali*, there is no solid to filter, so titrate with an indicator to find the exact volumes that react, then repeat without the indicator so no dye contaminates the salt.

TIP Fix the salt from the acid used: hydrochloric acid gives a *chloride*, sulfuric acid gives a *sulfate*, and nitric acid gives a *nitrate*. The metal part of the salt comes from the metal, base or carbonate used. Learning these three acid-to-salt pairings decides the product in almost every question in this chapter.

TIP The most-tested indicator error is the alkali colour of methyl orange: it is *yellow*, not blue. Litmus is the one that turns blue in alkali. Both indicators are red in acid, so they differ only in alkali.

TIP Crystallisation evaporates only *some* of the water, then leaves the solution to cool slowly so large crystals form. Boiling a filtrate until every trace of water is gone forces the salt out all at once as a fine powder, not crystals; always stop evaporating while the solution is still hot and concentrated, then let it cool undisturbed.

2 Atoms, elements and compounds

KEY FORMULAS

Nucleon (mass) number

$$A = Z + N$$

Use to find the nucleon (mass) number A from the proton number Z and the number of neutrons N. The nucleon number counts protons and neutrons together, never the electrons.

Number of neutrons

$$N = A - Z$$

Use to find the number of neutrons in an atom, since it is never given directly. Subtract the proton number Z from the nucleon (mass) number A.

Deducing an ionic formula by charge balance

$$n_+ q_+ + n_- q_- = 0$$

Use to find the formula of an ionic compound: choose the smallest whole numbers of each ion, n_+ and n_-, so the positive and negative charges q_+ and q_- cancel to zero. A magnesium ion Mg^{2+} needs two chloride ions Cl^-, giving MgCl_2.

Shared electrons in a covalent bond

$$\text{shared electrons} = 2 \times (\text{number of bonds})$$

Use to count the electrons involved in covalent bonding, since each shared pair (one bond) contains two electrons. A molecule with two covalent bonds shares $2 \times 2 = 4$ electrons.

KEY CONCEPTS

- **Electronic configuration**: Electrons fill shells from the innermost outwards. For proton numbers 1 to 20 the shells hold 2, then 8, then 8, then 2, written as comma-separated numbers, for example sodium is $2, 8, 1$. An atom with a full outer shell is a stable, unreactive noble gas.
- **Element, compound and mixture**: An *element* is a substance made of only one type of atom and cannot be split into simpler substances by chemical means. A *compound* is formed when two or more different elements are chemically combined together in fixed proportions, giving properties different from the elements it was made from. A *mixture* contains two or more substances that are not chemically combined, so each keeps its own properties, the proportions can vary, and it can be separated by physical means.
- **Ions and the ionic bond**: An *ion* is a charged particle formed when an atom loses or gains electrons; only electrons move, never protons. Metal atoms *lose* electrons to form positive ions (*cations*); non-metal atoms *gain* electrons to form negative ions (*anions*). An *ionic bond* is the strong electrostatic attraction between oppositely charged ions.
- **The covalent bond**: A *covalent bond* is formed when a pair of electrons is shared between two non-metal atoms. By sharing, each bonded atom gains a full outer shell, the same stable arrangement as a noble gas.
- **The three sub-atomic particles**: An atom has a central *nucleus* of protons and neutrons, surrounded by electrons in shells. Relative charges are proton $+1$, neutron 0, electron -1. Relative masses are proton 1, neutron 1, electron negligible. A neutral atom has no overall charge, so its number of electrons equals its number of protons.
- **Configuration maps to Group and Period**: An element's electronic configuration gives its position in the Periodic Table. The number of *occupied shells* equals the *Period* number, and the number of

outer-shell electrons equals the *Group* number for Groups I to VII. So $2, 8, 6$ means three shells (Period 3) and six outer electrons (Group VI).

- **Properties of ionic compounds**: Ionic compounds have *high melting and boiling points*, because a large amount of energy is needed to overcome the strong electrostatic attractions between the many oppositely charged ions. They *conduct electricity when molten or dissolved but not when solid*, because conducting needs charged particles that are free to move.
- **Properties of simple molecular substances**: A simple molecular substance is made of small, separate molecules: strong covalent bonds hold the atoms *within* each molecule, but only *weak forces* act *between* the molecules. Melting or boiling only has to overcome those weak forces between molecules, so melting and boiling points are *low*. The molecules are neutral with no free ions, so a simple molecular substance does *not* conduct electricity in any state.
- **Telling compounds and mixtures apart**: Two boundaries are tested most. *Element or compound*: both can exist as molecules, so "is it a molecule?" is not the test; oxygen O_2 is an element (one kind of atom) while carbon dioxide CO_2 is a compound (two kinds). *Compound or mixture*: both can contain different elements, so the test is whether they are chemically combined in a fixed ratio (compound) or simply mixed in any ratio (mixture).

EXAM TIPS

TIP Steel looks and behaves like a single uniform metal, yet it is a *mixture*, mainly iron with small amounts of carbon and other metals. It is a mixture because its composition is not fixed and the atoms are not chemically combined in one set ratio. Looking uniform is never evidence of a compound; only a fixed combining ratio is.

TIP The mass (nucleon) number A counts protons *and* neutrons together. The number of neutrons is what is left after subtracting the protons, $N = A - Z$. Reading a mass number of 35 as "35 neutrons" is the single most common error; always subtract the proton number first.

TIP A solid ionic compound contains ions, yet it does not conduct, because the ions are fixed in position in the lattice and cannot move. Melting or dissolving frees the ions so they can move and carry charge. State both the fact and the reason: "solid, ions fixed; molten or aqueous, ions free to move."

TIP When a simple molecular substance melts, the *weak forces between* the molecules are overcome; the *strong covalent bonds within* each molecule stay intact. This is why melting and boiling points are low even though the covalent bonds themselves are strong.

3 Biological molecules

KEY CONCEPTS

- **Building blocks of the three food groups**: A carbohydrate is built from many *glucose* molecules. A protein is built from many *amino acids* joined in a chain. A fat or oil is built from *fatty acids and glycerol*. A molecule is classed by what it is built from, not by its role.
- **Elements in carbohydrates, fats and proteins**: Carbohydrates and fats contain only *carbon, hydrogen and oxygen* (C, H, O). Proteins contain *carbon, hydrogen, oxygen and nitrogen* (C, H, O, N). Nitrogen is the element that identifies protein among the three food groups.
- **Starch, glycogen and cellulose are all made from glucose**: Starch (stores energy in plants), glycogen (stores energy in animals) and cellulose (forms plant cell walls) are all carbohydrates built from the single building block *glucose*. Three different roles, one shared building block.
- **The four food tests: reagent and positive result**: Iodine test for starch: iodine solution, no heating, browny-orange to *blue-black*. Benedict's test for reducing sugar: Benedict's solution, *heat* in a water bath, blue to a *brick-red* precipitate. Biuret test for protein: biuret solution, no heating, blue to *purple*. Emulsion test for fats and oils: dissolve in *ethanol* then add to water, clear to a *cloudy white* layer.
- **The Benedict's test for reducing sugars**: Add an equal volume of blue *Benedict's solution* to the food in solution and *heat* in a water bath. A reducing sugar such as glucose gives a *brick-red (orange-red) precipitate*; with no reducing sugar the solution stays blue.
- **The biuret test for proteins**: Add *biuret solution* to the food; no heating is needed. If protein is present the blue solution turns *purple (lilac)*; if protein is absent it stays blue.
- **The emulsion test for fats and oils**: Dissolve the food in *ethanol*, then pour the ethanol into an equal volume of water. Fat or oil comes out of solution as tiny droplets and forms a *cloudy white* emulsion; with no fat the mixture stays clear. The reagent to name is ethanol, not water alone.
- **The iodine test for starch**: Add a few drops of *iodine solution* to the food; no heating is needed. If starch is present the orange-brown iodine turns *blue-black*; if starch is absent it stays browny-orange.
- **Enzymes such as amylase are proteins, not carbohydrates**: Molecule names ending in "-ase", such as amylase and lipase, are enzymes, and all enzymes are proteins built from amino acids. Although amylase acts on the carbohydrate starch, amylase itself is a protein, not a carbohydrate.
- **Reducing sugars and why starch gives a negative Benedict's result**: A *reducing sugar* is a sugar, such as glucose, that gives a positive Benedict's test. Starch is a large carbohydrate made of joined-up glucose units, not free glucose, so it does not react with Benedict's solution and the solution stays blue.

EXAM TIPS

TIP Only proteins contain nitrogen among the three food groups. A pure sample found to contain nitrogen must be, or contain, protein; a sample with only carbon, hydrogen and oxygen cannot be protein.

TIP A "describe the result" mark needs the colour change *and* its direction, for example browny-orange to blue-black for iodine. Writing only the final colour, or reversing the direction, loses the mark.

TIP Of the four tests, only Benedict's is heated in a water bath. A result described as "brick-red without heating" cannot be a valid Benedict's result. The iodine, biuret and emulsion tests are all carried out at room temperature.

TIP Both reagents are blue to begin with, a classic confusion. Biuret turns *purple with no heating* and shows protein; Benedict's turns *brick-red only after heating* and shows a reducing sugar. Use the heating step and the final colour together to tell the two apart.

4 Cells

KEY FORMULAS

Magnification equation

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

Use to find how many times larger a drawing or photograph is than the real specimen. Measure image size and actual size in the *same unit* before dividing.

Magnification has no unit

$$\text{magnification} = \times n$$

Magnification is a ratio of two lengths measured in the same unit, so the units cancel. Always give it as a plain number written with a *times* sign, for example $\times 100$, never with mm attached.

Rearranging to find the actual size

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

Use when a drawing gives the image size and its magnification and the real size of the specimen is needed. Keep the image size and the answer in the same unit, usually millimetres.

Rearranging to find the image size

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

Use when the real size and the magnification are known and the length of the drawing or photograph is needed. Give the answer in the same unit as the actual size.

KEY CONCEPTS

- **Functions of the main cell structures**: Cell membrane: controls entry and exit of substances. Nucleus: holds the genetic material and controls the cell's activities. Cytoplasm: where most chemical reactions happen. Mitochondria: site of aerobic respiration. Ribosomes: site of protein synthesis. Cell wall: supports and shapes the cell. Chloroplast: absorbs light for photosynthesis. Permanent vacuole: keeps the cell firm.
- **Structure of a bacterial cell**: A bacterial cell has a cell wall, a cell membrane, cytoplasm and ribosomes. Its genetic material is a single circular loop of *chromosomal DNA* lying free in the cytoplasm, often with one or more smaller separate loops called *plasmids*. It has no nucleus, no mitochondria and no chloroplasts.
- **Structures common to all cells**: Every living cell has a *cell membrane* that controls which substances enter and leave, *cytoplasm* where most of the cell's chemical reactions happen, and *ribosomes* where proteins are made. Plant and animal cells also have a *nucleus*, which holds the genetic material (DNA) and controls the cell's activities.
- **Structures found only in plant cells**: A typical plant cell has three structures an animal cell does not: a *cell wall* made of cellulose that supports and shapes the cell, *chloroplasts* containing chlorophyll for photosynthesis, and a large *permanent vacuole* filled with cell sap that keeps the cell firm.
- **Levels of organisation in an organism**: Cells build up into larger structures in a fixed order of increasing complexity: a *cell* is the basic unit; a *tissue* is a group of similar cells with one function; an *organ* is several different tissues working together; an *organ system* is a group of organs; and an *organism* is the complete individual.

EXAM TIPS

TIP The cell wall lies *outside* the membrane; it is an extra layer, not a replacement. Every living cell has a membrane, so it is wrong to say a plant cell has a wall "instead of" a membrane.

TIP Bacterial, plant and animal cells all make proteins, so all three contain ribosomes. It is wrong to treat ribosomes as a plant-only or nucleus-only feature; they belong to every living cell.

TIP A bacterium does carry DNA, but its genetic material is a free circular loop in the cytoplasm rather than being enclosed by a nuclear membrane. "No true nucleus" means no membrane-bound nucleus, not "no genetic material".

TIP A plant cell wall and a bacterial cell wall both support and shape the cell, but they are not the same material: the plant wall is made of *cellulose*, while the bacterial wall is made of a different substance.

5 Characteristics of living organisms

KEY CONCEPTS

- **Excretion**: Excretion is the removal of the waste products of metabolism and of substances in excess of requirements. This covers wastes the body itself made, such as carbon dioxide from respiration and urea from the breakdown of excess protein, together with useful substances taken in or made in amounts greater than the body needs.
- **Growth**: Growth is a permanent increase in size and dry mass. *Dry mass* is the mass of an organism once all its water has been removed, so growth means an organism has made new living material, not simply taken up water.
- **Nutrition**: Nutrition is the taking in of materials for energy, growth and development. Animals take in and digest food; plants take in carbon dioxide, water and mineral ions and use them, with light, to build their own food.
- **Respiration**: Respiration is the chemical reactions that break down nutrients to release energy. It is a *chemical* process that goes on continuously inside every living cell, not a physical process in the lungs.
- **The seven characteristics of living organisms (MRS GREN)**: Every living organism shows seven characteristics, remembered by the mnemonic *MRS GREN*: Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion and Nutrition. To count as living, an organism must be capable of showing all seven at some point in its life. The mnemonic itself earns no marks; marks are given only for reproducing the exact definition of each characteristic and applying it correctly.
- **Dry mass and fresh mass**: *Fresh mass* is the mass of an organism including all the water it contains; *dry mass* is its mass once all that water has been removed. Fresh mass can rise or fall quickly with no new living material made, so only a change in dry mass shows true growth.
- **Movement**: Movement is an action, by an organism or by part of an organism, that causes a change of position or place. In most animals the whole organism moves; in plants, usually only a part moves, such as a shoot or flower slowly turning to follow the direction of light.
- **Reproduction**: Reproduction is the processes that make more of the same kind of organism. The definition names no fixed number of parents, so it covers organisms that reproduce from a single parent, such as a dividing bacterium, as well as organisms that need two parents.
- **Sensitivity**: Sensitivity is the ability to detect and respond to changes in the environment. Both parts are needed: the change detected is the *stimulus*, and the reaction to it is the *response*. Plants show sensitivity too, for example by detecting the direction of light and growing towards it.
- **How the seven characteristics link together**: The seven characteristics depend on one another rather than acting alone. *Nutrition* supplies the materials an organism needs; *respiration* breaks those materials down to release energy; that energy powers active processes such as *movement* and *growth*; and *excretion* removes the waste, such as carbon dioxide and urea, that these reactions produce.
- **Why an inactive organism can still be alive**: The seven characteristics describe abilities an organism keeps over its whole lifetime, not activities it must perform at every single moment. An organism that is resting, dormant or between periods of visible activity is still alive provided it retains the ability to show all seven characteristics when conditions allow.

EXAM TIPS

TIP Excretion removes wastes the body itself made, or substances taken in and held in excess, such as urea and carbon dioxide. Egestion removes *undigested* food from the gut, such as faeces, which never took part in the body's metabolism. Egestion is not one of the seven characteristics.

TIP Respiration is a *chemical* process inside cells that releases energy; breathing (ventilation) is a *physical* process that moves air into and out of the lungs. Breathing is not one of the seven characteristics, so do not write "breathing" when a question asks for a characteristic of living organisms.

TIP A rise in fresh mass caused only by taking up water, for example a wilted plant after watering, is not growth: no new living material has been made. A change is only growth if it is a *permanent* increase in *dry* mass.

TIP A scenario can show more than one characteristic at once. Read the question carefully and name the characteristic shown by the *exact action it describes*, not every characteristic the organism could show in general.

TIP Treat any claim that only animals can show a given life process with caution. All seven definitions are written to apply to every kind of organism, so plants, fungi and single-celled organisms show each one in their own way, for example a plant detecting and growing towards light as its form of sensitivity.

6 Chemical energetics

KEY CONCEPTS

- **Endothermic reactions**: An *endothermic* reaction takes in thermal energy from the surroundings, so the temperature of the surroundings falls. Dissolving certain salts, such as ammonium nitrate or ammonium chloride, in water is a common endothermic change.
- **Exothermic reactions**: An *exothermic* reaction transfers thermal energy to the surroundings, so the temperature of the surroundings rises. Combustion, neutralisation and the reaction of a reactive metal with an acid are all exothermic.
- **Measuring a temperature change**: A temperature change is found from two readings: the *initial* temperature, taken before the reactants are mixed, and the *highest* (exothermic) or *lowest* (endothermic) temperature reached once the reaction has happened. The change is the difference between these two readings, not the final reading alone.
- **What is meant by the surroundings**: The *surroundings* means everything outside the reacting chemicals themselves, such as the solution, the container and the air around it. Exothermic and endothermic are always defined by the temperature change of the surroundings, not by a change in the reacting chemicals directly.
- **Fair testing in a temperature-change investigation**: When investigating how one variable, such as the mass or concentration of a reactant, affects a temperature change, every other variable must be kept the same, for example the volume and concentration of the other reactant and the starting temperature. At least five different values of the independent variable should be tested so a reliable pattern can be seen.
- **Reading a value from a temperature-change graph**: A graph of temperature change against concentration (or mass) can be read in reverse to find a concentration that gives a stated temperature change: draw a horizontal line across from that temperature change to the line of best fit, then a vertical line down to the concentration axis to read off the answer.

EXAM TIPS

TIP Standing the reaction cup inside an *insulated container*, or using a plastic cup rather than a glass beaker, reduces the loss or gain of thermal energy to or from the surroundings during the experiment. This makes the measured temperature change closer to the true value, not the true value itself any bigger.

TIP A reaction "feeling hot" or "feeling cold" is only the physical consequence of an exothermic or endothermic change, not its definition. Touch is a subjective judgement that varies between people; a thermometer gives an objective, repeatable reading that can be compared with the starting temperature.

TIP To decide which of several reactions releases or absorbs the most thermal energy, compare the *size* of each temperature change, not the final temperatures reached. Two mixtures can finish at different temperatures only because they started at different temperatures, so the final reading alone is misleading.

TIP If one plotted point lies well away from an otherwise clear trend, treat it as unreliable and exclude it when drawing the line of best fit. The line should follow the trend shown by the majority of the results, drawn as a single thin line with the remaining points spread evenly on both sides.

7 Chemical reactions

KEY FORMULAS

Rate of reaction from gas volume

$$\text{rate} = \frac{\text{volume of gas produced}}{\text{time taken}}$$

Use to calculate how fast a reaction goes when a gas is collected, for example in a gas syringe or by displacing water. The unit is cm^3 per second.

Rate of reaction from loss in mass

$$\text{rate} = \frac{\text{mass lost}}{\text{time taken}}$$

Use when a reaction gives off a gas that escapes from an open flask standing on a balance, so the total mass falls. The unit is g per second.

Rearranging to find the time taken

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

Use to find how long a reaction takes to reach a given volume of gas or loss of mass, once the rate is known.

Rearranging to find the quantity produced

$$\text{quantity} = \text{rate} \times \text{time}$$

Use to find the volume of gas or mass produced when the mean rate and the time taken are known.

KEY CONCEPTS

- **Chemical change**: A *chemical change* forms one or more new substances with different properties from the starting materials, and it is usually difficult to reverse. Burning and rusting are both chemical changes.
- **Four factors that change the rate**: Increasing the concentration of a solution, increasing the surface area of a solid (smaller pieces or powder), raising the temperature, and adding a suitable catalyst all *increase* the rate of reaction. Reversing any factor (diluting, using larger lumps, cooling, removing the catalyst) *decreases* the rate.
- **Oxidation and reduction in terms of oxygen**: At this tier, *oxidation is the gain of oxygen* and *reduction is the loss of oxygen*. When a metal oxide loses its oxygen to become the metal, it is reduced; the substance that takes that oxygen is oxidised.
- **Physical change**: A *physical change* alters only the state, shape or appearance of a substance; no new substance is formed, and the change can usually be reversed. Melting, boiling, freezing and dissolving are all physical changes.
- **Redox reaction**: A *redox reaction* is one in which oxidation and reduction happen at the same time. Whenever one substance gains oxygen, another substance must lose it, so the two changes always occur together in the same reaction.
- **Signs that suggest a chemical change**: A permanent colour change, a gas given off, a precipitate forming, or a temperature change all *suggest* a chemical change, but none proves it alone. A change of state can give off a gas and still be physical, if the gas is the same substance, as when boiling water releases steam.
- **Why diluting a solution decreases the rate**: Diluting a solution with water lowers the *concentration* of the reactant, so there is less of it in a given volume available to react, and the rate decreases.

- **Why increasing surface area increases the rate**: Breaking a solid reactant into smaller pieces or powder increases the *total surface area* exposed to the other reactant, so more of the solid is available to react at once and the rate increases. The same mass of solid reacts faster as a powder than as large lumps.
- **Naming ions by their oxidation state**: The roman numeral in a name such as *iron(III)* or *copper(II)* gives the oxidation number of the ion, showing its combining charge. Whatever the equation, the analysis is always the same: which substance gained oxygen and which lost it.

EXAM TIPS

TIP A *catalyst* increases the rate of a reaction but is chemically unchanged and not used up at the end, so only a small mass is needed and the same catalyst can be reused for further batches.

TIP A colour change, a gas given off, or a large temperature change can each happen during a chemical change, but none proves one alone. The only reliable question is *has a new substance been formed?*

TIP Breaking a solid into powder does not change how much of it there is in a given volume; that is fixed by the mass used. What it changes is the *total surface area exposed* to the other reactant. Using "concentration" to describe a surface-area effect is a common and costly slip.

TIP On a graph of quantity of product against time, the *gradient* is the rate: the curve is steepest at the start, where the rate is greatest, and flattens as the reactants are used up. A flat, horizontal curve means the reaction has finished.

TIP A stop-watch read by eye is reliably accurate only to about a second, so reaction times should be recorded to the nearest second rather than to one decimal place, which would overstate the precision.

8 Chemistry of the environment

KEY CONCEPTS

- **Composition of clean, dry air**: By volume, clean dry air is approximately *78% nitrogen* and approximately *21% oxygen*. The remaining approximately *1%* is a mixture of the noble gases (mainly argon) and carbon dioxide, not a single pure gas. State the figures as approximate and keep the final 1% as a mixture.
- **The adverse effects of the air pollutants**: Pair each pollutant with its harm. CO_2 and CH_4 are greenhouse gases and cause global warming. CO is toxic: it combines with haemoglobin in red blood cells more strongly than oxygen does, so less oxygen is carried around the body. Particulates cause respiratory problems by reaching deep into the lungs. SO_2 and oxides of nitrogen cause acid rain; oxides of nitrogen also cause respiratory problems.
- **The main air pollutants and their sources**: Learn each pollutant with a named source. CO_2: complete combustion of carbon-containing fuels. CO and particulates: *incomplete* combustion, where there is too little oxygen. CH_4: livestock digestion and decaying organic waste. Oxides of nitrogen (NO_x): the air's own nitrogen and oxygen reacting at the high temperature inside engines. SO_2: burning fuels that contain sulfur impurities, such as coal.
- **Treatment of the domestic water supply**: Raw water is treated in a fixed sequence, one stage with one job each. *Sedimentation*: large insoluble particles settle out under gravity. *Filtration*: sand and gravel trap the smaller insoluble solids. *Carbon*: removes tastes and odours. *Chlorination*: chlorine kills microbes such as bacteria, making the water safe to drink.
- **Two chemical tests for the presence of water**: Two anhydrous salts each give one fixed colour change when water is added. Anhydrous copper(II) sulfate is *white* and turns *blue*. Anhydrous cobalt(II) chloride is *blue* and turns *pink*. Both tests show only that water is *present*; neither proves the liquid is *pure* water.
- **Why distilled water is used instead of tap water**: Distilled water is used for titrations and for making up solutions of known concentration because it contains far fewer dissolved chemical impurities than tap water. Those impurities could react with the reagents or add to the amount measured, making the results inaccurate. Distillation boils the water to steam and condenses it back, leaving the dissolved solids behind.
- **"Safe to drink" is not "chemically pure"**: Treated tap water is safe and pleasant to drink, but sedimentation, filtration, carbon and chlorination remove insoluble solids, tastes, odours and microbes only; they leave dissolved chemical impurities behind. For a quantitative experiment those impurities could still react with the reagents or add to the amount measured, so distilled water is used instead.
- **Grouping the six pollutants by effect**: Two families cover most of the pollutant effects. *Greenhouse gases*: carbon dioxide and methane cause global warming. *Acid-rain gases*: sulfur dioxide and oxides of nitrogen. Standing apart as direct health hazards are carbon monoxide (binds haemoglobin, reducing the oxygen carried in the blood) and particulates (respiratory problems from reaching deep into the lungs). Acid rain in turn harms plants and aquatic life and erodes buildings made of limestone and marble.

EXAM TIPS

TIP The same carbon-containing fuel gives a different pollutant depending on the oxygen supply. *Complete* combustion (plenty of oxygen) gives carbon dioxide. *Incomplete* combustion (too little oxygen) gives carbon monoxide and particulates instead. A question naming "too little oxygen" is pointing at carbon monoxide, not carbon dioxide.

TIP A blue result with copper(II) sulfate, or a pink result with cobalt(II) chloride, confirms only that water is *present*. A dilute solution would give the same colour change. To confirm the liquid is *pure* water, its boiling point (100 °C) and melting point (0 °C) must both be checked.

TIP Oxides of nitrogen are not an impurity in the fuel. They form when the air's own nitrogen and oxygen are forced to react by the high temperature inside an engine, so switching to a fuel with no nitrogen impurity would not stop them forming.

TIP *Anhydrous* means "containing no water". If the copper(II) sulfate or cobalt(II) chloride already contained water of crystallisation, it would already be the hydrated colour (blue, or pink) before the test liquid was even added, so no colour change would be seen and the test could not show anything.

9 Diseases and immunity

KEY CONCEPTS

- **Direct contact transmission**: In *direct contact* transmission the pathogen passes straight from an infected host to an uninfected host, with nothing carrying it in between, for example skin touching infected skin or contact with infected body fluids.
- **Indirect transmission and its four routes**: In *indirect* transmission the pathogen passes between hosts by way of an intermediate carrier. The four routes are the *air* (droplets from a cough), *contaminated water*, *contaminated food*, and a *vector*, a separate organism such as a mosquito that carries the pathogen from host to host.
- **The body's defences against pathogens (overview)**: The body defends itself in layers: *barriers* keep pathogens out (skin, mucus and cilia in the airways, stomach acid), *clotting* seals a wound if the skin is broken, and *white blood cells* destroy pathogens that get in.
- **What a pathogen is**: A *pathogen* is a disease-causing organism. Pathogens fall into four groups: *bacteria* (e.g. cholera), *viruses* (e.g. influenza), *fungi* (e.g. athlete's foot) and *protozoa* (e.g. malaria). Not every disease is caused by a pathogen: a *deficiency* disease comes from a poor diet and an *inherited* disease passes through genes, and neither involves an infecting organism.
- **What a transmissible disease is**: A *transmissible disease* is one in which the pathogen can be passed from an infected host to an uninfected host. "Transmissible" describes only whether the pathogen can spread between hosts, not how severe the disease is or what type of organism causes it: cholera (bacterium), influenza (virus) and malaria (protozoan) are all transmissible because each pathogen can move from host to host.
- **Blood clotting seals a wound**: When the skin is cut, *platelets* trigger *clotting*, which seals the wound and limits how many more pathogens can enter through the break. Clotting acts only once the skin barrier has already been broken.
- **Comparing cases of a transmissible disease**: Because a transmissible disease spreads between hosts, the number of cases can be surveyed and compared, between places, between age groups, or before and after a change, provided the sample sizes being compared are checked first.
- **Mucus and cilia in the airways**: The trachea and bronchi are lined with sticky *mucus* that traps pathogens breathed in with the air, and with *cilia*, tiny beating hairs that sweep the trapped mucus up and out of the airway to be swallowed or coughed away.
- **White blood cells destroy pathogens that get in**: *Phagocytes* engulf and digest pathogens. *Lymphocytes* produce *antibodies*, proteins that help destroy a specific pathogen. Both are white blood cells, the body's last line of defence once a pathogen is inside.
- **Skin and clotting act in sequence, not together**: The unbroken *skin* keeps a pathogen out; once it is cut, that barrier has already failed, and *platelets* triggering *clotting* is the defence that takes over from that point, sealing the wound and limiting further entry. The two defences act one after the other, not at the same time.
- **Stomach acid as a chemical barrier**: *Stomach acid* (hydrochloric acid) kills many pathogens swallowed in food and drink, adding a chemical barrier alongside the physical barriers of skin, mucus and cilia.

EXAM TIPS

TIP A *pathogen* is the organism that causes the disease, not the disease itself. Do not write "a pathogen is a disease": the pathogen produces the disease.

TIP Ask "did the two hosts have to touch, with nothing in between?" If yes, it is direct contact. If something else, air, water, food or a vector, carried the pathogen, it is indirect, even though the pathogen still passed from one person to another.

TIP When asked how the airways defend against a pathogen breathed in, name *both* jobs: the sticky *mucus* traps it, and the beating *cilia* sweep the trapped mucus up and out. A one-sided answer earns only one mark.

TIP A "percentage increase" question always divides the rise in cases by the *original* (starting) value, never by the final value or by the increase itself: find the increase, divide by the original value, then multiply by 100.

TIP Before comparing raw case counts between two groups, check the *sample sizes* were the same. Equal samples, such as 100 tested in each group, make a direct comparison of counts fair; unequal samples require converting to percentages first.

10 Drugs

KEY CONCEPTS

- **Antibiotic resistance and MRSA**: Some bacteria are *resistant* to an antibiotic: the antibiotic no longer kills them or stops their growth, so it becomes less effective against that strain. *MRSA* is a well-known strain of bacteria that has become resistant to many antibiotics and is therefore very difficult to treat, especially in hospitals.
- **Antibiotics have no effect on viruses**: Antibiotics kill bacteria or stop them growing, but they have *no effect on viruses*. Illnesses caused by viruses, such as a cold or influenza, cannot be treated with antibiotics because the drug has nothing to act on.
- **Definition of a drug**: A *drug* is any substance taken into the body that modifies or affects the chemical reactions taking place in the body. This definition makes no reference to benefit or harm, so a helpful medicine and a harmful substance are both drugs.
- **What an antibiotic is and does**: An *antibiotic* is a drug used to treat infections caused by bacteria. It works by killing the bacteria or by stopping them from growing and reproducing, which lets the body clear the infection. Penicillin is a well-known example.
- **How a resistant strain develops**: A resistant strain arises by *natural selection*. Within a large bacterial population there is natural variation, so a few bacteria are resistant by chance before an antibiotic is ever used. The antibiotic kills the non-resistant bacteria while the resistant ones survive and reproduce, passing on their resistance, so repeated use lets the resistant strain come to dominate.
- **Substances that are not drugs**: Substances that are ordinary inputs to the body's own chemistry are *not* drugs, even though they are taken in from outside. Glucose is the fuel respired for energy and oxygen is a reactant in aerobic respiration; each drives the body's normal chemistry rather than modifying it.
- **Using antibiotics only when essential**: Prescribing antibiotics only when they are essential, that is only for confirmed bacterial infections that genuinely need treating, gives resistant bacteria fewer opportunities to be selected and to spread. This helps antibiotics stay effective for longer.
- **Antibiotic, antiviral and painkiller distinguished**: These three drugs do different jobs. An *antibiotic* acts on bacteria, killing them or stopping their growth. An *antiviral* acts on viruses. A *painkiller* relieves the sensation of pain without removing any pathogen, so naming the wrong one for a given infection is a common error.
- **Why "harms the body" is the wrong definition of a drug**: A drug is defined by whether it *modifies the body's chemical reactions*, not by whether it is harmful. Antibiotics and other helpful medicines are drugs just as much as harmful substances, so a definition built around harm is incomplete.

EXAM TIPS

TIP MRSA is a strain of *bacteria*, not a virus. Only bacteria can be antibiotic-resistant, because antibiotics act on bacteria and have no effect on viruses. Writing "MRSA is a resistant virus" loses the mark.

TIP "Best treatment" questions usually offer the same drug with two different reasons. The mark is for the *justification*, not just the drug, so choose the option that pairs an antibiotic with a correct reason such as "it will kill the bacteria causing the infection", and reject one giving a false reason.

TIP An antibiotic only helps if the infection is bacterial. Before choosing it as the treatment, check the question states or implies a bacterial cause; if the infection is viral, such as a cold or hepatitis B, an antibiotic cannot help because it has no effect on viruses.

TIP Using antibiotics only when essential *reduces the opportunities* for resistance to develop; it does not guarantee resistance will never appear, because resistant bacteria can still arise wherever antibiotics are used. Avoid absolute wording such as "this stops resistance completely"; examiners reward "limits" or "slows".

11 Electricity

KEY FORMULAS

Definition of resistance

$$R = \frac{V}{I}$$

Use to find the resistance of a component from the p.d. across it and the current through it; R is in ohms (Ω), V in volts and I in amperes. Rearranges to $V = IR$ and $I = \frac{V}{R}$.

Electrical power

$$P = IV$$

Use to find the rate at which a component transfers energy, from the current through it and the p.d. across it; P is in watts (W).

Resistors in series

$$R = R_1 + R_2 + \ldots$$

Use to find the combined resistance of resistors connected in series; the individual resistances simply add, so the total is always larger than any one of them.

Electrical energy transferred

$$E = IVt$$

Use to find the electrical energy transferred by a component from the current, the p.d. and the time; E is in joules (J) when t is in seconds. Equivalently $E = Pt$.

Heating effect of a current

$$P = I^2R$$

Use to find the power dissipated as heat in a resistance from the current through it and its resistance; keep current and resistance together, do not substitute p.d. in this form.

Resistors in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

Use to find the combined resistance of two resistors connected in parallel. The combined value is always less than the smaller of the two resistors.

Cost of running an appliance

$$E = P \times t \quad \text{(kWh)}, \qquad \text{cost} = E \times \text{price per kWh}$$

For household bills, work in *kilowatt-hours*: with power in kW and time in hours, E comes out in kWh directly. Multiply by the price per kWh to find the running cost.

KEY CONCEPTS

- **Electric current and charge carriers**: *Electric current* is the flow of electric charge, measured in amperes (A). In a metal wire it is carried by *free electrons* drifting through the fixed lattice of positive ions, not by the ions themselves. A *conductor* such as copper lets charge flow through it freely; an *insulator* such as plastic does not.
- **Energy transfers in cells, generators and motors**: A *cell* or *battery* transfers *chemical energy to electrical energy*. A *generator* transfers *kinetic energy to electrical energy* when its shaft is turned. An *electric motor* transfers *electrical energy to kinetic energy* when supplied with current.
- **Fuse, earthing and double insulation**: A *fuse* is a thin wire, placed in the *live* wire, that melts and breaks the circuit if the current becomes too large. *Earthing* connects a metal case to the ground by an earth wire, so a fault current flows to earth and blows the fuse before a user is shocked. A *double-insulated* appliance has a non-conducting plastic case and needs no earth wire, since a user can never touch a live part through it.
- **Rules for a parallel circuit**: A *parallel circuit* has components connected on separate branches between the same two points, giving more than one path for the current. The *branch currents add* to give the larger source current, and *each branch has the full p.d.* of the supply. One branch can fail without breaking the others.
- **Rules for a series circuit**: A *series circuit* has components connected one after another in a single loop, giving only one path for the current. The *current is the same* at every point, since there is nowhere for it to split, and the source voltage is *shared*, so the component p.d.s add up to it. A break anywhere stops the current everywhere.
- **One machine, run in opposite directions**: A motor and a generator are the same kind of machine run in opposite directions. Driven electrically it spins, transferring *electrical energy to kinetic energy* as a motor; spun mechanically it produces a voltage, transferring *kinetic energy to electrical energy* as a generator.
- **Parallel resistance is always less than the smallest branch**: Adding a resistor in parallel gives the current an extra path, making it easier overall for current to flow, so the combined resistance always falls *below* the smallest individual resistance in the group, never between or above the individual values.
- **Voltage of the source and p.d. of a component**: The *voltage* of a source is the push, measured in volts, that drives current round the circuit; it is present even when the circuit is open, since it describes the source itself. The *potential difference* (p.d.) across a component is the share of that source voltage used up across that one component, also measured in volts and read with a voltmeter.
- **A fault on one branch does not affect the others**: In a parallel circuit, each branch is an independent path. If the fuse protecting one branch blows, only the components on *that* branch lose their current; a separate branch across the same supply keeps working normally, since it is not part of the broken loop.

EXAM TIPS

TIP An *ammeter* measures current and is always connected *in series* with the component, so the same current flows through both. A *voltmeter* measures p.d. and is always connected *in parallel* across the component, so it reads the share of voltage used by that component.

TIP A correctly rated fuse sits just above the appliance's normal operating current, not far above it. Rating a fuse much higher "to be safe" is wrong: it would let a dangerously large fault current flow before melting, so it fails to protect the user quickly.

TIP When an analogue meter offers more than one scale, pick the one whose full-scale reading is closest to, but not below, the expected value. A small current such as 0.3 A is read far more precisely on a 0 to 1 A scale than on a 0 to 5 A scale, since the divisions are smaller.

TIP When a live wire touches an earthed metal case, a *large* fault current is desirable, not dangerous in itself: it is exactly what melts the fuse (or trips the breaker) quickly, disconnecting the supply before anyone touching the case can be shocked.

12 Electrochemistry

KEY CONCEPTS

- **Anode, cathode and electrolyte**: The *anode* is the electrode connected to the *positive* terminal of the power supply; the *cathode* is the electrode connected to the *negative* terminal; the *electrolyte* is the molten or aqueous ionic substance that conducts the current and is decomposed. Name each part from its terminal connection, not from the products formed.
- **Cations and anions**: A *cation* is a positively charged ion; it moves towards the cathode during electrolysis. An *anion* is a negatively charged ion; it moves towards the anode. Each ion moves towards the electrode of opposite charge.
- **Definition of electrolysis**: Electrolysis is the *decomposition* of an ionic compound, when *molten or in aqueous solution*, by the passage of an *electric current*. The compound must be ionic and its ions must be free to move, so melting or dissolving it is a necessary first step, but a current must still be passed to force the decomposition.
- **Discharge of ions at the electrodes**: At the cathode, a positive ion *gains electrons* and becomes a neutral atom. At the anode, a negative ion *loses electrons* and becomes a neutral atom or molecule. This gain or loss of electrons that turns an ion into a neutral particle is called *discharge*.
- **Inert electrodes**: An *inert electrode*, made of platinum or carbon/graphite, conducts the current into and out of the electrolyte without reacting with the electrolyte or the products. Because the electrode itself takes no part in the reaction, whatever forms at it comes only from the ions already present in the electrolyte.
- **Why a solid ionic compound cannot be electrolysed**: In a solid, the ions are locked in a fixed lattice and cannot move, so no current can flow through it. Melting the compound, or dissolving it in water, frees the ions so they can move to the electrodes and be discharged. The charge on each ion does not change, only its freedom to move.
- **Molten and aqueous electrolytes both free the ions**: A *molten* electrolyte is the ionic compound melted to a liquid with no water present; an *aqueous* electrolyte is the same compound dissolved in water. Both states break up the fixed lattice and free the ions to move, so both can be electrolysed; a solid cannot.
- **Products of concentrated aqueous sodium chloride**: Concentrated aqueous sodium chloride is electrolysed with inert electrodes. *Hydrogen* gas forms at the cathode, not sodium metal. *Chlorine*, a greenish-yellow gas with a sharp choking smell, forms at the anode.
- **Products of dilute sulfuric acid**: Dilute sulfuric acid is electrolysed with inert electrodes. *Hydrogen* forms at the cathode and *oxygen* forms at the anode, in a fixed volume ratio of two volumes of hydrogen to one volume of oxygen.
- **Products of electrolysing molten lead(II) bromide**: Molten lead(II) bromide is electrolysed with inert electrodes. At the cathode, *lead* forms as a silvery bead of molten metal. At the anode, *bromine* forms and is seen as an orange-brown vapour. Both products come from the electrolyte's own ions, since the electrodes are inert.
- **Anode and cathode are defined by charge, not material**: The anode and cathode are named from their terminal connection and charge, never from what they are made of. Either electrode can be made of an inert material such as platinum or graphite, so a claim that one electrode "must" be a particular material is always wrong.
- **Electrolysis as the reverse of a battery reaction**: A battery converts *chemical energy* into *electrical energy* through a spontaneous reaction. Electrolysis reverses this: it uses *electrical energy* to force a decomposition reaction that would not happen on its own. The current supplied drives the reaction rather than being produced by it.

EXAM TIPS

TIP The most common lost mark in this topic is swapping the anode and cathode. Anchor them to the supply first: *anode to the positive terminal, cathode to the negative terminal*. A memory hook: *cat*hode attracts *cat*ions.

TIP An electrode, the anode or cathode, is a conducting rod that carries current into or out of the cell. The electrolyte is the separate molten or aqueous substance being decomposed between the electrodes. Never call the electrolyte "the anode" or "the cathode".

TIP A *metal or hydrogen* is always formed at the cathode, and a *non-metal other than hydrogen* is always formed at the anode. Use this as a fast check on any answer: a metal at the anode, or a non-metal other than hydrogen at the cathode, is always wrong.

TIP Not every liquid can be electrolysed. Molten sodium chloride has free-moving ions and conducts, but liquid ethanol is a covalent compound with no ions, so it cannot be decomposed by electrolysis however it is tested. Always check that the substance is ionic before assuming it will conduct.

13 Enzymes

KEY CONCEPTS

- **Denaturation**: To be *denatured* means an enzyme has been permanently changed, usually by a high temperature or an extreme pH, so that it can no longer work. Denaturation is permanent: cooling a heat-denatured enzyme back down does not restore its activity.
- **Effect of pH on enzyme activity**: Each enzyme has an *optimum pH*, the single pH value at which it works fastest. Moving away from the optimum pH, in either direction, lowers the rate of reaction, so a graph of activity against pH rises to a peak at the optimum and falls away on both sides of it.
- **Effect of temperature on enzyme activity**: As temperature rises from a low value, the rate of an enzyme-controlled reaction increases up to a maximum at the enzyme's *optimum temperature*, the single temperature at which it works fastest. Raising the temperature well beyond the optimum makes activity fall, because the enzyme becomes *denatured*.
- **Enzymes are biological catalysts**: An *enzyme* is a *protein* that works as a *biological catalyst*: it speeds up a chemical reaction inside a living cell without being used up or permanently changed. Because it is released unchanged at the end of the reaction, the same enzyme molecule can catalyse the same reaction again and again. Enzymes contain carbon, hydrogen, oxygen and nitrogen, the elements that confirm every enzyme is a protein.
- **What a catalyst does**: A *catalyst* is a substance that speeds up a chemical reaction without being used up or permanently changed by that reaction. A *biological catalyst* is a catalyst produced by a living organism, such as an enzyme, that speeds up a *metabolic* reaction taking place inside a cell.
- **Different enzymes have different optimum pH values**: Enzymes that work in different parts of the body have different optimum pH values, matched to where they work. An enzyme with a low optimum pH suits an acidic environment, such as the stomach, while an enzyme with a high optimum pH suits an alkaline environment, such as the small intestine.
- **Independent, dependent and controlled variables**: In an investigation into an enzyme, such as the effect of temperature or pH on its activity, the *independent variable* is the one condition deliberately changed, the *dependent variable* is the outcome that is measured, and a *controlled variable* is any other condition that could affect the result and so must be kept the same in every test.
- **Specificity of enzymes**: Each enzyme normally acts on only one particular type of substance; this property is called *specificity*. An enzyme that breaks down only one kind of food molecule, and no other, is displaying its specificity.
- **Optimum temperature and optimum pH are separate properties**: An enzyme's optimum temperature and optimum pH are two independent properties: the optimum temperature is the single temperature at which it works fastest, and the optimum pH is the single pH value at which it works fastest. Moving away from either one, in either direction, lowers activity, but changing one does not change the other.

EXAM TIPS

TIP Enzymes are molecules, not living organisms, so a high temperature cannot "kill" them. The correct term is that high temperature *denatures* an enzyme, permanently changing it so it stops working.

TIP A catalyst, including an enzyme, is released unchanged at the end of a reaction and is never used up, no matter how many times it reacts. Describing an enzyme as "used up" or "destroyed" during a normal reaction is incorrect; only denaturation, not the reaction itself, stops an enzyme working.

TIP An enzyme investigation is only a fair test if every controlled variable, such as the volume and concentration of substrate, the volume of enzyme and the reaction time, is kept identical between tubes. Changing more than one condition at once, for example enzyme concentration alongside pH, means any difference in result cannot be linked to a single cause.

TIP An enzyme investigation is normally repeated at least twice at each temperature or pH tested. Repeating shows whether results are consistent, allows a mean to be calculated, and makes it easier to spot a result that does not fit the general trend so it can be treated as anomalous rather than used in the best-fit line.

14 Experimental techniques and chemical analysis

KEY CONCEPTS

- **Choosing measuring apparatus**: Time is measured with a stop-watch, temperature with a thermometer and mass with a balance. For volume, a measuring cylinder gives an approximate reading, a volumetric pipette delivers one fixed volume precisely and a burette measures a variable volume delivered precisely. A gas syringe measures the volume of a gas produced.
- **Filtration and crystallisation**: *Filtration* separates an insoluble solid from a liquid: the solid stays on the filter paper as the residue, while the liquid passes through as the filtrate. *Crystallisation* obtains a soluble solid from its solution: the solution is warmed to evaporate some solvent, then left to cool slowly so that pure crystals grow as the solubility falls.
- **Key experimental terms**: A *solute* is the substance that dissolves; a *solvent* is the liquid it dissolves in; together they form a *solution*. A *saturated solution* holds the maximum mass of solute that will dissolve at a given temperature. In filtration, the insoluble solid trapped on the filter paper is the *residue*, and the liquid that passes through is the *filtrate*.
- **Paper chromatography**: Paper chromatography separates a mixture of soluble coloured substances. A spot of the mixture is placed on a pencil baseline, above the level of the solvent in the tank. The solvent rises up the paper, dissolving the substances and carrying them with it. A substance that is more soluble in the solvent travels further, so the components separate into individual spots.
- **Reading purity from a chromatogram**: A pure substance produces a single spot on a fully developed chromatogram. A mixture produces two or more spots, one for each coloured substance it contains. Counting the spots on a chromatogram is the standard way to show whether a sample is pure or a mixture of several substances.
- **Simple and fractional distillation**: *Simple distillation* obtains a pure solvent from a solution: the solvent evaporates, condenses in a condenser and is collected, while the dissolved solute stays behind. *Fractional distillation* separates two or more miscible liquids with different boiling points, using a fractionating column so that the liquid with the lower boiling point is collected first.
- **Testing cations with aqueous sodium hydroxide**: Adding aqueous sodium hydroxide gives a coloured metal hydroxide precipitate. Copper(II) gives a blue precipitate, iron(II) a green precipitate and iron(III) a red-brown precipitate, all insoluble in excess. Calcium gives a white precipitate insoluble in excess, while zinc gives a white precipitate that dissolves in excess. Ammonium ions give no precipitate but release ammonia gas on warming.
- **Tests for common gases**: Hydrogen gives a squeaky pop with a lighted splint. Oxygen relights a glowing splint. Carbon dioxide turns limewater milky. Ammonia turns damp red litmus paper blue. Chlorine bleaches damp litmus paper.
- **Choosing a separation technique**: Match the technique to the mixture. Use filtration for an insoluble solid in a liquid, crystallisation for a soluble solid from its solution, simple distillation for a solvent from a solution and fractional distillation for miscible liquids with different boiling points. Filtration cannot separate two miscible liquids.
- **Identifying a substance by comparison**: An unknown substance is identified by running it alongside known reference substances, on the same paper, in the same solvent, under identical conditions. An unknown spot that lines up at the same height as a reference spot is very likely the same substance.
- **Solubility and crystallisation**: *Solubility* is the maximum mass of solute that will dissolve in a fixed amount of solvent at a given temperature. For most solids, solubility rises as temperature rises, so it falls as a solution cools. A hot saturated solution therefore deposits crystals on cooling, because it can no longer hold all of its dissolved solute.
- **Tests for anions**: For a carbonate, adding dilute acid produces effervescence and the gas turns limewater milky. For a sulfate, adding dilute nitric acid then aqueous barium nitrate gives a white precipitate. For the halides, adding dilute nitric acid then aqueous silver nitrate gives a white precipitate with chloride, a cream precipitate with bromide and a yellow precipitate with iodide.
- **Confirming an identification with a second solvent**: A single match between an unknown spot and a reference spot in one solvent is good evidence, but not certain. Running the same unknown and reference again in a different solvent, and finding the spots still line up, gives much stronger evidence that the unknown really is that reference substance.
- **Flame test colours**: In a flame test, a clean wire is dipped in the compound and held in a hot blue Bunsen flame. Lithium gives a red flame, sodium a yellow flame, potassium a lilac flame and

copper(II) a blue-green flame. The colour identifies the metal cation present.

- **Slow cooling gives larger, purer crystals**: Cooling a saturated solution slowly allows crystals to grow gradually, giving large, well formed, pure crystals. Cooling rapidly, for example in iced water, forces many small crystals to form at once, and these are smaller and more likely to trap impurities.

EXAM TIPS

TIP The volume delivered from a burette is the final reading minus the initial reading, never the final reading alone. Read the meniscus at eye level, from the bottom of the curve, to avoid a parallax error. A burette is numbered from 0 at the top down to the tap, the opposite way round from a measuring cylinder.

TIP A burette is numbered from 0 at the top down to the tap, because liquid runs out of the bottom. This is the opposite way round from a measuring cylinder, which is numbered bottom to top. Check the direction of the scale before reading it.

TIP Always draw the baseline in pencil, never in ink. Pencil is insoluble in the solvent, so the baseline stays fixed while the sample spots move. An ink line would dissolve and travel up the paper, spoiling the result.

TIP Colourless substances, such as amino acids, leave no visible spots on a chromatogram. Spray the dried chromatogram with a locating agent, such as ninhydrin, which reacts with the substances to produce coloured spots that can then be seen and compared.

15 Gas exchange in humans

KEY FORMULAS

Breathing rate from a timed count

$$\text{breathing rate} = \text{count} \times \frac{60}{\text{time in seconds}}$$

Use to turn a number of breaths counted over a fixed time into breaths per minute. One breath is one inhalation plus one exhalation; the answer has units of breaths per minute.

Percentage increase

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

Use to express how much a measurement such as breathing rate has risen, as a percentage of its starting value. Find the increase first (new value minus original value), then divide by the *original* value, not the new one.

Percentage decrease

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

Use to express how much a measurement such as the percentage of oxygen in exhaled air has fallen, as a percentage of its starting value. Find the decrease first (original value minus new value), then divide by the *original* value.

Scale factor for a timed breath count

$$\text{scale factor} = \frac{60}{\text{time in seconds}}$$

Use to work out the multiplier that converts a breath count taken over any fixed time into breaths per minute, before multiplying by the count. A count taken over exactly 60 seconds needs no scaling, since the scale factor is 1.

KEY CONCEPTS

- **Direction of gas exchange at the alveolus**: At the alveolus, *oxygen* diffuses from the alveolar air into the blood, and *carbon dioxide* diffuses from the blood into the alveolar air. Each gas moves in its own direction, oxygen in and carbon dioxide out.
- **How air is drawn into the lungs**: During inhalation the *intercostal muscles* contract to pull the rib cage up and out, and the *diaphragm* contracts and flattens. Together they increase the volume of the chest cavity, which lowers the pressure inside it below atmospheric pressure, so air flows in.
- **How breathing changes during exercise**: During exercise muscles respire faster, using oxygen and producing carbon dioxide more quickly. The body responds by increasing both the *rate* of breathing (more breaths per minute) and the *depth* of breathing (a bigger volume of air with each breath).
- **Route of air to the gas exchange surface**: Air passes from the *trachea* (the windpipe, held open by rings of cartilage) into two *bronchi*, one to each lung, then into many branching *bronchioles*, and finally into the *alveoli*, the tiny air sacs where gas exchange takes place.
- **Composition change between inhaled and exhaled air**: Compared with inhaled air, exhaled air has a *lower* percentage of oxygen (about 21% falling to about 16%) and a *higher* percentage of carbon dioxide (about 0.04% rising to about 4%), because the body has used some of the oxygen and produced carbon dioxide.
- **The recovery period after exercise**: When exercise stops, breathing does not return to its resting rate immediately. During the *recovery* period the breathing rate stays raised and then falls gradually, while the body clears the excess carbon dioxide produced during exercise.
- **The limewater test for carbon dioxide**: Limewater turns milky (cloudy) in the presence of carbon dioxide, and turns milky faster and more strongly the more carbon dioxide is present. Passing

inhaled air through one tube and exhaled air through a second tube shows the exhaled-air tube turning milky while the inhaled-air tube stays clear.

EXAM TIPS

TIP The *bronchus* is the large tube that branches straight off the trachea into a lung; a *bronchiole* is one of the many small tubes deep inside the lung that lead into the alveoli. Sort them by size and position, not by name alone.

TIP In the limewater test, the tube through which a person *breathes out* is always the one that turns milky faster, because exhaled air contains far more carbon dioxide than inhaled air. Do not assume the *breathed-in* tube reacts just because it was used first.

TIP A question asking how breathing changes during exercise needs *both* answers: the rate increases and the depth increases. Giving only one of the two is the commonest way to drop a mark on this topic.

TIP When calculating a percentage increase or decrease, always divide by the *original* value, not the new value. Dividing by the new value instead gives an answer that looks plausible but is wrong.

16 Human influences on ecosystems

KEY CONCEPTS

- **Causes of endangerment and extinction**: A species may become endangered or extinct through *habitat destruction*, *hunting* or *overharvesting*, *pollution*, *introduced species*, or *climate change*. More than one cause can act on the same species at once.
- **Endangered and extinct species**: An *endangered* species is one whose population has fallen so low that it is at risk of becoming extinct. A species is *extinct* when all of its members have died and none remain alive anywhere.
- **Reasons for habitat destruction**: Humans destroy natural habitats to clear land for *farming* (crops and grazing livestock), to build *houses, roads and factories*, and to extract resources such as *timber and minerals*; pollution can also damage a habitat without any land being cleared.
- **The undesirable effects of deforestation**: Deforestation causes *loss of habitats and biodiversity*, *soil erosion*, *flooding*, and a *rise in atmospheric carbon dioxide*.
- **What an ecosystem is**: An *ecosystem* is a unit made up of a *community of organisms* together with the *non-living environment* in which they live and interact, including the soil, water, air and climate.
- **What biodiversity is**: *Biodiversity* is the number of *different species* that live in an area. It counts species, not individuals, so an area crowded with one species still has low biodiversity.
- **How an introduced species can reduce a native population**: An *introduced species* is one moved into a new area, often by humans, where it did not naturally occur. Native organisms that never evolved defences against it can be preyed on or outcompeted, so their numbers fall.
- **Why deforestation increases soil erosion**: Tree roots normally *bind soil particles together* and take up water from the ground. Once the trees are removed, nothing holds the loose soil in place, so heavy rain washes it away more easily.
- **Why deforestation raises atmospheric carbon dioxide**: Living trees remove carbon dioxide from the air by *photosynthesis*. Cutting the forest down means less photosynthesis is happening, so less carbon dioxide is removed and the atmospheric concentration rises.
- **A population does not recover the instant a cause is removed**: Removing a cause of extinction, such as pollution or overharvesting, stops further harm, but a reduced population still needs *time to reproduce* and grow back to its earlier size; recovery is not immediate.
- **Effects reach organisms that were never felled**: Because an ecosystem is a community of interacting organisms, removing trees also removes the shelter, food or nesting sites that other organisms in that community depended on, so species that were never directly cut down are still affected.

EXAM TIPS

TIP Judge biodiversity on the *variety* of species present, never on how many organisms there are or how large an area looks. A park with one type of grass has low biodiversity even if it is crowded; a reserve with many different species has high biodiversity even with fewer individuals of each.

TIP *Hunting* is killing organisms directly, for example for their horns or fur. *Overharvesting* is the wider term for removing organisms, by any method such as fishing, faster than the population can reproduce and replace them.

TIP A definition of ecosystem that lists only the organisms loses the mark. An ecosystem is a community *together with* the non-living surroundings, such as the soil, water and air, that those organisms interact with.

TIP A declining species is not always explained by a single cause. Habitat destruction, hunting, pollution, introduced species and climate change can act together, so removing only one threat may not stop the decline.

17 Human nutrition

KEY FORMULAS

Energy released from a nutrient

$$E = m \times e$$

Use to find the energy E released when a mass m (in grams) of a nutrient is respired, where e is the energy value of that nutrient per gram. Keep the mass in grams so the answer comes out in kilojoules.

Standard energy values of the nutrients

$$\text{fat} \approx 37\ \text{kJ g}^{-1}, \quad \text{carbohydrate and protein} \approx 17\ \text{kJ g}^{-1}$$

Use these fixed values when working out how much energy a food provides. Fat releases roughly twice the energy per gram of carbohydrate or protein, which is why fatty foods are so energy-rich.

Comparing energy contributed by two nutrients

$$E_{total} = (m_1 \times e_1) + (m_2 \times e_2)$$

Use to compare how much energy two different nutrients contribute to the same food. Multiply each nutrient's mass by its own energy value, then compare the two amounts to see which contributes more.

Finding a nutrient's energy value from a total

$$e = \frac{E}{m}$$

Rearrange the energy equation when you are given the total energy E released and the mass m that produced it, and need the energy value e per gram instead. Divide the total energy by the mass.

KEY CONCEPTS

- **Physical and chemical digestion**: *Physical digestion* breaks food into smaller pieces, for example by chewing, without changing the food molecules themselves. *Chemical digestion* uses enzymes to break large, insoluble food molecules into small, soluble molecules.
- **The alimentary canal and associated organs**: The *alimentary canal* is the continuous tube food passes through, in order: mouth, oesophagus, stomach, small intestine, large intestine, rectum, anus. The *associated organs* (salivary glands, pancreas, liver, gall bladder) add digestive juices, but food does not pass through them.
- **The components of a balanced diet**: A *balanced diet* supplies all the required nutrients in the right amounts and proportions needed for good health. The components are *carbohydrates*, *fats and oils*, *proteins*, *vitamins*, *mineral ions*, *fibre* (roughage) and *water*.
- **The five processes that act on food**: *Ingestion* takes food and drink into the body through the mouth. *Digestion* breaks large food molecules into small, soluble ones. *Absorption* moves those products from the intestines into the blood. *Assimilation* is the uptake and use of nutrients by cells. *Egestion* removes undigested food from the body as faeces.
- **Uses of the main nutrients**: *Carbohydrate* is the body's main source of energy for everyday activities. *Fat* is a store of energy and insulates the body against heat loss. *Protein* is needed for the growth and repair of body tissues. *Iron* is needed to make haemoglobin, and *calcium* to harden bones and teeth.
- **Following food through the alimentary canal**: Food passes through the alimentary canal in a fixed order: down the *oesophagus* from the mouth, churned in the J-shaped *stomach*, along the long, coiled *small intestine*, then the wider *large intestine*, before reaching the rectum and anus. Diagrams often test this order using unlabelled shapes.

- **Mineral ions: calcium and iron**: *Calcium* is needed to harden bones and teeth. *Iron* is needed to make *haemoglobin*, the substance in red blood cells that carries oxygen; a diet low in iron can leave the blood carrying too little oxygen.
- **Vitamins C and D and their deficiency diseases**: A prolonged lack of *vitamin C* causes *scurvy* (bleeding gums, poor wound healing); good sources are fresh fruit and vegetables. A lack of *vitamin D* causes *rickets*, in which bones become soft and weak, because vitamin D is needed for the body to use calcium.
- **What a molecule model of digestion shows**: A molecule-model diagram often shows one large, clustered shape (a large, insoluble molecule) before digestion, and several small, separate shapes (small, soluble molecules) after digestion. The large shape represents the molecule before chemical digestion; the small shapes represent the products afterwards.
- **Why small intestine damage reduces absorption**: The small intestine is the main site where digested nutrients move from the gut into the blood. If its wall is damaged, digestion of food can still happen almost normally, but far less of the digested nutrients can cross into the blood, so absorption is reduced even though digestion is not.

EXAM TIPS

TIP *Egestion* removes undigested food, such as fibre, that never entered the body's cells. *Excretion* removes waste made by the body's own reactions. If a question describes faeces leaving the body, that is egestion, not excretion.

TIP More is not automatically better. A *balanced diet* supplies the correct amount of each nutrient. A diet can supply exactly the right total energy and still not be balanced if it lacks protein, vitamins, minerals or fibre.

TIP Physical digestion produces smaller pieces of the *same* large, insoluble molecules; it does not change the molecules. Chemical digestion is the one that turns large, insoluble molecules into small, soluble molecules. Don't assume that "broken into smaller pieces" always means chemical digestion has happened.

18 Metals

KEY FORMULAS

Extracting a metal below carbon

$$\text{metal oxide} + \text{carbon} \rightarrow \text{metal} + \text{carbon dioxide}$$

Use for a metal ore below carbon in the reactivity series, such as iron(III) oxide or zinc oxide. The carbon removes the oxygen from the metal oxide, so this is a *reduction* reaction for the ore.

Metal plus dilute acid

$$\text{metal} + \text{dilute acid} \rightarrow \text{a salt} + \text{hydrogen}$$

Use for any metal above hydrogen in the reactivity series. Dilute hydrochloric acid gives a chloride and dilute sulfuric acid gives a sulfate, for example $Mg + 2HCl \rightarrow MgCl_2 + H_2$.

Displacement of copper by iron

$$Fe + CuSO_4 \rightarrow FeSO_4 + Cu$$

Use when a more reactive metal is placed in a solution of a less reactive metal's salt. Iron is above copper in the reactivity series, so it takes the sulfate and pushes out copper metal, coating the iron with a layer of copper.

Metal plus cold water

$$\text{metal} + \text{cold water} \rightarrow \text{metal hydroxide} + \text{hydrogen}$$

Use only for the most reactive metals, potassium, sodium and calcium; the reaction is more vigorous higher up the reactivity series, for example $2K + 2H_2O \rightarrow 2KOH + H_2$.

Metal plus steam

$$\text{metal} + \text{steam} \rightarrow \text{metal oxide} + \text{hydrogen}$$

Use for a moderately reactive metal such as magnesium, which reacts little with cold water but readily with steam: $Mg + H_2O \rightarrow MgO + H_2$. The product is an *oxide*, in contrast to the *hydroxide* formed with cold water.

KEY CONCEPTS

- **Chemical reactions of metals**: Metals react with dilute acid, and the most reactive metals also react with cold water or steam. Metal plus dilute acid gives *a salt plus hydrogen*. Metal plus cold water gives *a metal hydroxide plus hydrogen*, and only potassium, sodium and calcium react this way. Metal plus steam gives *a metal oxide plus hydrogen*, shown by a less reactive metal such as magnesium.
- **Conditions for rusting and how to prevent it**: *Rusting* is the corrosion of iron, and it needs *oxygen and water present together*. Remove either one and iron does not rust, however long it is left. Rust is prevented by *barrier methods*: painting, greasing and coating with plastic all work the same way, by covering the surface so oxygen and water cannot reach the iron.
- **Every use is a property doing a job**: A metal is chosen for a use because a specific physical property suits the job. *Aluminium* has a low density and resists corrosion, so it is used for aircraft bodies and food containers. *Copper* is an excellent conductor of electricity and is ductile, so it is used for electrical wiring. To justify a use, name the property, not just the metal.
- **Physical properties of metals**: Most metals are good conductors of heat and electricity, shiny (lustrous), and *malleable* (can be hammered or pressed into shape) and *ductile* (can be drawn into a wire). They generally have high melting points, unlike most non-metals, which are poor conductors, dull, and often low-melting or gases.

- **Reactivity sets the extraction method**: How a metal is extracted from its ore is fixed by its reactivity. Very unreactive metals (silver, gold) are found *native*, as the uncombined element. Metals *below carbon* (zinc, iron, copper) are extracted by heating their oxide with carbon, which removes the oxygen. Metals *above carbon* (potassium to aluminium) are too reactive for carbon and must be extracted by *electrolysis*, for example aluminium from bauxite.
- **The reactivity series**: The reactivity series lists metals in order of decreasing reactivity, with the non-metals carbon and hydrogen included as reference points: potassium, sodium, calcium, magnesium, aluminium, (carbon), zinc, iron, (hydrogen), copper, silver, gold. The higher a metal sits, the more vigorously it reacts with water, steam and dilute acid.
- **What an alloy is**: An *alloy* is a mixture of a metal with one or more other elements, usually other metals, made by melting the components together and letting them solidify. An alloy is usually harder and stronger than the pure metal it is made from. The two syllabus examples are *brass* (copper and zinc) and *stainless steel* (iron with chromium, and often nickel and carbon), where the chromium resists corrosion.
- **Displacement reactions**: A more reactive metal *displaces* a less reactive metal from a solution of its salt, because the more reactive metal holds the compound more strongly. When excess zinc is added to blue copper(II) sulfate solution, the blue colour fades as copper(II) ions are replaced by colourless zinc sulfate, and reddish-brown copper metal forms.
- **Ores and reduction**: An *ore* is a rock or mineral from which a metal can be extracted, usually because it contains a compound of the metal. Iron's main ore is *hematite*; aluminium's main ore is *bauxite*. Extracting the metal from its oxide ore is a *reduction* reaction, because the oxide loses oxygen to leave the metal.
- **Why an alloy is harder than the pure metal**: In a pure metal all the atoms are the same size and sit in regular layers that slide over one another when a force is applied, which is why pure metals are soft and malleable. In an alloy the added atoms are a *different size*, so they distort the regular layers and stop them sliding as easily, making the alloy harder and stronger than the pure metal it is made from.

EXAM TIPS

TIP A metal *above hydrogen* reacts with dilute acid to give hydrogen; a metal *below hydrogen* (copper, silver, gold) does not. A metal *below carbon* can be extracted by heating its oxide with carbon; a metal *above carbon* is too reactive and must be extracted by electrolysis.

TIP Rusting needs oxygen *and* water together, so a full answer must name both. Oxygen alone, in dry air, will not rust iron, and water alone, with the air excluded, will not either. Stating only that rust "needs air" or "needs moisture" misses a mark, because it names just one of the two conditions.

TIP *Malleable* means the metal can be hammered or pressed into a new shape without shattering, a squashing force. *Ductile* means it can be drawn out into a thin wire, a pulling force. Keep the two words distinct; the exam awards the mark for the correct one.

TIP When a question asks why metal X is chosen "even though metal Y is better at one thing", name the property Y wins on *and* the property X wins on, then say which matters more for that job. Overhead cables use aluminium rather than the better-conducting copper because aluminium's much lower density keeps the cable light enough for the pylons to support.

TIP A diagram of an alloy shows atoms of *two different sizes* packed together, unlike a pure metal's diagram of same-sized atoms in neat rows. Identify an alloy by the mixed atom sizes, and explain hardness by linking that mismatch to the disrupted layers, not by naming the metals alone.

19 Motion, forces and energy

KEY FORMULAS

Average speed

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

Use for a journey whose speed is not steady. The total time must include any time spent stopped, which is why the average speed is not the mean of the separate speeds.

Density

$$\rho = \frac{m}{V}$$

Use to find the density ρ of a material of mass m and volume V. Measured in g/cm^3 or kg/m^3. Rearranges to $m = \rho V$ and $V = \frac{m}{\rho}$.

Power

$$P = \frac{W}{t} = \frac{E}{t}$$

Use to find power as the rate of doing work or transferring energy. Measured in watts, where 1 W = 1 J/s.

Pressure

$$p = \frac{F}{A}$$

Use to find the pressure p from a force F acting on an area A. Measured in pascals, where 1 Pa = 1 N/m^2. For a fixed force a smaller area gives a greater pressure.

Speed

$$v = \frac{s}{t}$$

Use to find the speed v of an object moving a distance s in a time t. Speed is measured in metres per second (m/s) when s is in metres and t is in seconds. Rearranges to $s = vt$ and $t = \frac{s}{v}$.

Weight

$$W = mg$$

Use to find the weight W (in newtons) of a mass m (in kilograms) in a gravitational field of strength g. Near the Earth's surface $g = 9.8$ N/kg. Rearranges to $g = \frac{W}{m}$ and $m = \frac{W}{g}$.

Work done

$$W = Fd$$

Use to find the work done, and so the energy transferred, when a force F moves an object a distance d in the direction of the force. Measured in joules (J); convert any distance in centimetres to metres first.

KEY CONCEPTS

- **Energy stores and conservation of energy**: Energy is stored kinetically, gravitationally (as gravitational potential energy), chemically, elastically, nuclearly, electrostatically and internally (thermally), and is transferred mechanically, electrically, by heating or by waves. The *principle of conservation of energy* states that energy cannot be created or destroyed, only transferred from one store to another, so the total amount stays the same.
- **Force and resultant force**: A *force* is a push or a pull that can change an object's size, shape or motion. When forces act along one straight line, forces in the same direction add and forces in opposite directions subtract; the single *resultant force* that remains points the way of the larger force and decides how the motion changes.
- **Mass compared with weight**: *Mass* is the quantity of matter in an object, measured in kilograms, and stays the same wherever the object is. *Weight* is the gravitational force on that mass, measured in newtons, and changes with the gravitational field strength g of the location, for example becoming smaller on the Moon.
- **Measuring length, volume and time**: Length is measured with a *ruler* or metre rule, read to the nearest millimetre and viewed straight on to avoid *parallax* error. The volume of a liquid is measured with a *measuring cylinder*, reading the bottom of the meniscus at eye level. Time intervals are measured with a *stop-watch* or digital timer.
- **Reading distance-time and speed-time graphs**: On a *distance-time* graph the gradient is the *speed*: a horizontal line means the object is at rest and a steeper line means a greater speed. On a *speed-time* graph a horizontal line means a constant speed, a line sloping upward means the object is *accelerating*, and a line sloping downward means it is *decelerating*.
- **Area and pressure**: For a fixed force, pressure and contact area are inversely related: a smaller area gives a greater pressure. This is why a sharp knife or a drawing pin, with a tiny contact area, presses hard, while a wide snowshoe or a filing cabinet on broad feet spreads the same weight over a large area and so gives a small pressure.
- **Energy resources**: Useful energy is obtained from fossil fuels, biofuels, wind, waves, hydroelectric power, and solar cells and panels, most of which trace back to radiation from the Sun. The three resources that do *not* come from the Sun are *geothermal* (heat from hot rocks), *nuclear* fission and *tidal* (from the gravity of the Moon and Sun).
- **Friction, drag and terminal velocity**: *Friction* opposes relative motion between two surfaces in contact and causes heating; *drag* is the friction of a fluid, such as air resistance or water resistance, and it increases as speed increases. When the drag on a falling object grows until it balances the object's weight, the resultant force becomes zero and the object falls at a constant *terminal velocity*.
- **Measuring density, floating and sinking**: Find the volume of a regular solid from its dimensions, and of an irregular solid by *displacement* (the rise in water level in a measuring cylinder equals its volume). An object *sinks* in a liquid if it is denser than the liquid and *floats* if it is less dense, so whether an object floats depends on comparing the two densities.

EXAM TIPS

TIP The phrases "constant speed", "moving steadily" and "at rest" are all code for a *resultant force of zero*. Whenever a question describes steady motion, balance the forces first: a steady speed does not mean no forces are acting, it means the forces acting are equal and opposite.

TIP Check the axis labels before reading a motion graph. On a *distance-time* graph the gradient gives the *speed*, so a straight sloping line means a constant speed. On a *speed-time* graph the shape tells you what is happening to the speed: rising means *accelerating*, falling means *decelerating*, and flat means constant speed, but the gradient value itself is not needed at Core level.

TIP Every energy transfer wastes some energy, almost always as thermal energy to the surroundings, so the useful energy output is always less than the total energy input. Use *conservation of energy* to find the wasted amount: it is simply the total input minus the useful output, since the total energy is unchanged overall.

TIP A quantity too small to measure once, such as the thickness of one sheet of paper or the period of one pendulum swing, is found by measuring many together and dividing. Timing 20 swings of a pendulum and dividing by 20 spreads a fixed timing error, such as reaction time, across all 20 swings, giving a far more accurate period than timing a single swing.

TIP To obtain a pressure in pascals the area must be in m^2. Convert an area in cm^2 by dividing by $10\,000$, since 1 m^2 $= 10\,000$ cm^2. When a load is shared over several contact areas, add the areas together first, then convert once, then divide the force by the total area.

20 Movement into and out of cells

KEY FORMULAS

Mass change before converting to a percentage

$$\text{mass change} = \text{final mass} - \text{initial mass}$$

The first step before calculating percentage change in mass. A positive value shows the tissue gained mass, so water moved in; a negative value shows it lost mass, so water moved out. Converting this to a percentage of the initial mass lets chips of different starting sizes be compared fairly.

Percentage change in mass

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

Use to measure the effect of osmosis on plant tissue, such as potato chips left in a range of sucrose solutions. A *positive* value means water moved in; a *negative* value means water moved out; a value near *zero* means the solution's concentration is close to matching the tissue's.

Rearranged to find the final mass

$$\text{final mass} = \text{initial mass} \times \left(1 + \frac{\%\ \text{change in mass}}{100}\right)$$

Use when the initial mass and the percentage change are known and the final mass is needed. A positive percentage change increases the mass above the initial value; a negative percentage change decreases it below the initial value.

Rearranged to find the initial mass

$$\text{initial mass} = \frac{\text{final mass}}{1 + \frac{\%\ \text{change in mass}}{100}}$$

Use when the final mass and the percentage change are known and the starting mass is needed. Divide the final mass by one plus the percentage change expressed as a decimal.

KEY CONCEPTS

- **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, caused by the particles' own random movement. The word *net* matters: particles move in every direction, but overall more travel from the crowded region to the sparse region than the reverse.
- **Definition of osmosis**: Osmosis is the net movement of water molecules from a dilute solution to a more concentrated solution, through a *partially permeable* membrane. It is a special case of diffusion in which the only substance that moves is water.
- **Diffusion needs no energy**: Diffusion needs no energy input from the cell. It happens because of the particles' own constant random movement, which is why it is described as a *passive* process.
- **Partially permeable membrane**: A partially permeable membrane lets small water molecules pass through but holds back larger dissolved molecules such as sugar. Both conditions, a partially permeable membrane and a difference in water concentration across it, must be present for osmosis to occur.
- **Importance of diffusion in gas exchange**: A respiring cell constantly uses up oxygen and produces carbon dioxide, so the oxygen concentration stays low and the carbon dioxide concentration stays high inside the cell compared with outside. These concentration gradients are what drive oxygen in and carbon dioxide out by diffusion. Without diffusion a cell could not obtain the oxygen or remove the carbon dioxide that respiration depends on.
- **Substances that diffuse through the cell membrane**: Some substances move into and out of cells by diffusion through the cell membrane. Oxygen and carbon dioxide are the two most important

examples in a respiring cell, and each diffuses down its own concentration gradient independently of the other.

- **The cell membrane, not the cell wall, controls osmosis**: In a plant cell it is the *cell membrane* that acts as the partially permeable barrier controlling osmosis. The cell wall lets all substances pass freely, so it does not control which substances cross; naming the wall instead of the membrane is a common error.
- **Why percentage change, not raw change, is calculated**: *Percentage* change in mass is calculated rather than the raw change so that potato chips of slightly different starting mass can still be compared fairly. A chip that starts smaller would show a smaller raw change even with the same proportional water movement, but its percentage change would match a larger chip's.

EXAM TIPS

TIP An osmosis statement is correct only if it passes two checkpoints: it is *water* that moves, never the dissolved solute, and it moves from *dilute to concentrated*, through a *partially permeable* membrane. Check both before choosing an answer.

TIP Osmosis can be thought of as diffusion restricted to one substance: water. If a question describes any substance other than water crossing a membrane, the correct term is diffusion, not osmosis, even if the membrane is partially permeable.

TIP A common wrong answer describes diffusion as particles moving from *low* to *high* concentration. Diffusion is always the *net* movement from *higher* to *lower* concentration, down the concentration gradient; particles never diffuse against the gradient without an energy source.

TIP Several variables must be controlled for a fair test in the potato osmosis investigation: the chips must be cut from the *same potato* to the *same starting size*, left in the solutions for the *same time* at the *same temperature*, and blotted dry in the *same way* before weighing. Leaving any of these uncontrolled makes the percentage-change results unfair to compare.

21 Organic chemistry

KEY FORMULAS

Complete combustion of a hydrocarbon

$$\text{hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}$$

Use for the burning of any hydrocarbon fuel, such as an alkane, in a *plentiful* supply of oxygen. Complete combustion always gives carbon dioxide and water as the only products; nothing else forms.

Complete combustion of methane

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Balanced equation for the complete combustion of methane, the simplest alkane, in a plentiful supply of oxygen. The products are *carbon dioxide* and *water* only; the same complete-combustion pattern applies to any hydrocarbon fuel.

Incomplete combustion of a hydrocarbon

$$\text{methane} + \text{oxygen} \rightarrow \text{carbon monoxide} + \text{water}$$

Use when a hydrocarbon burns in a *limited* supply of oxygen, for example a Bunsen burner with its air hole nearly closed. The carbon is not fully oxidised, so *carbon monoxide* and/or *carbon* (soot) form alongside water, instead of carbon dioxide.

Repeat unit of poly(ethene)

$$(-CH_2 - CH_2-)_n$$

Use to represent poly(ethene) formed from n ethene monomers by addition polymerisation. Each ethene monomer's carbon-carbon double bond opens up so the units link by single bonds into a long chain; the part inside the brackets is the *repeat unit* and n is a very large number of monomers.

KEY CONCEPTS

- **Bonding and reactivity of alkanes**: In an alkane every bond, including every carbon-carbon bond, is a *single covalent bond*, so alkanes are *saturated hydrocarbons*. Alkanes are *generally unreactive*, except in terms of combustion; they do not react with dilute acids or with aqueous bromine.
- **Fossil fuels and hydrocarbons**: The three fossil fuels are *coal*, *natural gas* and *petroleum*. A *hydrocarbon* is a compound that contains hydrogen and carbon only, no other element. *Natural gas* is mainly *methane*, CH_4; *petroleum* is a *mixture* of many different hydrocarbons.
- **Fractional distillation of petroleum**: Petroleum is separated into *fractions* by *fractional distillation*, because it exploits the different boiling points of the hydrocarbons it contains. The petroleum is heated to vaporise it and fed into a fractionating column that is *hot at the bottom and cooler at the top*; each fraction condenses at the height where the temperature matches its boiling point.
- **Polymers and monomers**: A *polymer* is a very large molecule built up from many smaller molecules called *monomers* joining together. Poly(ethene) is the polymer formed when many *ethene* monomers join; ethene is the small starting molecule and poly(ethene) is the large molecule it builds.
- **Saturated and unsaturated compounds**: A *saturated* compound has molecules with only single bonds between all of its carbon-carbon atoms. An *unsaturated* compound has molecules with one or more carbon-carbon bonds that are not single bonds. The classification depends only on the carbon-carbon bonds; another atom on the chain, such as chlorine or bromine, does not change it.
- **The carbon-carbon double bond and alkenes**: Every alkene molecule contains a carbon-carbon *double* bond, $C{=}C$. This double bond makes alkenes *unsaturated* hydrocarbons and is the reactive site that lets other atoms add across it. Ethene, C_2H_4, is the alkene named on this course.

- **Addition polymerisation of ethene**: Poly(ethene) forms from *ethene* monomers by *addition polymerisation*: many ethene molecules join together as their carbon-carbon double bonds open up, with *no other product* formed. Only an unsaturated monomer, one with a double bond, can polymerise this way.
- **The aqueous bromine test**: *Aqueous bromine* (bromine water), which is orange-brown, distinguishes a saturated from an unsaturated hydrocarbon. An unsaturated hydrocarbon (an alkene) *decolourises* it, because its carbon-carbon double bond reacts with the bromine. A saturated hydrocarbon (an alkane) has no double bond to react, so the bromine water is left unchanged.
- **The petroleum fractions and their uses**: The five named fractions, from the top of the column to the bottom, are *refinery gas* (heating and cooking), *gasoline*/petrol (fuel for cars), *naphtha* (chemical feedstock), *diesel oil* (fuel for diesel engines) and *bitumen* (making roads). A fraction leaving low down has a high boiling point; one leaving near the top has a low boiling point.

EXAM TIPS

TIP An alkane's one reliable reaction is *combustion*: it burns in oxygen. It does not decolourise aqueous bromine, does not react with dilute acid and does not undergo any other reaction on this course. A claim that an alkane "never reacts at all" overstates the case; it burns.

TIP Four of the five named fractions are burned as fuels. *Naphtha* is the exception: it is a *chemical feedstock*, the raw material from which other chemicals are manufactured, not something that is burned. A question asking which fraction is not used directly as a fuel has exactly one correct answer.

TIP Whether a compound is saturated or unsaturated depends *only* on the type of bond between its carbon atoms. A side atom such as chlorine or bromine attached to the chain does not change the classification: 1-bromopropane has only single carbon-carbon bonds, so it is saturated, even though it is not a hydrocarbon.

TIP Always give the colour change with its direction: aqueous bromine turns from *orange-brown to colourless* with an unsaturated hydrocarbon. Writing only "colourless", or reversing the direction, loses the mark. "Decolourised" means the colour has gone; it does not mean "turned white" or "cloudy".

22 Organisms and their environment

KEY CONCEPTS

- **A food chain always begins with a producer**: A *food chain* shows the transfer of energy from one organism to the next, and always *begins with a producer* because energy must enter the living world through photosynthesis before any animal can feed. Each arrow points from the organism that is eaten to the organism that eats it, so the arrow shows the direction of energy flow.
- **Carbon is recycled through five processes**: Unlike energy, *carbon is recycled* endlessly between the atmosphere and living organisms. The cycle has five processes: *photosynthesis* removes carbon dioxide from the air; *respiration*, *decomposition* and *combustion* release carbon dioxide into the air; and *feeding* transfers carbon from one organism to the next without changing the amount in the atmosphere.
- **Energy flow is one-way**: Energy *flows through* living organisms rather than being stored forever: it enters producers as chemical energy, passes to consumers by feeding, and at every stage some is released by respiration and eventually transferred to the environment, mostly as *heat*. The overall path is Sun to producers to consumers to environment. Energy is never recycled, so a food chain depends on a constant new supply of light energy.
- **Herbivores, carnivores and decomposers**: A *herbivore* is an animal that gets its energy by eating plants. A *carnivore* is an animal that gets its energy by eating other animals. A *decomposer* is an organism that gets its energy from *dead or waste* organic material; bacteria and fungi are the main decomposers. The trigger words for a decomposer are dead, decaying or waste.
- **Producers and consumers**: A *producer* is an organism that makes its own organic nutrients, usually using light energy in *photosynthesis*; green plants and algae are producers. A *consumer* is an organism that gets its energy by *feeding on other organisms*. The distinction is about how the organism obtains its energy, not whether it is a plant or an animal.
- **The Sun is the principal source of energy**: The *Sun* is the principal source of energy input to biological systems. Sunlight is captured by producers during *photosynthesis*, which converts light energy into chemical energy stored in nutrients such as glucose. Even the energy in a consumer that never sees sunlight, such as a fox, traces back through what it eats to the Sun.
- **Trophic levels of consumers**: Consumers are numbered by how far along the chain they feed, counting from the producer. A *primary consumer* eats the producer; a *secondary consumer* eats the primary consumer; a *tertiary consumer* eats the secondary consumer. In a coral reef food web where phytoplankton (a producer) is eaten by zooplankton, the zooplankton is the primary consumer.
- **A food web is a network of interconnected food chains**: In a real habitat most organisms eat more than one kind of food and are eaten by more than one predator, so a single straight-line chain is a simplification. A *food web* shows all the feeding relationships in a community at once. In a freshwater web where duckweed is eaten by tadpoles, tadpoles by caddis fly larvae, caddis fly larvae by brown trout, and brown trout by both mink and ospreys, the brown trout sits at a point where two separate predator chains diverge, a pattern only a web can show.
- **An ecosystem**: An *ecosystem* is a unit made up of a community of living organisms together with their non-living environment, all interacting together in a specific area. A desert, a lake or a woodland, taken with all its organisms and physical surroundings, is an example. This is the setting in which energy flows and carbon is recycled.
- **What each process does to atmospheric carbon dioxide**: Carbon dioxide is *removed* from the atmosphere by *photosynthesis*, when producers use it to make glucose. It is *returned* to the atmosphere by *respiration* (in all organisms), *decomposition* (as decomposers respire) and *combustion* (burning fuels, including wood and fossil fuels). *Feeding* only moves carbon between organisms and does not change the amount in the air.

EXAM TIPS

TIP A food chain written backwards, with the predator first, is a classic distractor. Always check two things: the *producer* is at the start, and each arrow points *towards* the organism doing the eating. Reading each arrow as the words "is eaten by" makes the whole chain read as a story of energy moving up from the producer.

TIP Herbivore, carnivore and the primary, secondary and tertiary levels are all *kinds* of consumer, not alternatives to it. Every carnivore is a consumer, but not every consumer is a carnivore; the same animal can even feed as a herbivore in one relationship and a carnivore in another.

TIP Decomposition returns carbon to the air *because decomposers respire* while they break down dead material. A common error is to treat decomposition as a separate mechanism from respiration, but the carbon dioxide comes from the decomposers respiring as they feed on the dead organisms and waste.

TIP Keep the two ideas separate. Energy makes a *one-way trip*: it enters from the Sun, flows through organisms and is eventually transferred to the environment, so it is never recycled. Matter, such as carbon, is *recycled* round and round between organisms and the atmosphere.

TIP A consumer's level describes its position in a *particular* food chain, counted from the producer, not a permanent label stuck to the species. The same animal can be a primary consumer in one chain and a secondary consumer in another, depending on what it is eating in that chain.

23 Plant nutrition

KEY CONCEPTS

- **Chlorophyll is a green pigment in the chloroplasts**: *Chlorophyll* is a green pigment found inside *chloroplasts*. It absorbs the light energy that drives photosynthesis. Chlorophyll gives leaves their green colour, and chloroplasts are the structures within a plant cell that contain it.
- **Definition, raw materials and products**: *Photosynthesis* is the process by which plants make carbohydrates from simple raw materials using light energy. The raw materials are *carbon dioxide*, taken in from the air, and *water*, absorbed by the roots. The products are *glucose*, a carbohydrate the plant uses as food, and *oxygen*, released as a by-product.
- **Guard cells and stomata**: A *stoma* is a small pore in the lower epidermis. Each stoma is surrounded by a pair of *guard cells*, which change shape to open or close the pore, controlling the movement of gases and water vapour into and out of the leaf.
- **Palisade mesophyll**: The *palisade mesophyll* is a layer of tall, closely packed column cells directly beneath the upper epidermis. It contains most of the leaf's chloroplasts and is the main site of photosynthesis.
- **Spongy mesophyll**: The *spongy mesophyll* lies below the palisade mesophyll and is made of rounded, loosely packed cells with large air spaces between them. These spaces let carbon dioxide and oxygen diffuse easily to and from every cell.
- **Waxy cuticle**: The *waxy cuticle* is a thin, transparent, waterproof layer covering the upper surface of the leaf. It lets light through to the cells beneath while reducing water loss by evaporation from the epidermis.
- **Word equation for photosynthesis**: The word equation for photosynthesis is $\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$. Carbon dioxide and water are the reactants on the left; glucose and oxygen are the products on the right. Light and chlorophyll are conditions written on the arrow, never listed as raw materials.
- **Testing a leaf for starch**: To test a leaf for starch, dip it in boiling water to kill the cells and stop the reaction, then boil it in ethanol to remove the green chlorophyll so a colour change is visible, rinse it in water to soften it, then add iodine solution. A blue-black colour shows starch is present; the leaf stays yellow-brown where no starch has been made.
- **Why a plant is destarched before an investigation**: A plant is kept in a dark cupboard for 24 to 48 hours before testing whether light, chlorophyll or carbon dioxide is needed for photosynthesis. This *destarching* uses up any starch already present, so any starch found in the leaf afterwards must have been made during the test itself.
- **Xylem and phloem in a leaf vein**: A vein, or vascular bundle, running through a leaf contains two transport tissues. The *xylem* carries water and mineral ions up to the leaf, supplying a raw material for photosynthesis. The *phloem* carries the glucose made in photosynthesis away to the rest of the plant.

EXAM TIPS

TIP When a question asks for the *raw materials* of photosynthesis, give carbon dioxide and water, never light or chlorophyll. Light is the energy source and chlorophyll is the pigment that absorbs it; neither is a substance used up in making glucose.

TIP In a cross-section, name each tissue by where it sits. Waxy cuticle: a thin line on top. Palisade mesophyll: tall columns just beneath it. Spongy mesophyll: rounded cells with air gaps further down. Lower epidermis, with stomata and guard cells: at the bottom.

TIP Light entering a leaf is strongest at the upper surface and grows weaker with depth. Placing the palisade mesophyll, the layer with the most chloroplasts, directly beneath the upper epidermis lets it absorb the strongest light available, maximising photosynthesis.

TIP The spongy mesophyll is an internal tissue of rounded, loosely packed cells with large air spaces between them, not a flat protective surface layer. A single layer of flat, tightly packed cells forming the leaf's outer covering describes the epidermis, not the spongy mesophyll.

TIP Carbon dioxide and water are simple raw materials that are used up during photosynthesis. Glucose, the carbohydrate made from them, stores chemical energy the plant can respire or convert into other substances, which is why it, rather than the raw materials, is described as the food the plant has made.

KEY CONCEPTS

- **Parts of an insect-pollinated flower**: The male part is the *stamen*, made of an *anther* (produces and releases pollen grains) on a *filament* (the stalk that holds the anther in position). The female part is the *carpel*: a *stigma* (sticky top that receives pollen), a *style* (stalk joining stigma to ovary) and an *ovary* (contains the ovules). *Petals* attract insects with colour and scent, *nectaries* reward them with nectar, and *sepals* protect the unopened bud. Core is scoped to this insect-pollinated flower only; no wind-pollinated flower is examined.
- **The female reproductive system**: The *ovary* produces and releases egg cells, the female gametes. The *oviduct* carries an egg towards the uterus and is the *site of fertilisation*. The *uterus* is the muscular organ in which a fertilised egg implants and the fetus develops. The *cervix* is the ring of muscle at its lower opening, leading to the *vagina*.
- **The male reproductive system**: The *testis* produces sperm cells, the male gametes, and is held in the *scrotum*, a sac of skin outside the main body that keeps it slightly cooler. The *sperm duct* carries sperm towards the urethra. The *prostate gland* adds fluid to the sperm to form *semen*. The *urethra* runs through the *penis*, which passes semen out of the body.
- **What fertilisation is in a plant**: *Fertilisation* in a flowering plant is the fusion of a *nucleus from a pollen grain* with a *nucleus in an ovule*. It follows pollination, once a pollen tube has grown down the style to reach an ovule. After fertilisation the *ovule becomes a seed* and the *ovary becomes a fruit*.
- **What fertilisation is in humans**: *Fertilisation* in humans is the fusion of the *nuclei from a sperm cell and an egg cell*. Sperm swim from the vagina, through the uterus, into the oviduct, where one sperm nucleus fuses with the egg nucleus to form a single cell called a *zygote*, which then divides to form an embryo.
- **What pollination is**: *Pollination* is the transfer of pollen grains from an *anther* to a *stigma*. It is defined by *direction* (anther to stigma), never by the agent that carries the pollen, so hand-pollination with a brush counts equally with insect-carried pollen. Pollination alone says nothing about fertilisation or a seed forming.
- **Conditions needed for germination**: *Germination* is the beginning of the growth of a seed into a seedling. It needs three conditions: *water* (rehydrates the seed and activates its enzymes), *oxygen* (for respiration, releasing the energy the growing embryo needs) and a *suitably warm temperature* (so the reactions of germination happen fast enough). *Light is not needed*: a germinating seed lives off its own stored food until the shoot reaches the light.
- **Semen and why the testes lie outside the body**: *Semen* is a mixture of sperm cells and the fluid made by the *prostate gland*, which gives the sperm a medium to swim in. The *testes* are held in the *scrotum*, outside the main body, so they stay slightly *cooler* than core body temperature, the condition that suits sperm production.
- **The menstrual cycle**: The menstrual cycle describes the roughly *28-day* pattern of changes in the *ovaries* and the *uterus lining*. Days 1 to 5: the lining breaks down and is shed as a period, so the lining is thinnest here. Days 6 to 13: the lining thickens again. Around day 14: an ovary *releases an egg* (ovulation). Days 15 to 28: the lining is maintained ready to receive a fertilised egg, then breaks down again if fertilisation does not occur.
- **The order of events from pollination to seed**: The steps run in a strict order and each depends on the one before: *pollination* (pollen moves from anther to stigma), then *pollen tube growth* down the style towards an ovule, then *fertilisation* (a pollen nucleus fuses with an ovule nucleus), then *seed and fruit formation* (the ovule becomes a seed, the ovary becomes a fruit). Any step can still fail after the earlier ones succeed, which is why pollination alone never guarantees a seed.
- **Why fertilisation needs exactly one sperm nucleus and one egg nucleus**: Fertilisation is the fusion of *one* sperm nucleus with *one* egg nucleus. Combining exactly one of each brings together genetic material from both parents to form a single cell, the *zygote*, which then divides repeatedly to form an embryo. Extra sperm reaching the egg does not change this: only one nucleus fuses.

EXAM TIPS

TIP These two roles are the easiest marks in the chapter to lose by reversing them. The *anther* is the male part that *produces and releases* pollen; the *stigma* is the female part that *receives* it. Every pollination runs anther to stigma, never the other way round.

TIP Keep the three female organs apart by the verb attached to each: eggs are *made* in the *ovary*, fertilisation *happens* in the *oviduct*, and the fetus *develops* in the *uterus*. Made, fertilised, develops: ovary, oviduct, uterus.

TIP A flower can be pollinated and still form no seed. Pollination only *moves* pollen to a stigma; if fertilisation then fails, for example because the ovule dies, no seed forms. Never treat "pollinated" as proof that a seed will follow.

TIP Day 1 of the cycle is the first day of the period, when the previous cycle's lining is already breaking down. Across a cycle the uterus lining therefore *decreases first, then increases*: it thins during menstruation, then thickens ready for a possible fertilised egg. Reading it as "thickens first" is a common trap.

25 Respiration

KEY FORMULAS

Word equation for aerobic respiration

$$\text{glucose} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water}\ (+\ \text{energy})$$

Use to summarise aerobic respiration in words. Glucose and oxygen are the reactants used up; carbon dioxide and water are the products. Energy is shown in brackets because it is released rather than being a chemical substance. Do not reverse the equation, since the reverse describes photosynthesis, not respiration.

Rate of gas production

$$\text{rate} = \frac{\text{volume of gas produced}}{\text{time taken}}$$

Use to calculate how quickly a respiring organism produces a gas such as carbon dioxide. Divide the volume produced by the time taken; the units are a volume per unit time, for example cm^3 per minute.

Conservation of mass in respiration

$$\text{mass of reactants} = \text{mass of products}$$

Use to check that mass is conserved in the reaction between glucose and oxygen. Atoms are neither created nor destroyed, so the total mass of glucose and oxygen used equals the total mass of carbon dioxide and water formed; the energy released has no mass of its own.

Increase in a quantity

$$\text{increase} = \text{new value} - \text{original value}$$

Use to find how much a measurement, such as the volume of oxygen used per minute, has risen between two readings. Subtract the original (starting) value from the new value; keep the same units throughout.

KEY CONCEPTS

- **Aerobic respiration and its site**: Aerobic respiration is the set of reactions that use *oxygen* to break down glucose, releasing energy and producing carbon dioxide and water. Its main site in a cell is the *mitochondria*.
- **Definition of respiration**: Respiration is the set of chemical reactions in living cells that break down nutrient molecules to release energy. The nutrient molecule broken down is usually *glucose*. Respiration happens continuously inside every living cell, not only occasionally.
- **Reactants and products of aerobic respiration**: The two *reactants* of aerobic respiration are glucose and oxygen; they are taken in and used up. The two *products* are carbon dioxide and water, together with the energy released. Sorting each substance into fuel (glucose), reactant used (oxygen) and product (carbon dioxide, water) prevents the common mix-up over what is used and what is made.
- **Respiration is continuous**: Respiration happens all the time in every living cell, whether the organism is active or resting, because every cell needs a constant supply of energy. It is a life process carried out by all living organisms.
- **Uses of the energy released by respiration**: The energy released by respiration is used for: *movement*, for example muscle contraction; *growth*, by building large molecules such as proteins from smaller ones; *active transport* of substances against a concentration gradient; and *keeping warm*, by maintaining a constant body temperature.
- **The limewater test for respiration**: Limewater turns cloudy in the presence of carbon dioxide. Respiring organisms such as germinating peas produce carbon dioxide, so sealing them with limewater and observing it turn cloudy is a way to show that they are respiring.

- **Why active cells contain many mitochondria**: Mitochondria are the site of aerobic respiration, so a cell with a high energy demand contains large numbers of them to release enough energy. This is why liver cells and heart muscle cells, which are chemically very active, contain far more mitochondria than mostly inactive cells such as fat-storage cells.
- **Effect of temperature on the rate of respiration**: A higher temperature increases the rate of respiration, so carbon dioxide is produced faster. This is why limewater exposed to respiring peas turns cloudy sooner at a higher temperature, for example at $30°$C rather than $20°$C.

EXAM TIPS

TIP Respiration is the chemical release of energy inside cells. Breathing is the physical movement of air into and out of the lungs, and gas exchange is the movement of oxygen and carbon dioxide between the air and the blood. A question asking what is *broken down* in respiration wants a nutrient molecule such as glucose, never oxygen.

TIP The rate formula divides volume by time, so the units are a volume per unit time such as cm^3 per minute, never a time per volume such as minutes per cm^3. Dividing time by volume instead is a common error.

TIP A control flask of boiled, dead peas cannot respire, so its limewater should stay clear. Comparing it with a flask of living, respiring peas shows that any cloudiness in the living peas' limewater is caused by their respiration, not by air already present in the apparatus.

TIP Diffusion and osmosis are passive processes and need no energy from respiration. Only *active transport*, which moves substances against a concentration gradient, is powered by the energy that respiration releases.

26 Space physics

KEY FORMULAS

Distance from light-travel time

$$\text{distance} = \text{speed} \times \text{time}$$

Use to find how far light (or any wave) has travelled from its speed and the time taken. For light in space, speed $c \approx 3.0 \times 10^8$ m/s; the time must be in seconds.

Time from distance and speed

$$\text{time} = \frac{\text{distance}}{\text{speed}}$$

Rearrangement used to find how long light takes to travel a known distance, for example to find how many years old the light reaching us from a star is.

Converting years to seconds

$$t_\text{s} = t_\text{years} \times 3.2 \times 10^7$$

Converts a light-travel time in years into seconds so it matches the units of the speed of light (3.0×10^8 m/s) before substituting into $\text{distance} = \text{speed} \times \text{time}$.

Distance in metres from a light-year value

$$d = 3.0 \times 10^8 \times (n \times 3.2 \times 10^7)$$

Combines both conversions to find, in one line, the distance in metres to an object n light-years away: convert n years to seconds, then multiply by the speed of light.

KEY CONCEPTS

- **Classifying objects by what they orbit**: Classify any Solar System object by *what it orbits*. A planet, dwarf planet or asteroid orbits the Sun directly; a moon orbits a planet, not the Sun. Orbiting the Sun directly is not enough to make an object a planet, since dwarf planets and asteroids do so too.
- **Order of the planets and the asteroid belt**: The eight planets in order of increasing distance from the Sun are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune. The *asteroid belt* lies between Mars and Jupiter.
- **The life cycle of a star**: Every star begins the same way: gravitational attraction pulls an interstellar cloud of gas and dust (a *nebula*) together into a *protostar*, which develops into a stable star. The ending stage depends on the star's mass: a *small mass* star becomes a red giant, sheds a planetary nebula and leaves a *white dwarf*; a *large mass* star becomes a red supergiant, explodes as a supernova and leaves a *neutron star*; a *very large mass* star follows the same supergiant-and-supernova path but leaves a *black hole*.
- **The Sun as a star**: The Sun is a *medium-sized star*, made mostly of *hydrogen and helium* and held together by its own gravity. It radiates most of its energy in the *infrared, visible and ultraviolet* regions, though it also emits smaller amounts across the rest of the spectrum.
- **What the Solar System contains**: The Solar System is the Sun together with everything held in orbit around it by the Sun's gravity: exactly *one star* (the Sun), *eight planets*, *minor planets* (dwarf planets and asteroids, which orbit the Sun directly but are not counted among the eight), and *moons*, which orbit the planets.
- **Why the planets orbit the Sun**: The Sun contains most of the mass of the Solar System, so it produces the strongest gravitational field. The force that keeps each planet in orbit is the

gravitational attraction of the Sun, always directed from the planet towards the Sun. A moon orbits its planet by the same mechanism, pulled by the *gravitational attraction of the planet*.

- **Galaxies and the Milky Way**: A *galaxy* is a huge collection of many billions of stars held together by gravity. The Sun is one star in the galaxy called the *Milky Way*, about *100 000 light-years* across, itself one of many billions of galaxies in the Universe.
- **Inner rocky planets versus outer gas giants**: The four inner planets (Mercury, Venus, Earth, Mars) are small and rocky; the four outer planets (Jupiter, Saturn, Uranus, Neptune) are large gas giants. The asteroid belt marks the boundary between them.
- **The light-year and seeing into the past**: A *light-year* is a unit of *distance*: the distance light travels through space in one year, not a unit of time. Because light travels at a constant speed, light-travel time in years equals the distance in light-years, so a star 50 light-years away is seen as it was 50 years ago.
- **Planet versus dwarf planet**: A planet and a dwarf planet both orbit the Sun directly and are held together by their own gravity, but a planet has *cleared* its orbital region of other objects while a dwarf planet has not. Pluto is a dwarf planet because it shares its orbit with many other icy bodies; its reclassification changed only its category, not its membership of the Solar System.

EXAM TIPS

TIP In a classification question, underline the phrase that states what the object orbits. "Orbits Saturn" means a moon; "orbits the Sun, round, sharing its orbit with other bodies" means a dwarf planet. That one phrase decides the answer.

TIP In every light-travel calculation, convert years to seconds first (multiply by about 3.2×10^7), then use $\text{distance} = \text{speed} \times \text{time}$ with the speed of light in m/s. Substituting years directly against a speed in m/s gives an answer with the wrong units.

27 States of matter

KEY CONCEPTS

- **Effect of heating a gas at constant pressure on its volume**: When a fixed mass of gas is heated at constant pressure, its particles gain energy and move faster. The gas expands to make room for them, so its volume increases.
- **Particle model of the three states**: Describe each state by the *separation*, *arrangement* and *motion* of its particles. Solid: particles close together in a regular pattern, only vibrating about fixed positions. Liquid: particles close together but randomly arranged, able to slide past one another. Gas: particles far apart and randomly arranged, moving quickly in every direction. Liquid and solid particles sit about equally close together; the big jump in separation is between liquid and gas.
- **The five changes of state**: *Melting* is solid to liquid on heating. *Freezing* is liquid to solid on cooling. *Boiling* is liquid to gas throughout the whole liquid, at the boiling point. *Evaporating* is liquid to gas from the surface only, at any temperature below the boiling point. *Condensing* is gas to liquid on cooling.
- **The three states of matter and their properties**: A *solid* has a fixed shape and a fixed volume; it cannot be poured or squashed. A *liquid* has a fixed volume but no fixed shape, so it flows and takes the shape of its container, and it also resists being squashed. A *gas* has neither a fixed shape nor a fixed volume; it fills any container and can be squashed considerably. A fixed volume separates a liquid from a gas; a fixed shape separates a solid from a liquid.
- **What causes the pressure of a gas**: A gas's particles move constantly and rapidly in every direction, so they collide with the walls of their container many times each second. Each collision exerts a small force on the wall, and the combined effect of billions of collisions every second is the overall pressure of the gas.
- **Boiling compared with evaporating**: Both are changes from liquid to gas, but they differ in two ways. Boiling happens throughout the whole liquid, only at the boiling point. Evaporating happens only at the surface, at any temperature below the boiling point. A puddle drying on a cool day is evaporating from the surface, not boiling.
- **Effect of heating a gas at constant volume on its pressure**: Heating a fixed mass of gas in a rigid, constant-volume container raises its pressure. The particles gain energy and move faster, so they collide with the fixed walls more often and with greater force.
- **Effect of pressure on the volume of a gas at constant temperature**: Increasing the pressure on a fixed mass of gas at constant temperature decreases its volume: the same particles are squeezed into a smaller space.
- **State symbols**: A state symbol in brackets after a formula gives the physical state: *(s)* solid, *(l)* liquid, *(g)* gas and *(aq)* aqueous, meaning dissolved in water. The symbol *(aq)* is not a fourth state of matter; the dissolved substance itself is still a solid, a liquid or a gas.
- **Why a gas can be squashed considerably but a solid or liquid cannot**: A gas has large empty spaces between its far-apart particles that can be squeezed out. The particles of a solid or a liquid are already close together and touching, so there is almost no empty space left to remove.

EXAM TIPS

TIP Name the property that is present or absent and the state follows. A fixed shape belongs only to a solid. A fixed volume belongs to a solid and a liquid but not a gas. Being able to be poured belongs to a liquid and a gas but not a solid. One decisive property is enough to identify any state from a description.

TIP A pure substance melts and freezes at the *same* fixed temperature: its melting point equals its freezing point. Crossing that temperature swaps the substance between solid and liquid, in whichever direction it is heated or cooled.

TIP Do not write that liquid particles are spread out. Melting barely changes the particle spacing, so a liquid's particles sit about as close together as a solid's. The big increase in separation happens only when a liquid turns into a gas.

TIP For any gas question, first state which quantity is fixed. At constant pressure, a temperature change alters the volume. At constant temperature, a pressure change alters the volume. At constant volume, in a rigid container, a temperature change alters the pressure. Naming the fixed quantity makes the outcome follow directly.

28 Stoichiometry

KEY FORMULAS

Conservation of mass

$$\text{total mass of reactants} = \text{total mass of products}$$

Use to check a reaction or find an unknown mass. Atoms are only rearranged, never created or destroyed, so the total mass in a sealed container does not change; a sealed flask shows no change in balance reading even when a visible change, such as a precipitate forming, has taken place.

Mass found by difference

$$\text{mass of substance} = \text{mass of (dish + substance)} - \text{mass of empty dish}$$

Use whenever a solid is weighed inside a container. Weigh the empty dish first, then weigh the dish holding the solid, and subtract. An empty dish of 5.39 g holding copper up to 6.49 g gives a copper mass of $6.49 - 5.39 = 1.10$ g.

Total atom count from subscripts

$$\text{total atoms} = \text{sum of all subscripts}$$

Use to count every atom shown by a molecular formula: add together the subscript of each symbol, counting a symbol with no subscript as 1. For C_2H_4 this gives $2 + 4 = 6$ atoms in one molecule.

Percentage by mass of a component

$$\text{percentage by mass} = \frac{\text{mass of component}}{\text{total mass}} \times 100$$

Use to express one substance's mass as a percentage of a total mass, most often the mass of a metal recovered from a compound. Divide the component's mass by the total mass, multiply by 100, and round to an appropriate number of significant figures.

KEY CONCEPTS

- **Formulas you must know on sight**: Some formulas have no derivation and must simply be learned: water H_2O, carbon dioxide CO_2, ammonia NH_3 and methane CH_4; the acids hydrochloric HCl, nitric HNO_3 and sulfuric H_2SO_4; and the four *diatomic* elements H_2, O_2, N_2 and Cl_2.
- **State symbols**: A *state symbol* in brackets after a formula gives the physical state of a substance: (s) solid, (l) pure liquid, (g) gas, (aq) aqueous, meaning dissolved in water. A *precipitate*, an insoluble solid that forms when solutions are mixed, is always labelled (s), even though it appears within a solution.
- **Symbol equations and balancing**: A *symbol equation* uses formulas and must have equal numbers of atoms of every element on both sides of the arrow, because atoms are never created or destroyed. Balance only by placing *coefficients* in front of formulas; a subscript inside a formula must never be changed, since that would describe a different substance.
- **What a molecular formula tells you**: A *molecular formula* states only the number and type of atoms in one molecule, chemically joined together; it says nothing about mass or mixture. A *subscript* gives the count of the symbol immediately in front of it, and a subscript of 1 is never written, while a *coefficient* in front of a whole formula multiplies every atom that follows it.
- **Word equations**: A *word equation* names the reactants on the left of the arrow and the products on the right, with no formulas and no balancing. Reactants are the starting substances; products are the substances formed.
- **Deducing a formula from a diagram**: When a diagram shows atoms joined by bonds, count how many atoms of each type appear in *one* molecule and write each symbol with that count as a subscript. Watch for a diagram that draws two or more separate, identical molecules side by side: a

molecular formula describes one molecule only, so two separate H_2O molecules are still H_2O, never H_4O_2.

- **Naming with Roman numerals**: A Roman numeral in a metal's name, such as *copper(II) oxide*, states the size of the positive charge on that metal ion, here $+2$, which fixes the formula as CuO. A metal that only ever forms one charge, such as sodium, needs no Roman numeral.
- **A dissolved product keeps the (aq) state symbol**: A product formed in a reaction between aqueous substances stays dissolved unless it is insoluble. Magnesium reacting with dilute hydrochloric acid, $Mg(s) + 2HCl(aq) \rightarrow MgCl_2 + H_2(g)$, produces magnesium chloride that remains in solution, so it must be labelled (aq), not (s); only an insoluble precipitate takes (s).

EXAM TIPS

TIP If hydrogen, oxygen, nitrogen or chlorine appears as a free element, it must be written H_2, O_2, N_2 or Cl_2, never as a lone atom. Writing a single O instead of O_2 is one of the most common balancing errors and makes an equation impossible to balance correctly.

TIP (l) means a pure liquid, such as liquid water; (aq) means a substance dissolved in water to form a solution. The two state symbols are not interchangeable, even though both describe something that flows.

TIP Oxygen appears in both products of a combustion, CO_2 and H_2O, so balancing carbon and hydrogen first lets the oxygen total be fixed at the end without disturbing the elements already balanced.

TIP Adding a coefficient to fix one element's count can unbalance an element that was already correct, so every element must be re-tallied before an equation is accepted as balanced. Writing $H_2O_2 \rightarrow O_2 + H_2O$ misses that oxygen is 2 on the left but 3 on the right; the correct equation is $2H_2O_2 \rightarrow O_2 + 2H_2O$.

29 The Periodic Table

KEY CONCEPTS

- **Appearance of the halogens at room temperature**: Group VII, the *halogens*, are reactive non-metals that exist as *diatomic* molecules (Cl_2, Br_2, I_2). At room temperature and pressure they run through a set of states and colours: chlorine is a *pale yellow-green gas*, bromine is a *red-brown liquid*, and iodine is a *grey-black solid*. Learn the three appearances as a single set; they anchor almost every Group VII question.
- **Group VII trends down the group**: Group VII shows two general trends going *down* the group: density *increases* and reactivity *decreases*. This is the opposite reactivity direction from Group I, where reactivity increases down the group. The colour of the halogens also darkens down the group, matching the pale-gas to grey-black-solid sequence at room temperature.
- **Metallic to non-metallic character across a period**: Moving left to right across a period, the elements change from *metallic* to *non-metallic* character. Reactive metals sit on the left and non-metals sit on the right. A clean anchor is Period 3, running sodium (metal) through to chlorine (non-metal), with electrical conductivity falling the same way across the period.
- **Order and layout of the Periodic Table**: Elements are arranged in order of *increasing proton number*, going up one at a time from left to right and top to bottom. The layout carries meaning: a *period* is a horizontal row and its number equals the number of occupied electron shells; a *group* is a vertical column and its number equals the number of outer-shell electrons. Elements in the same group share the same number of outer electrons, so they have similar chemical properties.
- **The four characteristic properties**: The *transition elements* occupy the central block of the table (iron, copper, zinc and their neighbours). As a family they are metals with four properties examined every series: *high density*, *high melting point*, they *form coloured compounds* (copper compounds blue or green, iron compounds green or orange-brown), and they *often act as catalysts*, both as elements and in their compounds. On every one of these counts they are the opposite of the Group I metals.
- **The Group I alkali metals and their trends**: Group I, the *alkali metals* (lithium, sodium, potassium), are relatively *soft* metals of low density. Going *down* the group three trends hold: melting point *decreases*, density *increases*, and reactivity with water *increases*. Each metal reacts with water to give an alkaline solution, the reaction becoming more vigorous down the group.
- **Unreactive monatomic gases**: Group VIII (also labelled Group 0), the *noble gases* (helium, neon, argon), are *unreactive, monatomic gases*. Monatomic means they exist as single, separate atoms, unlike the diatomic halogens. Their inertness has one clean cause: each has a *full (complete) outer electron shell*, so the atom has no tendency to gain, lose or share electrons and therefore does not react.
- **Partial evidence is not full evidence**: A single matching property is not enough to confirm an element is a transition element. An element with a high density and a high melting point, but whose common compound is white rather than coloured, shows *some but not all* of the characteristic properties. All four markers, high density, high melting point, coloured compounds and acting as a catalyst, are expected together before an element is confidently classed as transition.
- **Shell count does not decide reactivity**: Having more electron shells does not, by itself, make an element more reactive. Argon has more shells than neon, yet both have a *full outer shell*, so both are equally unreactive noble gases. The single fact that governs reactivity for this group is whether the outer shell is full, not how many shells lie underneath it.

EXAM TIPS

TIP Two of the three Group I trends rise going down the group (density and reactivity with water) while melting point *falls*. The melting point is the one students misremember, so tag it as the exception. Density up, reactivity up, melting point down.

TIP The always-correct explanation of noble-gas inertness is a *full (complete) outer shell of electrons*, giving no tendency to gain, lose or share electrons. Do not write "eight outer electrons": that fails for helium, whose full shell holds only *two*. State the general rule, not a specific number.

TIP The two properties that most cleanly separate a transition metal from a Group I metal are *coloured compounds* and *acting as a catalyst*. If a question describes a metal whose compound is coloured, or which speeds up a reaction without being used up, think transition element. Group I compounds are white or colourless and Group I metals are not typical catalysts.

TIP Do not let the Group I habit leak into Group VII. In Group I, reactivity *increases* down the group; in Group VII, it *decreases*. Density and colour-darkening rise down both groups, so it is specifically the reactivity direction that flips between the two families. Keep a single mental table: Group I reactivity up, Group VII reactivity down.

TIP When a question describes an electron arrangement, work it out in two separate steps: the *number of occupied shells* fixes the period (the row), and the *number of outer-shell electrons* fixes the group (the column). Mixing these two up is the most common slip; keep "shells for period, outer electrons for group" as a fixed pairing.

30 Thermal physics

KEY CONCEPTS

- **Convection currents in fluids**: *Convection* is the transfer of thermal energy through a fluid, a liquid or a gas, by movement of the fluid itself, so it cannot happen in a solid. Fluid near a heat source is warmed, becomes *less dense* than the fluid around it, and rises; cooler, denser fluid sinks to take its place, setting up a circulating convection current.
- **Evaporation and the cooling of a liquid**: *Evaporation* is the escape of the more energetic particles from the surface of a liquid, and it can happen at any temperature below the boiling point. Because the particles that leave are the most energetic ones, the average kinetic energy, and so the temperature, of the liquid left behind falls.
- **Temperature and the motion of particles**: *Temperature* is a measure of the average kinetic energy of the particles of a substance. Heating a substance transfers energy to its particles, increasing their average kinetic energy, so they move faster: in a solid they vibrate more vigorously about fixed positions, and in a liquid or gas they move around more quickly.
- **The three states and the particle model**: Describe every state by *arrangement*, *separation* and *motion*. A solid has particles closely packed in a regular pattern, each vibrating about a fixed position, giving a fixed shape and fixed volume. A liquid has particles close together but irregularly arranged, moving around each other while staying close, giving a fixed volume but no fixed shape. A gas has particles far apart, arranged irregularly, and moving quickly and freely in all directions, so it has neither a fixed shape nor a fixed volume.
- **Thermal conductors and insulators**: A *thermal conductor* lets thermal energy pass through it easily; metals such as copper are good thermal conductors. A *thermal insulator*, such as wood, plastic or air, conducts thermal energy poorly.
- **Thermal expansion of solids, liquids and gases**: *Thermal expansion* is the increase in the size of a substance when it is heated at constant pressure, because its particles vibrate more and, on average, move a little further apart. Cooling has the opposite effect and the substance contracts.
- **Thermal radiation and the surface**: *Thermal radiation* is the transfer of thermal energy mainly by infrared radiation, and it needs no medium, so it can travel through a vacuum. The surface controls how well an object emits and absorbs it: a dull, black surface is a good absorber and a good emitter, while a shiny, light surface is a poor absorber and emitter and so a good reflector.
- **Comparing expansion across the three states**: For the same rise in temperature, a gas expands the most and a solid expands the least, because the particles of a gas are already far apart and free to spread further, while a solid's particles can only vibrate a little further from their fixed positions.
- **The changes of state**: *Melting* is solid to liquid on heating; *freezing* (solidifying) is liquid to solid on cooling; *condensing* is gas to liquid on cooling. *Boiling* happens throughout the whole liquid, only at the fixed boiling point, while *evaporation* happens only at the surface and at any temperature below the boiling point.
- **Why a gas can be compressed so much**: A gas's particles are far apart, so there is a lot of space between them. Reducing the volume of a fixed mass of gas pushes those particles closer together, closing up that space; a liquid or solid, whose particles are already close together, has almost no such space to lose.

EXAM TIPS

TIP For any question that asks you to describe or compare the particles in a state, give all three of *arrangement*, *separation* and *motion*, even when only one seems to be asked for. It is a reliable full-marks habit and stops you losing marks for a partial description.

TIP When explaining why evaporation cools a liquid, say that the *most energetic* particles escape from the surface, which lowers the *average* energy of those that remain. Writing only that particles escape misses the mark; the cooling comes specifically from losing the most energetic ones.

TIP When comparing which of two surfaces is the better emitter or absorber, everything except the surface must be identical: the same volume of liquid, the same starting temperature, and the same distance and time. State that the conditions are *identical* or *the same* explicitly, or you lose the fair-test marks even when the physics is right.

TIP A liquid that has just been heated or cooled is not necessarily the same temperature throughout. Stirring before taking a reading mixes the liquid so its temperature is uniform, giving an accurate reading wherever the thermometer sits.

KEY CONCEPTS

- **Comparing arteries, veins and capillaries**: The three vessel types are compared using three structural features: *wall thickness*, *lumen diameter* (the lumen is the central space blood flows through) and whether *valves* are present. An *artery* has a thick wall, a narrow lumen and no valves. A *vein* has a thinner wall, a wide lumen and valves. A *capillary* has a wall only one cell thick, with a lumen just wide enough for a red blood cell.
- **Direction rule: arteries away, veins back**: Blood is pumped *away* from the heart in *arteries* and returns to the heart in *veins*; the definition is by direction, not by the type of blood carried. The pulmonary artery still counts as an artery even though it carries deoxygenated blood, because it carries blood away from the heart. This direction rule does not change during exercise, only the rate does.
- **Structures of the mammalian heart**: The heart is a muscular double pump with *four chambers*: two upper *atria* receive blood entering the heart and two lower *ventricles* pump blood out. The wall of the *left ventricle* is the thickest, because it pumps blood all the way around the body. The *septum* is the wall of muscle separating the left and right sides, and internal *valves* give one-way flow through the heart.
- **The circulatory system: vessels, a pump and valves**: A circulatory system is described using three structures working together: *blood vessels* form the pathway blood travels along, a *pump* (the heart) contracts to push blood forward, and *valves* open to let blood pass and close to stop it flowing backward. Together they give *one-way flow* of blood around the body.
- **The four components of blood**: Blood has four components: *red blood cells* transport oxygen, *white blood cells* defend against pathogens, *platelets* help the blood clot, and *plasma* is the straw-coloured liquid that carries everything else. The first three are cells or cell fragments; plasma is the liquid they are suspended in.
- **How a valve opens and closes**: A valve is a passive flap with no muscle of its own. Blood moving forward pushes the flap *open* so it can pass through; blood beginning to slide backward pushes the flap *shut*, sealing the vessel. A valve that stayed permanently closed would block the circulation entirely; it must open for forward flow and only close to prevent backflow.
- **Investigation design: counting for three minutes and waiting between trials**: In the heart-rate investigation, beats are counted over *three minutes* rather than one, because a miscount of a beat or two matters less when spread over a longer count, giving a rate closer to the true value. Between trials the student *waits* (about 15 minutes), so heart rate falls back to its resting value and every trial starts from the same baseline.
- **Monitoring the heart's activity**: Heart activity can be monitored in three ways: an *ECG* (a trace of the electrical activity that triggers each beat), the *pulse rate* (the pressure wave felt at an artery for each beat) and the *valve sounds* heard through a stethoscope. When asked to name a way of monitoring the heart other than one already given, give either of the other two.
- **Platelets and plasma**: *Platelets* are small cell fragments that help the blood *clot*; at a wound they gather at the break and trigger clotting, sealing it. *Plasma* is the liquid part of blood; it carries the blood cells and platelets, and also transports dissolved substances: ions, nutrients such as glucose, hormones and waste such as carbon dioxide.
- **Red and white blood cells**: A *red blood cell* is a disc-shaped cell with *no nucleus*, leaving more room for *haemoglobin*, which carries oxygen; its function is transporting oxygen. A *white blood cell* is larger, less numerous, and *has a nucleus*; its function is defence, by engulfing pathogens (phagocytosis) and producing antibodies.
- **Why compare using percentage increase, not the plain increase**: Resting heart rates differ between trials and between people, so the same rise in beats per minute is not an equally big change for everyone. Dividing the increase by each trial's own resting rate removes that difference, so the percentage increase allows a fair comparison between trials, even when the result is a percentage increase greater than 100%.

EXAM TIPS

TIP The "lub-dub" heard through a stethoscope is made by the heart *valves snapping shut*, not by muscle contracting. Muscle contracting is a smooth squeeze with no sharp sound, so an answer that credits the atria for the sound is wrong.

TIP A pump and vessels alone would let blood slide backward whenever the pump relaxes. Describing a circulatory system needs all three: *vessels, a pump and valves*; leaving out the valves loses the one-way-flow idea.

TIP "Arteries always carry oxygenated blood" fails for the pulmonary artery, which carries deoxygenated blood to the lungs. The reliable rule is *direction*: arteries carry blood *away* from the heart, whatever type of blood it is. Remember arteries = Away, both start with A.

TIP A common slip is "carries lots of blood, so widest tube". An artery actually has a *narrow* lumen; it is the *vein* that has the wide lumen. Arteries also have *no valves*.

TIP Core asks you to *describe* the effect of activity on heart rate, not explain it: "as the intensity of the activity increases, the heart rate increases" is the trend statement to give. Read a bar chart by the height of each bar, not by the order the activities are listed.

32 Transport in plants

KEY CONCEPTS

- **Functions of phloem**: Phloem transports *sucrose* and *amino acids*, the dissolved food substances a plant moves to wherever they are needed for growth or storage. Unlike xylem, phloem can carry these substances in *either direction* through the plant.
- **Functions of xylem**: Xylem transports *water* and *mineral ions* in one direction only, upward from the roots to the rest of the plant. Its cells have thick, strengthened walls, so xylem also gives the plant *support*.
- **Positions of xylem and phloem in root, stem and leaf**: In a *root*, xylem lies at the centre, often in a star-shaped pattern, with phloem in patches around it. In a *stem*, xylem and phloem sit together in vascular bundles arranged in a ring, xylem on the inner side of each bundle and phloem on the outer side. In a *leaf* vein, xylem lies toward the upper surface and phloem toward the lower surface.
- **Stomata and guard cells**: Water vapour leaves a leaf through tiny pores called *stomata* (singular: stoma), mainly on the lower surface. Each stoma is surrounded by a pair of *guard cells* that change shape to widen or narrow the pore, controlling how fast water vapour passes out.
- **The pathway of water through the plant**: Once absorbed, water follows a fixed order through the plant: *root hair cell*, then *cortex cells*, then *xylem*, then *mesophyll cells* of the leaf. Water crosses inward through the cortex to reach the central xylem, travels up the xylem to the leaf, then moves out into the mesophyll cells.
- **The root hair cell**: A *root hair cell* is a cell in the outer layer (epidermis) of a young root with a long, thin extension that grows out into the soil. It absorbs *water* and *mineral ions* from the soil, and has no chloroplasts because it is underground and does not photosynthesise.
- **What transpiration is**: *Transpiration* is the loss of water vapour from the leaves of a plant. Two details are separately examined: the water leaves as *water vapour*, not liquid, and it is lost from the *leaves*, not the roots.
- **Direction of transport in xylem and phloem**: Xylem carries its substances in *one direction only*, upward from the roots. Phloem is different: it can carry sucrose and amino acids in *either direction*, up or down the plant, depending on where they are needed.
- **Distinguishing transpiration from translocation**: *Transpiration* is the loss of water vapour from the leaves; *translocation* is the transport of sucrose and amino acids in the phloem. The two are easily confused because both describe substances moving through a plant, but they involve different substances moving by different routes.
- **Why water must cross the cortex first**: The xylem lies at the centre of a root, so water absorbed at the surface by a root hair cell must pass inward through the *cortex* cells before it reaches the xylem. The cortex is a compulsory middle stage in the pathway, not an optional detour.
- **Measuring transpiration as loss of mass**: Because transpiration is a loss of water, it can be measured as a loss of mass over time. The rate is $\text{rate of mass loss} = \frac{\text{mass lost}}{\text{time taken}}$, where mass lost is the starting mass minus the final mass; a rate in grams per hour comes from dividing grams by hours.
- **The full path of water out of the leaf**: Inside the leaf, liquid water evaporates from the moist surfaces of the mesophyll cells into the air spaces between them, changing state from liquid to gas. The water vapour then diffuses out of the leaf through the open stomata into the drier air outside.
- **Why dead xylem cells suit their function**: Xylem vessels are made of dead, hollow cells, and that is exactly what makes them good pipes: the empty, hollow cells leave a clear, continuous tube for water to flow through, while their thickened walls still give the plant support. "Dead" does not mean "unimportant": these cells keep working precisely because they no longer have living contents blocking the tube.

EXAM TIPS

TIP The order is *root hair cell, cortex, xylem, mesophyll*; a common error is writing the cortex and xylem the wrong way round. Water crosses the cortex *before* it reaches the xylem, never after.

TIP If asked to name *two* substances carried by xylem, answer *water* and *mineral ions*, both of them; naming only one scores half the marks available. The same discipline applies to phloem: give *sucrose* and *amino acids* together, not one alone.

TIP In a mass-loss experiment, covering the soil with plastic film is not decoration: it stops water evaporating directly from the soil, so any mass the potted plant loses can only be water lost through the leaves by transpiration. If a question mentions the film, there is usually a mark for explaining this.

33 Waves

KEY FORMULAS

Wave equation

$$v = f\lambda$$

Use to link the speed, frequency and wavelength of any wave. Here v is the wave speed in metres per second, f is the frequency in hertz and λ is the wavelength in metres.

Rearranging the wave equation

$$f = \frac{v}{\lambda} \quad \text{and} \quad \lambda = \frac{v}{f}$$

Use when the wave equation must be solved for frequency or for wavelength instead of speed. Divide the speed by the wavelength to find the frequency, or by the frequency to find the wavelength, keeping units matched.

Speed of sound from distance and time, echo distance

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

Use to determine the speed of sound in air from a measured distance and a measured time, for example using two detectors a known distance apart and a timer. In an echo or sonar problem the sound travels to the reflecting surface and back, so the measured distance is twice the distance to the surface.

Using v = fλ for electromagnetic waves

$$v = f\lambda$$

The same wave equation applies to every region of the electromagnetic spectrum. A Core question always gives the speed to use, commonly 3.0×10^8 m/s in a vacuum, since every region travels at this same speed regardless of frequency.

KEY CONCEPTS

- **A wave transfers energy, not matter**: A wave is a travelling disturbance that transfers *energy* from one place to another without transferring *matter*. The particles of the medium oscillate about a fixed rest position and pass the disturbance to their neighbours, but are not carried along with it. Ripples spreading from a dropped pebble show this: the water mostly moves up and down, it does not travel outward with the ripples.
- **All electromagnetic waves travel at the same speed**: Every region of the electromagnetic spectrum travels at the same very high speed in a vacuum, and at approximately that same speed in air, whatever its frequency. Two electromagnetic signals sent the same distance, for example a radio wave and a gamma ray, always arrive together.
- **Audible range and ultrasound**: A typical human ear detects sound from about 20 Hz to $20\,000$ Hz. *Ultrasound* is any sound with a frequency above $20\,000$ Hz, so it is inaudible to humans even though it is still an ordinary sound wave.
- **How sound is made and why it needs a medium**: Sound is produced by a *vibrating source*. It needs a *medium* of particles to carry the vibration along, so it travels through solids, liquids and gases but *not* through a vacuum, since a vacuum has no particles to pass the disturbance on.
- **Law of reflection and the plane-mirror image**: At a plane surface the angle of incidence equals the angle of reflection, both measured from the *normal*, the line at right angles to the surface. The image in a plane mirror is the *same size* as the object, as far behind the mirror as the object is in front, and *virtual*, since the reflected rays only appear to come from behind the mirror.

- **Order of the electromagnetic spectrum**: In order of *increasing frequency* (and so *decreasing wavelength*): radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays. Radio waves have the longest wavelength and lowest frequency; gamma rays have the shortest wavelength and highest frequency. Visible light is the only region the human eye detects.
- **Refraction of light**: Refraction is the change in direction of a ray when its speed changes at a boundary between two media. Entering a *denser* medium such as glass the light slows down and bends *towards* the normal; leaving the denser medium it speeds up and bends *away* from the normal.
- **Image characteristics from a converging lens**: A real image forms where the two constructed rays actually cross, and is described as *enlarged*, *same size* or *diminished*, and *upright* or *inverted* compared with the object. An object placed beyond $2F$ gives a real, inverted, diminished image between F and $2F$; an object placed exactly at $2F$ gives a real, inverted image the same size as the object.
- **Loudness, pitch and echoes**: *Loudness* depends on *amplitude*, a larger amplitude sounds louder. *Pitch* depends on *frequency*, a higher frequency sounds higher. An *echo* is reflected sound; reflecting off a surface does not change the frequency, so an echo keeps the same pitch as the original sound.
- **Reflection and refraction of waves**: All waves reflect off a barrier and refract when their speed changes at a boundary. On reflection the wave stays in the same medium, so its speed and wavelength are unchanged and only its direction changes. On refraction into a slower medium, with the frequency fixed by the source, a lower speed corresponds to a shorter wavelength.
- **Thin converging lens: focal length and ray construction**: A converging lens brings a parallel beam of light to a point called the *principal focus*; the distance from the lens to that point is the *focal length*. Rays from a very distant object arrive parallel, so their image forms at the principal focus. To locate a closer object's image, trace one ray parallel to the axis that bends through the focus, and one ray straight through the centre of the lens.
- **Uses of the electromagnetic regions**: Radio waves are used for broadcasting and communication, microwaves for satellite and mobile-phone links, and infrared for heating, thermal imaging and remote controls. Visible light allows vision, ultraviolet is used for sterilising and security marking, X-rays for imaging bones and security scanners, and gamma rays for sterilising equipment and radiotherapy.
- **Wave features: amplitude, wavelength, frequency, crest and trough**: A *crest* is the highest point of a wave and a *trough* is the lowest point. *Wavelength* is the distance between two corresponding points on adjacent waves, such as crest to next crest, measured in metres. *Frequency* is the number of complete waves passing a fixed point each second, measured in hertz. *Amplitude* is the maximum displacement of a point from its rest position.
- **Dangers of electromagnetic radiation**: Higher-frequency regions carry more energy and can damage cells. *Ultraviolet* is absorbed at the surface, so it harms the *skin and eyes*, raising the risk of skin cancer and eye conditions. *X-rays* and *gamma rays* are penetrating, so they can mutate or damage cells *inside the body*, which is why a hospital radiographer stands behind a lead screen for every scan.
- **Dispersion of white light**: White light is a mixture of colours. Passing through a triangular glass prism, each colour refracts by a slightly different amount and the light separates into a *spectrum*, this is *dispersion*. The order red, orange, yellow, green, blue, indigo, violet runs from longest wavelength (red, bent least) to shortest wavelength (violet, bent most).

EXAM TIPS

TIP Amplitude is the maximum displacement from the rest position to *one* extreme, measured from the middle line up to a crest or down to a trough. The crest-to-trough distance is *twice* the amplitude, so halve a quoted high-to-low measurement before giving the amplitude.

TIP In every echo or sonar question the sound travels to the reflecting surface *and back*, so the total distance is twice the distance to the surface. Halve the total distance to find the depth or wall distance, or double that distance to find the total travel distance, depending on what the question asks.

TIP Angles of incidence, reflection and refraction are always measured from the normal, never from the surface. If a question quotes an angle to the mirror or to the surface, convert it with $90^\circ - \text{angle}$ before applying the law of reflection or refraction.

Scan to download the app
www.thepracticebook.org

Generated 2026/08/10