



Combined Science (0653)

IGCSE • Extended • CAIE

Standard Cheat Sheet

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1 Acids, bases and salts

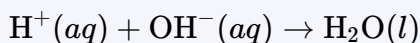
KEY FORMULAS

Acid and metal: magnesium with sulfuric acid



Use as the model for any acid and metal reaction, which gives a salt and hydrogen. Magnesium forms Mg^{2+} , so the salt is MgSO_4 , not Mg_2SO_4 ; the equation is already balanced with one magnesium, one sulfate and one hydrogen molecule on each side.

Neutralisation as an ionic equation



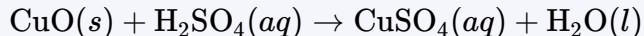
Use to summarise any acid and alkali neutralisation: the hydrogen ion from the acid and the hydroxide ion from the alkali combine to form water. This single equation underlies every salt-and-water reaction; the spectator metal and acid ions form the salt in solution.

Acid and carbonate: magnesium carbonate with hydrochloric acid



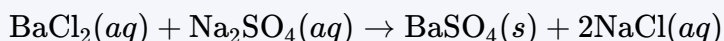
Use as the model for any acid and carbonate reaction, which gives a salt, water and carbon dioxide. Two HCl are needed so the two chlorides balance the Mg^{2+} ; the coefficient of 2 in front of the acid is the balancing number examiners most often test.

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



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; the blue solution confirms a copper(II) salt.

Precipitation equation: barium sulfate



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; it releases hydrogen ions and 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. A *salt* is the compound formed when the hydrogen of an acid is replaced by a metal or ammonium ion.
- **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 and CaO ; 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 acidic solutions 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* is a dye with different colours in acids and alkalis. Litmus is *red* in acid and *blue* in alkali; methyl orange is *red* in acid and *yellow* in alkali. To read an actual value, *universal indicator* is matched to a chart giving a pH: below 7 is acidic, exactly 7 is neutral (universal indicator is 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 then filtered, washed and dried. For a soluble salt keep the filtrate; for an insoluble salt keep the residue.
- **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* (a lit splint gives a squeaky pop); 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 the carbonate 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 and iron(III) oxide do not dissolve, so they are bases but not alkalis. 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.
- **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*.
- **Predicting the pH of an oxide's solution:** Classify the oxide first, then predict its solution. A *basic* oxide is a metal oxide; a soluble one, such as sodium oxide Na_2O , dissolves to give an alkaline solution with pH above 7. An *acidic* oxide is a non-metal oxide, such as sulfur trioxide SO_3 ; it dissolves to give an acidic solution with pH below 7. The reasoning chain is: element, then metal or non-metal, then basic or acidic oxide, then pH above or below 7.
- **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, *evaporate* some of the water, and leave it to *crystallise* slowly on cooling.

EXAM TIPS

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. 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. When acid is added to an alkali containing methyl orange, the colour changes from yellow towards orange and then red.

TIP Litmus and methyl orange show only *whether* a solution is acidic or alkaline; they cannot give a number. If a question asks for a *pH value*, or to compare how strongly acidic two solutions are, the indicator must be *universal indicator*. Remember it is *green* at neutral pH 7, not colourless.

2 Atoms, elements and compounds

KEY FORMULAS

Nucleon number

$$A = Z + N$$

Use to find the nucleon (mass) number A from the proton number Z and the number of neutrons N . All three are counts of particles with no unit; the nucleon number counts protons and neutrons together, never the electrons.

Number of neutrons

$$N = A - Z$$

Use to find the number of neutrons, since they are never given directly. Subtract the proton number Z from the nucleon number A ; the result is a whole number of particles with no unit.

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 Mg^{2+} ion needs two Cl^- ions, giving MgCl_2 ; the numbers of ions are set by making the electrons lost equal the electrons gained.

Shared electrons in covalent bonds

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

Use to count the electrons involved in covalent bonding, since each shared pair (one bond) contains two electrons. Methane CH_4 has four bonds, so $4 \times 2 = 8$ electrons are shared; a double bond counts as two bonds and therefore four shared electrons.

KEY CONCEPTS

- **Electronic configuration:** Electrons fill shells from the innermost outwards. For elements with proton number 1 to 20 the shells hold 2, then 8, then 8, then 2, written as comma-separated numbers: sodium is 2, 8, 1 and sulfur is 2, 8, 6. An atom with a full outer shell (2 for helium, 8 for the others) is a stable, unreactive noble gas, and every reaction in this chapter is an atom rearranging its outer electrons to reach a full outer shell.
- **Element, compound and mixture:** An *element* is a substance made of only one kind of atom and cannot be broken down into anything simpler by chemical means. A *compound* is two or more different elements chemically combined in a fixed proportion, with properties different from those of the elements it was made from. A *mixture* contains two or more substances that are not chemically combined, so each keeps its own properties and the proportions can be varied.
- **Ions and the ionic bond:** An *ion* is a charged particle formed when an atom loses or gains electrons; only electrons move, never protons. Metals *lose* electrons to form positive ions (*cations*); non-metals *gain* electrons to form negative ions (*anions*). The size of the charge equals the number of electrons transferred. An *ionic bond* is the strong electrostatic attraction between oppositely charged ions.
- **The covalent bond:** A *covalent bond* is a shared pair of electrons between two non-metal atoms; by sharing, each atom gains a full outer shell. One shared pair is a *single bond*, two shared pairs a *double bond* and three shared pairs a *triple bond*. Outer-shell electrons that are not shared form *lone pairs*. Each atom forms as many bonds as it needs shares to fill its outer shell: hydrogen 1, Group VII 1, oxygen 2, nitrogen 3, carbon 4.

- **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. Because a neutral atom carries no overall charge, the number of electrons equals the number of protons; because the electron mass is negligible, the mass of an atom is effectively the mass of its nucleus.
- **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). The Group VIII noble gases have a full outer shell, which is why they are unreactive.
- **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 the weak forces between molecules, so melting and boiling points are *low* and many such substances are gases or liquids at room temperature. The molecules are neutral, with no free ions or electrons, 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 O₂ is an element (one kind of atom) while water H₂O is a compound (two kinds). *Compound or mixture:* both can contain different elements, so the test is whether those elements are chemically combined in a fixed ratio (compound) or merely mixed in any ratio (mixture).
- **The giant ionic lattice:** Ionic compounds do not exist as separate molecules. Because each ion attracts oppositely charged ions in every direction, the ions pack into a *giant lattice*, a regular repeating three-dimensional arrangement in which positive and negative ions *alternate* so that every ion is surrounded by ions of opposite charge. The formula NaCl gives the *ratio* of ions, not the size of a particle; there is no such thing as a "NaCl molecule".

EXAM TIPS

TIP Brass looks and behaves like a single uniform metal, yet it is a *mixture* of copper and zinc. It is a mixture because the copper-to-zinc ratio can be varied and the atoms are not bonded in one fixed proportion. Looking uniform is never evidence of a compound; only a fixed combining ratio is.

TIP The nucleon (mass) 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 32 as "32 neutrons" is the single most common error; always subtract the proton number first.

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*. 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, so the building block is the defining feature.
- **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). All three food groups share carbon, hydrogen and oxygen; only proteins also contain nitrogen.
- **Starch, glycogen and cellulose are all made from glucose:** Starch (the energy store in plants), glycogen (the energy store in animals) and cellulose (the material of plant cell walls) are all carbohydrates built from the single building block *glucose*. Three very different roles, one shared building block.
- **The four food tests: reagent and positive result:** Iodine test for starch: iodine solution, no heating, brownish-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 change is semi-quantitative: with more reducing sugar the colour moves further along blue, green, yellow, orange, brick-red.
- **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 brownish-orange.

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 brownish-orange to blue-black for iodine. Writing only the final colour, or reversing the direction, loses the mark. When two foods are compared, judge each sample on its own colour.

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.

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. Image size and actual size must be measured in the *same unit* before dividing; magnification itself has no unit.

Millimetre to micrometre conversion

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

Use to change units so a length and its image are measured the same way. Multiply by 1000 to convert millimetres to micrometres; divide by 1000 to convert micrometres to millimetres.

Rearranging to find the actual size

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

Use when a diagram gives the image size and its magnification and you need the real size of the specimen. Keep the image size in a single unit, then convert the answer to millimetres or micrometres as the question asks.

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 you need the length of the drawing or photograph. Convert the actual size into the unit the answer must be given in before multiplying.

KEY CONCEPTS

- **Functions of the main cell structures:** Cell membrane: controls entry and exit of substances. Nucleus: stores DNA and directs the cell. Cytoplasm: site of chemical reactions. Mitochondria: site of aerobic respiration. Ribosomes: site of protein synthesis. Chloroplast: absorbs light for photosynthesis. Cell wall: support. 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 chemical reactions happen, and *ribosomes* where proteins are made. Plant and animal cells also have a *nucleus* that holds the genetic material (DNA) and controls the cell's activities.
- **Structures found only in plant cells:** A typical plant cell has three structures that an animal cell does not: a *cell wall* made of cellulose that gives shape and support, *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.
- **Specialised cells and their adaptations:** A *root hair cell* has a long, thin extension that increases surface area for absorbing water and mineral ions. A *palisade mesophyll cell* is column-shaped and packed with chloroplasts near the leaf surface for photosynthesis. A *red blood cell* is a biconcave disc with no nucleus, giving room for haemoglobin to carry oxygen.

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** If the image size is in millimetres and the actual size is in micrometres, the answer is wrong by a factor of 1000. Always express both lengths in the same unit, using $1 \text{ mm} = 1000 \mu\text{m}$, before substituting into the magnification equation.
- 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 the universal cell toolkit.
- 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".

5 Characteristics of living organisms

KEY CONCEPTS

- **Excretion:** Excretion is the removal of the waste products of metabolism and substances in excess of requirements. It removes wastes the body itself made, such as carbon dioxide from respiration and urea from the breakdown of excess protein, together with substances present in excess, such as excess water and salts.
- **Growth:** Growth is a permanent increase in size and dry mass. *Dry mass* is the mass of an organism after all its water has been removed, and *permanent* rules out temporary or reversible change. Measuring dry mass counts new living material rather than water gained or lost.
- **Nutrition:** Nutrition is the taking in of materials for energy, growth and development. A complete answer keeps all three purposes in view: the materials are respired to release energy and are used as building blocks for growth and development. Animals ingest and digest food; plants take in carbon dioxide, water and mineral ions and build their own food by photosynthesis.
- **Respiration:** Respiration is the chemical reactions in cells that break down nutrient molecules to release energy. The two load-bearing words are *chemical* and *cells*: respiration is a chemical process that takes place inside every living cell, in the cytoplasm and mitochondria, releasing energy continuously.
- **The seven characteristics of living organisms (MRS GREN):** The seven characteristics shared by every living organism are summarised by *MRS GREN*: Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion and Nutrition. An organism is treated as living only if it is capable of all seven over its lifetime. The mnemonic is only a memory aid; marks are earned by reproducing the exact definition of each characteristic and applying it to a given case.
- **Dry mass and fresh mass:** *Fresh mass* (wet mass) is the mass of an organism including all its water; *dry mass* is the mass after all the water has been removed. An organism can gain or lose water quickly with no new living material made, so only dry mass measures a true increase in living material. Finding dry mass requires drying the specimen, which kills it.
- **Movement:** Movement is an action by an organism, or part of an organism, causing a change of position or place. The definition is deliberately wide: in animals the whole organism usually travels, while in plants a *part* changes position, such as a shoot bending towards light or a Venus flytrap snapping its leaves shut. Both count as movement.
- **Reproduction:** Reproduction is the processes that make more of the same kind of organism. The phrase *the same kind* means offspring of the same species as the parent. The definition says nothing about the number of parents: one parent (asexual, as in a dividing bacterium or a fungus releasing spores) or two parents (sexual) both satisfy it.
- **Sensitivity:** Sensitivity is the ability to detect and respond to changes in the internal or external environment. Both parts are required: a change that is *detected* and then a *response* to it. The change is the *stimulus* and the reaction is the *response*. Plants show sensitivity too, for example by detecting the direction of light and growing towards it.

EXAM TIPS

TIP Excretion removes wastes the body made, or absorbed and then held in excess, such as urea and carbon dioxide; egestion removes *undigested* food from the gut. Urine is excreted; faeces are egested. Egestion is not one of the seven characteristics, so writing that "faeces are excreted" is a common and costly error.

TIP Respiration is a *chemical* process inside cells that releases energy; breathing (ventilation) is a *physical* process that moves air in and out of the lungs. Breathing is not one of the seven characteristics. Cellular respiration can continue using stored oxygen and nutrients even while breathing is paused, as in a diving mammal.

TIP When a scenario shows more than one characteristic, name the one demonstrated by the *exact action the question asks about*, not the overall story. A Venus flytrap closing its leaves is *movement*, even though the trapped insect is later digested by *nutrition*.

TIP Two red flags mark a "not growth" scenario: the change is in *water or fresh mass only*, or the change is *reversible or seasonal*. Watering a wilted plant raises its fresh mass within an hour but

adds no living material, so it is not growth; a hibernating mammal losing then regaining fat is a reversible cycle, not growth.

6 Chemical energetics

KEY FORMULAS

Activation energy from a reaction pathway diagram

$$E_a = \text{energy at peak} - \text{energy of reactants}$$

Use to find the activation energy from a numbered diagram. Measure from the reactants level up to the peak; the answer is always positive and is smaller than the peak's height above the axis.

Overall energy change from a reaction pathway diagram

$$\text{overall energy change} = \text{energy of products} - \text{energy of reactants}$$

Use to read the overall energy change off a numbered diagram. A negative value means energy is released (exothermic); a positive value means energy is absorbed (endothermic). The change spans the two flat levels, never the peak.

Overall energy change from bond energies

$$\text{overall energy change} = \text{energy in (breaking bonds)} - \text{energy out (making bonds)}$$

Use when the total energy to break all reactant bonds and the total energy released making all product bonds are given. A negative result means energy is released overall (exothermic); a positive result means energy is absorbed overall (endothermic).

Temperature change in an experiment

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

Use to find the size of a temperature change from thermometer readings. A larger rise means more thermal energy released to the surroundings; a larger fall means more thermal energy taken in. Compare the *size* of the change, not the final reading alone.

KEY CONCEPTS

- **Activation energy:** The *activation energy*, E_a , is the minimum energy that colliding particles must have in order to react. On a reaction pathway diagram it is the height of the barrier measured from the reactants level up to the peak, not the overall energy change and not the height of the peak above the axis.
- **Bond breaking and bond making:** Breaking a chemical bond takes energy in, so bond breaking is *endothermic*. Forming a new chemical bond gives energy out, so bond making is *exothermic*. A reaction is exothermic overall when more energy is released making the new bonds than is absorbed breaking the old bonds, and endothermic when the reverse is true.
- **Endothermic reactions:** An *endothermic* reaction takes in thermal energy from the surroundings, so the temperature of the surroundings falls. The defining observation is a fall in temperature of the reaction mixture. Common examples are thermal decomposition, dissolving ammonium salts such as ammonium chloride, and photosynthesis.
- **Exothermic reactions:** An *exothermic* reaction transfers thermal energy to the surroundings, so the temperature of the surroundings rises. The defining observation is a rise in temperature of the reaction mixture. Common examples are combustion, neutralisation, the reaction of a reactive metal with an acid, and respiration.
- **Reaction pathway diagrams:** A reaction pathway diagram plots energy on the vertical axis against progress of reaction on the horizontal axis. Reactants are marked at the start (left) and products at the end (right); the curve rises to a peak between them. For an exothermic reaction the products lie *lower* than the reactants; for an endothermic reaction the products lie *higher*.

- **A catalyst and the activation energy:** A *catalyst* provides an alternative reaction pathway with a lower activation energy, so a greater proportion of collisions have enough energy to react and the reaction speeds up. A catalyst lowers the barrier only; it does not change the energy levels of the reactants or products, so the overall energy change stays exactly the same.
- **Why a reaction is exothermic in terms of bond energies:** In every reaction the reactant bonds break, absorbing energy, and the product bonds form, releasing energy. The reaction is exothermic when the energy released making the new bonds is greater than the energy absorbed breaking the old bonds. The surplus energy is transferred to the surroundings, which is why the temperature rises.

EXAM TIPS

TIP A common error is to call bond breaking exothermic. Breaking bonds always takes energy in (endothermic) and making bonds always gives energy out (exothermic). Remember it as *break to take, make to give*.

TIP A mixture can dip in temperature during an endothermic change and then drift back up to room temperature once the reaction is over. The drift back up is not a second, exothermic reaction; it is simply the cold mixture re-warming from the room. Classify the change by the dip *during* the reaction, not by where the thermometer settles.

TIP On a pathway diagram the overall energy change is the vertical gap between the reactants level and the products level, shown as an arrow running directly from one to the other. It does not reach the peak. An arrow that only climbs to the top of the barrier is the activation energy, not the overall energy change.

7 Chemical reactions

KEY FORMULAS

Rate of reaction

$$\text{rate of reaction} = \frac{\text{quantity of reactant used or product formed}}{\text{time taken}}$$

Use to calculate how fast a reaction goes from a measured quantity and a time. The quantity may be a gas volume in cm^3 , a loss of mass in g, or a length of solid in mm; the unit of rate is that quantity per second. Always state the unit.

Mean rate from a change in mass

$$\text{mean rate} = \frac{\text{change in mass}}{\text{time taken}}$$

Use when a reaction gives off a gas that escapes from an open flask standing on a balance, so the total mass falls. A loose cotton-wool plug lets the gas out while stopping spray. The unit is g per second.

Rearranging the rate equation

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

Use to find the quantity of gas or mass produced when the mean rate and time are known. Rearranged the other way, $\text{time} = \frac{\text{quantity}}{\text{rate}}$ gives the time to reach a chosen quantity.

KEY CONCEPTS

- **Activation energy:** The *activation energy* is the minimum energy that colliding particles must have for a reaction to occur. On a reaction-pathway diagram it is the height of the barrier measured from the reactants level up to the top of the peak.
- **Catalyst:** A *catalyst* increases the rate of a reaction and is chemically unchanged and not used up at the end. It works by providing an alternative reaction pathway with a lower activation energy, so a greater proportion of collisions have enough energy to react. Only a small mass is needed because it is not consumed.
- **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, rusting, thermal decomposition, electrolysis, fermentation and neutralisation are all chemical changes.
- **Collision theory:** A reaction happens only when reacting particles *collide*, and only when they collide with at least a minimum energy called the *activation energy*. Collisions with less energy simply bounce apart unchanged. The rate therefore depends on how frequently particles collide and what proportion of those collisions are energetic enough to react.
- **Factors that change the rate:** Four factors increase the rate of a reaction: raising the concentration of a solution, increasing the surface area of a solid (using smaller pieces or powder), raising the temperature, and adding a suitable catalyst. Each factor run the other way (diluting, using larger lumps, cooling, removing a 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, dissolving and the fractional distillation of a mixture are all physical changes, because the same substances are still present afterwards.
- **Redox reaction:** A *redox reaction* is one in which oxidation and reduction happen at the same time, in the same reaction. Whenever one substance gains oxygen, another must lose it, so the two

changes always occur together. To analyse one, follow the oxygen: the substance that loses oxygen is reduced and the substance that gains it is oxidised.

- **Signs that suggest a chemical change:** A permanent colour change, a gas given off, a precipitate forming, a temperature change, or light emitted 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 raising the concentration increases the rate:** A higher concentration puts *more particles of reactant into the same volume* of solution, so the reacting particles collide more frequently. The proportion of collisions with enough energy is unchanged, so more frequent collisions mean more successful collisions each second, which is a higher rate.
- **Why raising the temperature increases the rate:** Heating gives the particles more kinetic energy, so they collide *more frequently* and a *greater proportion* of collisions now have at least the activation energy. Both effects raise the rate, and the second is the larger one. Temperature does not change the activation energy itself.

EXAM TIPS

TIP On a graph of quantity of product against time, the gradient is the rate: the curve is *steepest at the start* (fastest) and flattens as reactants are used up. *A flat, horizontal curve means the reaction has finished*. The rate is greatest where the curve is steepest, not where it is highest.

TIP Reversibility is not the test, and a dramatic effect is not proof. The only reliable question is *has a new substance, with new properties, been formed?* Some chemical changes can be reversed, and large temperature or mass changes can accompany a purely physical change.

TIP In a redox reaction exactly one substance loses oxygen (reduced) and one gains it (oxidised). "Both substances change, so both are reduced" is a trap. Name each separately by tracking the oxygen, not by whether the substance changed or changed state.

TIP The blue-to-white change of copper(II) sulfate on heating is a chemical change, because a new substance (white anhydrous copper(II) sulfate) forms, even though adding water reverses it. Argue from *new substance formed*, never from whether the change can be undone.

TIP Breaking a solid into powder does *not* change the number of particles per unit volume inside it; that is fixed. What it changes is the *total surface area exposed* to the other reactant. Using the concentration phrase for a surface-area effect is a common and costly slip.

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. State the figures as *approximate*: "80% nitrogen, 20% oxygen" loses the precision mark, and the final 1% is a mixture, not pure argon or pure carbon dioxide.
- **The adverse effects of the air pollutants:** Pair each pollutant with its harm. *Carbon dioxide* and *methane* are greenhouse gases that cause global warming. *Carbon monoxide* is toxic: it binds to haemoglobin more strongly than oxygen, so less oxygen is carried around the body. *Particulates* cause respiratory problems. *Sulfur dioxide* and *oxides of nitrogen* cause acid rain, and oxides of nitrogen also cause respiratory problems.
- **The greenhouse effect and global warming:** Greenhouse gases warm the atmosphere by acting on the thermal energy *radiated from the Earth's surface*, not on the incoming sunlight. The warmed surface radiates thermal (infra-red) energy outwards; greenhouse gases absorb *some* of it and re-emit part back towards the surface; this reduces the thermal energy lost to space, so the atmosphere warms. Raising their concentration strengthens the effect.
- **The main air pollutants and their sources:** Learn each pollutant with a named source. *Carbon dioxide* (CO_2): complete combustion of carbon-containing fuels. *Carbon monoxide* (CO) and *particulates*: *incomplete* combustion, where there is too little oxygen. *Methane* (CH_4): livestock digestion and decaying organic waste in landfill. *Oxides of nitrogen* (NO_x): nitrogen and oxygen from the air reacting at the high temperature inside engines. *Sulfur dioxide* (SO_2): burning fuels that contain sulfur impurities, such as coal.
- **Treatment of the domestic water supply:** Raw water is made safe to drink in a fixed sequence of stages, each with its own job. *Sedimentation*: large insoluble particles settle out under gravity. *Filtration*: beds of sand and gravel trap the smaller insoluble solids. *Carbon*: activated carbon removes tastes and odours. *Chlorination*: chlorine is added to kill microbes such as bacteria. Remember it as one stage, one job.
- **Two chemical tests for the presence of water:** Two anhydrous salts each give a fixed colour change when water is added. Anhydrous copper(II) sulfate is *white* and turns *blue* (white to blue). Anhydrous cobalt(II) chloride is *blue* and turns *pink* (blue to pink). Both tests show only that water is *present*, not that a liquid is *pure*; pure water is confirmed separately by its boiling point of 100°C and melting point of 0°C .
- **Why distilled water is used in quantitative chemistry:** Distilled water is used instead of tap water for titrations and for making up solutions of known concentration because it contains far fewer dissolved chemical impurities (dissolved ions). The impurities in tap water can react with the reagents, or add substances that were not accounted for, 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 it is not chemically pure. Sedimentation, filtration, carbon and chlorination remove insoluble solids, tastes, odours and microbes, yet they leave dissolved ions behind. For a quantitative practical those remaining impurities could still react with the reagents or add unaccounted mass or volume, so distilled water, from which distillation has stripped the dissolved solids, is used instead.
- **Acid rain and how to reduce it:** Acid rain forms when sulfur dioxide and oxides of nitrogen dissolve in rainwater. It damages plants and aquatic life and erodes buildings made of limestone and marble. The syllabus strategy targets the sulfur source: *use low-sulfur fuels*, so that burning them releases less sulfur dioxide, so less sulfur dioxide dissolves in rain to form acid.
- **Strategies to reduce climate change:** Four strategies, each named with the gas it lowers. *Planting trees*: trees absorb carbon dioxide during photosynthesis. *Reducing livestock farming*: fewer cattle release less methane. *Decreasing the use of fossil fuels*: less carbon dioxide is released. *Increasing renewable energy* (solar, wind, hydroelectric): electricity is generated without releasing carbon dioxide. A full answer always names the gas, not just the action.

EXAM TIPS

TIP Two words separate the correct answer from the traps in greenhouse-effect questions: *some* (not "all") and *from the surface* (not "from the Sun"). Greenhouse gases absorb *some* of the

thermal energy radiated *from the Earth's surface*; answers that say they absorb the Sun's incoming energy, or absorb "all" of the energy, do not score.

TIP Oxides of nitrogen are *not* formed from an impurity in the fuel. They form when the air's own nitrogen and oxygen are forced together by the high temperature inside an engine. This is why switching to a low-sulfur fuel cuts sulfur dioxide but does not remove oxides of nitrogen; do not attribute them to the fuel.

TIP A positive test with copper(II) sulfate or cobalt(II) chloride shows only that *water is present*, not that the liquid is *pure* water. A dilute salt solution would give the same colour change. To confirm *pure* water, measure its boiling point (100 °C) and melting point (0 °C).

9 Diseases and immunity

KEY CONCEPTS

- **Active immunity:** *Active immunity* is defence against a pathogen by the production of antibodies in the body itself. The body's own *lymphocytes* make antibodies against a specific pathogen. It is gained in two ways: after a natural infection, or by vaccination. Active immunity is long-lasting because the body keeps *memory cells* and can make more antibodies quickly.
- **Structure of a virus:** A virus is *not* a cell. Each particle is just a core of *genetic material* enclosed in an outer *protein coat*, with none of the cytoplasm, ribosomes or membrane a cell has. Because it lacks this machinery, a virus cannot reproduce on its own; it must invade a living *host cell* and use that cell's structures to make new virus particles.
- **The body's defences against pathogens:** The body defends itself in layers. *Barriers* keep pathogens out: the skin is a physical barrier, mucus and cilia trap and remove pathogens in the airways, and stomach acid kills pathogens that are swallowed. If the skin is cut, *platelets* clot the blood to seal the wound. *White blood cells* destroy pathogens that get in: phagocytes engulf them and lymphocytes produce antibodies.
- **Transmissible disease and how it spreads:** A *transmissible disease* is one in which the pathogen can be passed from an infected host to an uninfected host. It spreads either by *direct contact* (host to host, with nothing in between) or *indirectly* through an intermediate carrier: the air, contaminated water, contaminated food, or a *vector* such as a mosquito.
- **What a pathogen is:** A *pathogen* is a disease-causing organism. Pathogens fall into four groups: *bacteria*, *viruses*, *fungi* and *protozoa*. Not every disease is caused by a pathogen: inherited diseases pass through genes and deficiency diseases come from a poor diet, and neither involves an infecting organism.
- **Active versus passive immunity:** In *active immunity* the body makes its own antibodies, using its lymphocytes, and keeps memory cells, so it lasts a long time. In *passive immunity* ready-made antibodies are supplied from outside, for example injected or passed from a mother to her baby; it is short-lived because the body made no memory cells and cannot make more once those antibodies are used up.
- **Direct and indirect transmission:** In *direct contact* transmission the pathogen passes straight from one host to another, with the two hosts themselves as the point of contact. In *indirect* transmission an intermediate carrier moves the pathogen between hosts: droplets in the air, contaminated water, contaminated food, or a *vector* such as a mosquito. The useful test is whether the two people had to touch with nothing in between.
- **How a vaccine gives active immunity:** A *vaccine* contains a harmless or inactivated form of a pathogen, or its antigens. These *antigens* make the body's own lymphocytes produce antibodies and memory cells, without the person suffering the disease. If the live pathogen is met later, the memory cells trigger a fast response, so the vaccine gives active immunity in advance.

EXAM TIPS

TIP An *antibiotic* kills bacteria or stops them growing, so it treats bacterial infections only. It has no effect on a virus, because a virus is not a cell and has almost none of the structures a drug can attack. A cold is viral, so antibiotics do nothing for it.

TIP When asked how the airways defend against pathogens breathed in, name *both* jobs: the sticky *mucus* traps the pathogens, and the beating *cilia* sweep the trapped mucus up and out to be swallowed or coughed away. A one-sided answer earns only one mark.

TIP "The pathogen still passes from one person to another" is true of *every* transmissible disease, so it does not make a route direct. Direct contact requires the two *hosts* to be the point of contact, with nothing carrying the pathogen in between. If air, water, food or a vector carries it, the route is indirect.

KEY CONCEPTS

- **Antibiotic resistance and MRSA:** Some bacteria are *resistant* to antibiotics: the antibiotic no longer kills them or stops their growth, which reduces its effectiveness 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 kill bacteria but not viruses:** Antibiotics kill bacteria or stop them growing, but they have *no effect on viruses*. Illnesses caused by viruses, such as the common cold and influenza, cannot be treated with antibiotics because the drug has nothing to act on. The cause of an infection must be known to be bacterial before an antibiotic is an appropriate treatment.
- **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. The definition makes no reference to benefit or harm, so a life-saving medicine and a harmful substance are both drugs. A substance qualifies only if it is taken in from outside *and* alters the body's chemistry, rather than merely feeding the body's ordinary reactions.
- **Using antibiotics only when essential:** Using antibiotics *only when they are essential* helps to limit the development of resistant bacteria. Every use of an antibiotic exposes bacteria to it and selects for any that are resistant, so restricting antibiotics to confirmed bacterial infections that genuinely need treating gives resistant bacteria fewer opportunities to be selected and to spread.
- **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 allows the body to clear the infection. Penicillin is the classic example. Because it acts on the bacteria themselves, an antibiotic *cures* a bacterial infection rather than only relieving the symptoms.
- **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 the antibiotic is ever used. The antibiotic kills the non-resistant bacteria while the resistant ones survive and reproduce, passing on their resistance. Over repeated exposures the resistant strain comes to dominate. The antibiotic *selects for* resistance that already exists; it does not create it.
- **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, oxygen is a reactant in aerobic respiration, and water is the solvent for the body's reactions. Each supplies or drives the body's normal chemistry rather than modifying it, so none of them is a drug.
- **The disc-diffusion test for comparing antibiotics:** Different antibiotics can be compared by spreading bacteria evenly over an agar plate and placing paper discs, each soaked in a different antibiotic, on the surface. Where an antibiotic is effective it kills the bacteria or stops them growing, leaving a clear ring with no growth called a *zone of inhibition*. A larger clear zone shows the antibiotic was effective over a greater area, so it is the more effective antibiotic against that species.

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, since a virus could never be antibiotic-resistant in the first place.

TIP A patient can have a bacterial infection and a separate viral infection at the same time. Answer in two halves: the antibiotic kills the bacteria and clears the bacterial infection, but it has no effect on the virus, so the viral symptoms remain. Marks are usually available for each half.

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 such as "it will strengthen the skin against future infection".

11 Electricity

KEY FORMULAS

Current, charge and time

$$I = \frac{Q}{t}$$

Use to relate the current to the charge passing a point and the time taken; I is in amperes (A), Q in coulombs (C) and t in seconds (s). Rearranges to $Q = It$.

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). 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 parallel

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

Use to find the combined resistance of two resistors in parallel; equivalently $R = \frac{R_1 R_2}{R_1 + R_2}$. The combined value is always less than the smaller resistor.

Resistors in series

$$R = R_1 + R_2 + \dots$$

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 $E = Pt$.

Power from current and resistance

$$P = I^2 R = \frac{V^2}{R}$$

Use when current and resistance, or p.d. and resistance, are known instead of both current and p.d.; both forms follow from $P = IV$ with $V = IR$. Use $P = I^2 R$ for the heating effect in a resistance.

KEY CONCEPTS

- **e.m.f. and potential difference:** *Electromotive force* (e.m.f.) is the electrical work done by a source in moving a unit charge around a complete circuit; it describes the source. *Potential difference* (p.d.) is the work done by a unit charge passing between two points; it describes a component. Both are measured in volts (V) and read with a voltmeter connected in *parallel*.
- **Electric current:** *Electric current* is the flow of electric charge, measured in amperes (A). In a metal it is carried by *delocalised electrons* drifting through the fixed lattice of positive ions. *Conventional current* flows in the external circuit from the positive terminal to the negative terminal, while the electrons flow the opposite way. An ammeter measures current and is connected in *series*.
- **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. A motor and a generator are the same machine run in opposite directions.
- **Fuse, earthing and double insulation:** A *fuse* is a thin wire 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 case and needs no earth wire.
- **Rules for a parallel circuit:** In a *parallel circuit* there is more than one path, so the *branch currents add* to give the larger source current, *each branch has the full p.d.* of the supply, and the *combined resistance is less* than the smallest branch. One branch can fail without breaking the others.
- **Rules for a series circuit:** In a *series circuit* there is one path for the current, so the *current is the same* at every point, the source voltage is *shared* so the component p.d.s add up to the e.m.f., and the *resistances add*. A break anywhere stops the current everywhere.
- **Diodes and LEDs conduct one way:** A *diode*, including a *light-emitting diode (LED)*, allows current to flow in *one direction only*. Connected the correct way round it is *forward biased* and conducts; the wrong way round it is *reverse biased* and blocks the current. An LED therefore needs a d.c. supply and lights only when connected with the correct polarity.
- **One machine: motor and generator:** A motor and a generator are the same machine driven in opposite directions. Supplied with current it spins, transferring *electrical energy to kinetic energy* as a motor; with its shaft turned by hand a voltage appears across it, transferring *kinetic energy to electrical energy* as a generator.
- **The two types of electric charge:** There are two types of charge, *positive* and *negative*, measured in coulombs (C). *Like charges repel* and *unlike charges attract*. A *conductor* such as copper lets charge flow freely; an *insulator* such as plastic does not, which is why an insulating rod holds a static charge after being rubbed.

EXAM TIPS

TIP In $I = \frac{Q}{t}$, in $E = IVt$ and in every equation that uses seconds, a time given in minutes must be multiplied by 60 first. Using "2.0 minutes" as 2.0 is the most common slip in this topic.

TIP Keep the two voltages apart: use *e.m.f.* only for what a source gives each coulomb all the way round the circuit, and *p.d.* for the energy each coulomb gives up across a component. Both are measured in volts, so the mark is for the correct wording, not the unit.

TIP For the heat produced in a cable or element, use $P = I^2R$ and keep current and resistance together; do not substitute the wrong quantity. Sanity-check the size: a kilowatt-scale element should give a power in the thousands of watts.

12 Electrochemistry

KEY FORMULAS

Anode half-equation for molten lead(II) bromide



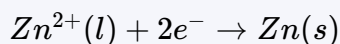
Use for the reaction at the anode when molten lead(II) bromide is electrolysed. Bromine is diatomic, so two Br^- ions are needed, each losing one electron, giving two electrons in total. The product is bromine gas, seen as an orange-brown vapour.

Cathode half-equation for molten lead(II) bromide



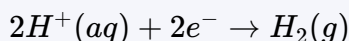
Use for the reaction at the cathode when molten lead(II) bromide is electrolysed. Each Pb^{2+} ion gains two electrons (one per unit of positive charge) to form a neutral lead atom. Balance both the atoms and the charge, and include state symbols.

Cathode half-equation for molten zinc chloride



Use for the cathode reaction when molten zinc chloride is electrolysed. Each Zn^{2+} ion gains two electrons to form solid zinc. Note the molten ion carries state symbol (l) while the deposited metal is (s); a single electron or an (aq) label would be wrong.

Discharge of hydrogen ions at the cathode



Use for the cathode reaction when hydrogen is the cathode product, for example in dilute sulfuric acid or concentrated aqueous sodium chloride. Two hydrogen ions each gain one electron, so two electrons form one molecule of hydrogen gas.

KEY CONCEPTS

- **Anode, cathode and electrolyte:** The *anode* is the electrode connected to the *positive* terminal; 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. The electrolyte is not an electrode. Name every part from the terminals first, never from the products.
- **Definition of electrolysis:** Electrolysis is the *decomposition* of an ionic compound, when *molten or in aqueous solution*, by the passage of an *electric current* through it. Every part of that sentence is examinable: a compound is broken down (not built up), it must be ionic, its ions must be free to move, and a current must be passed. Melting or dissolving frees the ions but does not, by itself, cause electrolysis.
- **Discharge of ions at the electrodes:** Positive ions (cations) are attracted to the cathode, where they *gain electrons* and are discharged. Negative ions (anions) are attracted to the anode, where they *lose electrons* and are discharged. Gaining electrons is reduction; losing electrons is oxidation. Every product prediction follows from this single rule.
- **The general rule for electrode products:** A *metal or hydrogen* is formed at the cathode, and a *non-metal (other than hydrogen)* is formed at the anode. Use this as a fast check: a metal appearing at the anode, or a non-metal other than hydrogen at the cathode, always signals a wrong answer.
- **Products of concentrated aqueous sodium chloride:** With inert electrodes, concentrated aqueous sodium chloride gives *hydrogen* at the cathode (not sodium, which is too reactive to be discharged from solution) and *chlorine* at the anode. Chlorine is a greenish-yellow gas with a sharp, choking smell. The coloured, smelly gas is the anode product.

- **Products of dilute sulfuric acid:** Electrolysing dilute sulfuric acid with inert electrodes is effectively the electrolysis of water: *hydrogen* is given off at the cathode and *oxygen* at the anode. The two gases form in a fixed volume ratio of hydrogen to oxygen of 2 : 1, because water is H_2O .
- **Products of electrolysing molten lead(II) bromide:** Molten lead(II) bromide contains Pb^{2+} and Br^- ions. At the cathode, lead is discharged as a silvery bead of molten metal. At the anode, bromine is discharged and seen as an *orange-brown vapour*. Inert electrodes are used, so both products come entirely from the electrolyte.

EXAM TIPS

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

TIP Count the charge on the ion to fix the number of electrons: a $2+$ ion needs two electrons at the cathode, a $3+$ ion needs three. Check that atoms balance and the total charge is equal on both sides, then add state symbols. Watch for diatomic non-metals such as Br_2 , Cl_2 and O_2 , which force a "two ions, two electrons" pattern at the anode.

TIP In a solid, the ions are locked in a fixed lattice and cannot move, so no charge flows and the solid does not conduct. Melting the compound, or dissolving it in water, frees the ions so they can drift to the electrodes. The charges on the ions do not change; only their freedom to move does.

13 Enzymes

KEY CONCEPTS

- **Active site and enzyme-substrate complex:** The *substrate* is the molecule an enzyme acts on. It binds to a specially shaped region of the enzyme called the *active site*, forming a temporary *enzyme-substrate complex*. Inside this complex the substrate is converted into *product*, which is then released, leaving the active site free and unchanged to bind another substrate molecule.
- **Denaturation:** *Denaturation* is a *permanent* change in the shape of an enzyme's active site, caused by a high temperature or an extreme pH. Once the active site has lost its shape, the substrate can no longer fit, no enzyme-substrate complex forms, and the enzyme stops working. Cooling a heat-denatured enzyme does not restore its activity.
- **Effect of pH on enzyme activity:** Each enzyme has an *optimum pH* at which its activity is highest. Moving the pH away from the optimum in either direction distorts the active site, so the substrate fits less well and activity falls, giving a peak-shaped curve. Different enzymes have different optimum pH values, matching where they work in the body.
- **Effect of temperature on enzyme activity:** As temperature rises, enzyme activity increases to a maximum at the *optimum temperature* (about 37 °C for human enzymes), then falls steeply. The rise and the fall have different causes: below the optimum, molecules gain *kinetic energy*; above it, the enzyme *denatures*.
- **Enzymes are biological catalysts:** An *enzyme* is a *protein* that acts as a *biological catalyst*: it speeds up a chemical reaction in a living organism without being used up or permanently changed. Because it is released unchanged, a single enzyme molecule can catalyse the same reaction many thousands of times, so a cell needs only a tiny amount of each enzyme. Enzymes control *metabolic* reactions, both building large molecules and breaking them down.
- **Specificity and the lock-and-key model:** Each enzyme is *specific*: it normally catalyses only one reaction, acting on only one substrate. The active site has a definite shape that is *complementary* to that one substrate, so only the correct substrate can fit. In the *lock-and-key* model the active site is the lock and the substrate is the key. A substrate of the wrong shape cannot fit, so no enzyme-substrate complex forms and no reaction occurs.
- **Optimum pH matches the working environment:** An enzyme's optimum pH matches the conditions where it works. An enzyme of the *acidic* stomach has a low optimum (about pH 2), while enzymes of the mouth or blood work near pH 7 and those of the *alkaline* small intestine have a high optimum. Read where an enzyme acts and you can predict its optimum pH.
- **Why the rate falls past the optimum:** Above the optimum, a second effect takes over: the extra heat breaks the bonds holding the enzyme's shape, so the active site is distorted and the enzyme *denatures*. As more active sites lose their shape, fewer fit the substrate, and this loss lowers the rate faster than the rising kinetic energy can raise it. Because many molecules denature over a small temperature range, activity falls *steeply*.
- **Why the rate rises towards the optimum:** Below the optimum temperature, raising the temperature gives the enzyme and substrate molecules more *kinetic energy*, so they move faster. Faster movement means more frequent *effective collisions* with the active site, so more enzyme-substrate complexes form each second and the rate of reaction increases. Kinetic energy, effective collision frequency and the amount of product all rise together.

EXAM TIPS

TIP Denaturation happens to the *enzyme*, because an enzyme is a protein with a delicate folded shape. Writing that "the substrate is denatured" or "the substrate changes shape" loses the mark. The substrate is changed into product; the enzyme's active site is what loses its shape when heated or exposed to an extreme pH.

TIP When explaining why the rate rises with temperature, the mark scheme wants the full chain: more kinetic energy, faster movement, more frequent *effective* collisions, more enzyme-substrate complexes, higher rate. Dropping the word *effective* (or *successful*) is the most common way to lose the collision mark.

TIP The temperature curve is *lopsided*: a gentle rise from kinetic energy, then a steep fall as the enzyme denatures. A single-enzyme pH curve is much more *symmetrical* about its optimum.

Examiners often give an unlabelled axis and ask you to name it from the curve's symmetry, so learn the two shapes as a pair.

14 Experimental techniques and chemical analysis

KEY FORMULAS

R_f value

$$R_f = \frac{\text{distance travelled by substance}}{\text{distance travelled by solvent}}$$

Use to identify a substance from a chromatogram; both distances are measured from the baseline. The substance never moves further than the solvent, so R_f has no units and always lies between 0 and 1.

Volume delivered from a burette

$$\text{volume delivered} = \text{final reading} - \text{initial reading}$$

Use to find the volume of liquid run out of a burette, for example the volume of acid added in a titration. Read both levels from the bottom of the meniscus at eye level, to the nearest 0.05 cm³.

Finding a distance from an R_f value

$$\text{distance travelled by substance} = R_f \times \text{distance travelled by solvent}$$

Use to predict how far a substance of known R_f will travel, given the distance moved by the solvent front. It is the R_f equation rearranged to make the substance distance the subject.

Percentage of oxygen in air

$$\text{percentage of oxygen} = \frac{\text{decrease in volume of air}}{\text{initial volume of air}} \times 100$$

Use when air is passed repeatedly over heated copper until no further change occurs; the copper removes the oxygen, so the fall in volume equals the volume of oxygen. Air is about 21% oxygen, so 100 cm³ of air falls to about 79 cm³.

KEY CONCEPTS

- **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 and the solvent rises up the paper by capillary action, carrying the substances with it. Substances that are more soluble in the solvent travel further, so the components separate into individual spots.
- **Simple and fractional distillation:** *Simple distillation* obtains a pure solvent from a solution: the solvent evaporates, then condenses in a water-cooled 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 for cations with aqueous sodium hydroxide:** Adding aqueous sodium hydroxide gives a coloured metal hydroxide precipitate. Copper(II) gives a light 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, turning it white.
- **Apparatus for measuring quantities:** Time is measured with a stop-watch, temperature with a thermometer and mass with a balance. For volume, a measuring cylinder gives an approximate value, a volumetric pipette delivers one fixed volume precisely, and a burette measures a variable volume delivered. A gas syringe measures the volume of a gas produced.
- **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.
- **Interpreting chromatograms:** A pure substance produces a single spot on a fully developed chromatogram, while a mixture produces two or more spots. An unknown substance can be identified by running it alongside known references under identical conditions: a spot at the same height, and so the same R_f value, as a reference indicates the same substance.
- **Tests for anions:** For a carbonate, adding dilute acid produces effervescence and the carbon dioxide 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.

EXAM TIPS

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.

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.

Minute ventilation

$$\text{minute ventilation} = \text{tidal volume} \times \text{breathing rate}$$

Use to find the total volume of air breathed in each minute. Tidal volume is the volume of a single breath; keep it in cm^3 so the answer comes out in cm^3 per minute.

Multiplying numbers in standard form

$$(a \times 10^m) \times (b \times 10^n) = (a \times b) \times 10^{m+n}$$

Use when combining a very large and a very small quantity, such as the number of alveoli times the area of each. Multiply the front numbers and *add* the indices; never multiply the powers of ten together.

Total surface area of the alveoli

$$\text{total area} = \text{number of alveoli} \times \text{area of each alveolus}$$

Use to find the combined surface area of all the alveoli. The two quantities are written in standard form, so multiply the front numbers and add the powers of ten; the answer is in m^2 .

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 down its own concentration gradient, from where it is more concentrated to where it is less concentrated.
- **Features of an efficient gas exchange surface:** An efficient gas exchange surface has a *large surface area* (more diffusion at once), a *thin surface* one cell thick (a short diffusion distance), a *moist lining* (gases dissolve before diffusing), and a *good blood supply with good ventilation* (a steep concentration gradient). Every feature makes diffusion faster.
- **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 below atmospheric pressure, so air flows in.
- **How breathing changes during exercise:** When muscles respire faster during exercise they use oxygen and produce carbon dioxide more quickly. The body responds by increasing both the *rate* of breathing (more breaths per minute) and the *depth* of breathing (a larger tidal volume), moving far more air in and out each minute.
- **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.
- **Keeping the diffusion gradient steep:** A steep concentration gradient across the alveolar wall is maintained by two features acting on opposite sides. A *good blood supply* keeps the blood side low in oxygen and high in carbon dioxide; *good ventilation* keeps the air side high in oxygen and low in carbon dioxide. Together they maximise the difference across the wall.
- **The muscles of breathing:** Two sets of muscles change the volume of the chest. The *diaphragm* is a sheet of muscle *below* the lungs that separates the chest from the abdomen; the *intercostal*

muscles lie *between* the ribs and move the rib cage. Both contract during inhalation and relax during exhalation.

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 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 For a fixed amount of gas, a larger chest volume gives a lower pressure and a smaller volume gives a higher pressure. The classic trap pairs an increase in volume with an increase in pressure; the two always move in opposite directions.

16 Human influences on ecosystems

KEY CONCEPTS

- **Causes of endangerment and extinction:** A species may become endangered or extinct through habitat destruction, hunting and overharvesting, pollution, introduced species that prey on or compete with native organisms, and climate change. A species is often endangered by more than one cause 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.
- **Methods of conserving endangered species:** Endangered species are conserved by protecting habitats (national parks, nature reserves and marine protected areas), monitoring *and* protecting species (counting populations and running anti-poaching patrols), captive breeding programmes, seed banks, controlling introduced species and pollution, and legal protection such as bans on hunting or trade.
- **Reasons for habitat destruction:** Humans destroy natural habitats to clear land for farming (crops and grazing livestock), to build houses, roads and factories, to extract resources such as timber, minerals and fuel, and through pollution that damages a habitat even without clearing it.
- **The undesirable effects of deforestation:** Deforestation causes soil erosion, flooding, loss of habitats and biodiversity leading to extinction of species, and a rise in atmospheric carbon dioxide with a fall in oxygen.
- **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. It includes the soil, water, air and climate, not only the living things.
- **What biodiversity is:** Biodiversity is the number of *different species* that live in an area. It counts different species, not the total number of individuals, so an area crowded with a single species has low biodiversity.
- **How deforestation changes atmospheric gases:** Living trees remove carbon dioxide and release oxygen by photosynthesis. Cutting down the forest means less photosynthesis, so less carbon dioxide is removed and less oxygen released; burning or decay of the felled wood releases stored carbon straight back as carbon dioxide. The net result is carbon dioxide rising and oxygen falling.
- **What a captive breeding programme is:** A captive breeding programme keeps animals of an endangered species in a controlled environment such as a zoo, where they are protected and encouraged to breed so their numbers rise. Individuals may later be released into the wild to boost the wild population.
- **What a seed bank is and does:** A seed bank stores seeds from an endangered plant species at low temperature and humidity so they stay viable (able to germinate) for many years. It is a safeguard: even if the plant disappears from the wild, it can be grown again from the stored seeds.
- **Why deforestation increases soil erosion and flooding:** Tree roots bind the soil particles together and take up water from the ground. Once the trees are removed, nothing holds the soil in place or drains it, so heavy rain washes the loose soil away (erosion) and reaches rivers faster and in greater volume, so the rivers overflow (flooding).

EXAM TIPS

TIP Decide biodiversity on the *variety* of species, never on how crowded an area looks. A field of a million grass plants of one species has low biodiversity; a hedgerow of fifty species has high biodiversity. "More individuals" is the classic distractor.

TIP Effective conservation combines methods. Captive breeding is pointless if there is no habitat left to release animals into, and monitoring is useless without protection. For the top marks, state that the methods must be used together.

TIP If you define an ecosystem as "all the organisms in an area" you lose the mark. The non-living surroundings (soil, water, air and climate) must be included; an ecosystem is a community *together with* the environment it interacts with.

TIP The atmospheric effect of deforestation works in both directions at once: carbon dioxide *rises* and oxygen *falls*. A common slip is to change only one gas. State both.

TIP Monitoring a population only *measures* how its numbers change; it does nothing by itself to remove a threat. Protection, for example anti-poaching patrols, is what actually changes the population's fate. Carefully counting a falling population does not save it.

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 calculating the energy content of food. Fat releases roughly twice the energy per gram of carbohydrate or protein, which is why fatty foods are so energy-rich.

Energy per 100 g of food

$$E_{100} = \frac{E}{m} \times 100$$

Use to compare foods fairly by scaling the energy E of a sample of mass m (in grams) to a standard 100 g. This lets you decide which of two foods gives more energy per equal portion.

Total energy content of a food

$$E = (m_c \times 17) + (m_f \times 37) + (m_p \times 17)$$

Use to find the total energy E (in kJ) of a food from its masses of carbohydrate m_c , fat m_f and protein m_p in grams. Multiply each mass by its energy value per gram, then add the three amounts.

KEY CONCEPTS

- **Physical and chemical digestion:** *Physical* (mechanical) digestion breaks food into smaller pieces, for example by the teeth and by churning in the stomach, without changing the molecules. *Chemical* digestion uses enzymes to break large insoluble molecules into small soluble ones. Physical digestion increases the surface area for chemical digestion to act on.
- **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 correct amounts and proportions. The components are *carbohydrates*, *fats*, *proteins*, *vitamins*, *mineral ions*, *fibre* (roughage) and *water*. Carbohydrate is the main energy source, fat is a store of energy and insulation, and protein supplies amino acids for growth and repair.
- **The five processes that act on food:** *Ingestion* takes food into the mouth; *digestion* breaks large molecules into small soluble ones; *absorption* moves those products from the intestine into the blood; *assimilation* is the uptake and use of nutrients by cells; *egestion* removes undigested material as faeces. They always occur in this order.
- **The three digestive enzymes and their products:** *Amylase* breaks down starch into simple sugars such as maltose. *Protease* breaks down proteins into amino acids. *Lipase* breaks down fats and oils into fatty acids and glycerol. Each enzyme acts on one type of substrate.
- **Uses of the main nutrients:** Carbohydrate is the body's main source of energy released in respiration. Fat is a concentrated energy store and, under the skin, insulates against heat loss. Protein provides amino acids for the growth and repair of tissues. Iron is needed to make *haemoglobin* and calcium to harden bones and teeth.

- **Functions of the main digestive organs:** The stomach churns food and adds hydrochloric acid and protease. The *small intestine* completes digestion and absorbs the soluble products into the blood. The *large intestine* absorbs water. The liver makes *bile* to help digest fats, and the gall bladder stores that bile before releasing it into the small intestine.
- **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 lack of iron causes *anaemia*, in which the blood carries too little oxygen. Both are inorganic nutrients required in small amounts.
- **The two functions of hydrochloric acid:** Hydrochloric acid in the stomach has two roles. It kills many harmful microorganisms swallowed with food, and it provides the low pH that is the optimum for stomach *protease*. The acid does not itself digest food, so it is not an enzyme.
- **Vitamins C and D and their deficiency diseases:** Vitamin C is needed for healthy connective tissue; a prolonged lack causes *scurvy* (bleeding gums, poor wound healing). Its main sources are fresh fruit and vegetables. Vitamin D is needed so the body can absorb calcium; a lack causes *rickets*, in which bones become soft and weak.

EXAM TIPS

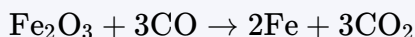
TIP *Egestion* removes undigested food that never entered the body's cells. *Excretion* removes the waste products of the body's own reactions, such as carbon dioxide and urea. Faeces are egested, not excreted.

TIP More is not automatically better. A balanced diet supplies the *correct* amount of each nutrient, and an excess of some nutrients is harmful. A diet can also supply the right total energy yet still be unbalanced if it lacks a specific nutrient such as vitamin C or fibre.

TIP Large food molecules such as starch and protein are too big and insoluble to cross the gut wall. Only the small soluble products of chemical digestion, such as simple sugars and amino acids, can pass into the blood, so digestion must happen before absorption.

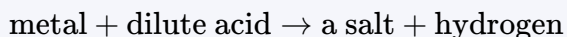
KEY FORMULAS

Extraction of iron in the blast furnace



Use for the reduction of hematite (iron(III) oxide) to iron. This is the third of three linked reactions: $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$ releases heat, then $\text{C} + \text{CO}_2 \rightarrow 2\text{CO}$ makes the reducing agent, then carbon monoxide reduces the ore. Carbon monoxide, not solid carbon, is the reducing agent.

Metal plus dilute acid



Use for any metal above hydrogen in the reactivity series. Dilute hydrochloric acid gives a chloride and dilute sulfuric acid gives a sulfate; balance the salt using the metal's ionic charge, for example $\text{Zn} + \text{H}_2\text{SO}_4 \rightarrow \text{ZnSO}_4 + \text{H}_2$.

Displacement of copper by zinc



Use when a more reactive metal is placed in a solution of a less reactive metal's salt. Zinc is above copper in the reactivity series, so it takes the sulfate and pushes out copper metal. Iron behaves the same way: $\text{Fe} + \text{CuSO}_4 \rightarrow \text{FeSO}_4 + \text{Cu}$.

Metal plus cold water



Use only for the most reactive metals (potassium, sodium, calcium); the reaction is more vigorous higher up the series. A Group I metal follows $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$. Cold water gives a *hydroxide*, in contrast to the oxide formed with steam.

Metal plus steam



Use for a moderately reactive metal such as magnesium, which does little in cold water but reacts readily with steam: $\text{Mg} + \text{H}_2\text{O} \rightarrow \text{MgO} + \text{H}_2$. The product is an *oxide* because the water arrives as steam, not the hydroxide that cold water gives.

KEY CONCEPTS

- **Chemical reactions of metals:** Three standard reactions recur. Metal plus dilute acid gives a *salt plus hydrogen*. Metal plus cold water gives a *metal hydroxide plus hydrogen*, and only the most reactive metals (potassium, sodium, calcium) do this. Metal plus steam gives a *metal oxide plus hydrogen*, shown by a less reactive metal such as magnesium. In every case the gas released is hydrogen.
- **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 in the same way, by covering the surface so that 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,

overhead electrical cables 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), *malleable* (can be hammered or pressed into shape) and *ductile* (can be drawn into wire), and they generally have high melting and boiling points. Non-metals show the opposite pattern: they are poor conductors, dull, brittle when solid, and often have low melting points or are 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 acid. A more reactive metal displaces a less reactive metal from a solution of its salt.
- **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.
- **Carbon monoxide is the reducing agent:** In the blast furnace it is *carbon monoxide*, not solid carbon, that reduces the ore. Coke burns to carbon dioxide, which then reacts with more hot coke to make carbon monoxide; the carbon monoxide removes oxygen from iron(III) oxide. In $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$ the iron(III) oxide is *reduced* (it loses oxygen) and the carbon monoxide is *oxidised* to carbon dioxide.
- **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. Displacement is the reactivity series settling which metal keeps the compound.
- **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. The distorted layers can no longer slide over each other easily, so more force is needed to deform the metal, making the alloy harder and stronger.

EXAM TIPS

TIP A metal *above hydrogen* reacts with dilute acid to give hydrogen; a metal *below hydrogen* (copper, silver, gold) does not react with dilute acid. 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 boiled out, 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 A common exam error is to say "carbon reacts directly with the iron ore". The carbon's job is to make the carbon monoxide ($\text{C} + \text{CO}_2 \rightarrow 2\text{CO}$); the carbon monoxide then does the reducing. Reduction cannot happen first, because it needs carbon monoxide as a reactant and that is only made after the earlier reactions.

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). Both follow from the same picture of atom layers sliding over one another, but the exam awards the mark for the correct word, so keep them distinct.

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; the small loss in conductivity is outweighed by the large saving in weight.

19 Motion, forces and energy

KEY FORMULAS

Acceleration

$$a = \frac{\Delta v}{t}$$

Use to find the acceleration a from the change in speed Δv over a time t . The unit is metres per second squared (m/s^2). A deceleration is a negative acceleration, so carry the minus sign through.

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.

Change in gravitational potential energy

$$\Delta E_p = mgh$$

Use to find the change in gravitational potential energy when a mass m moves through a height h in a field of strength g . Convert any prefixed energy (kJ) to joules before rearranging.

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

Kinetic energy

$$E_k = \frac{1}{2}mv^2$$

Use to find the kinetic energy of a mass m moving at speed v . Because the speed is squared, doubling the speed multiplies the kinetic energy by four. Measured in joules (J).

Newton's second law

$$F = ma$$

Use to link the *resultant* force F (in newtons) on a mass m (in kilograms) to its acceleration a (in m/s^2). The resultant force and the acceleration always point the same way. Rearranges to $a = \frac{F}{m}$.

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 $1 \text{ W} = 1 \text{ J/s}$.

Pressure

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

Use to find the pressure p from a force F acting on an area A . Measured in pascals, where $1 \text{ Pa} = 1 \text{ N/m}^2$. 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 $g = 9.8 \text{ N/kg}$. Rearranges to $g = \frac{W}{m}$.

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.

Efficiency

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \times 100\%$$

Use to find what fraction of the input energy comes out usefully; the same formula works with powers in place of energies. Efficiency has no unit and is always the smaller quantity over the larger, so a value above 100% means the division is the wrong way round.

KEY CONCEPTS

- **Conservation of energy:** Energy is stored kinetically, gravitationally, 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 stays the same.
- **Distance-time and speed-time graphs:** On a *distance-time* graph the gradient is the *speed*: a horizontal line means at rest, a steeper line means a greater speed. On a *speed-time* graph the gradient is the *acceleration* and the area under the line is the *distance travelled*.
- **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* 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 is the same everywhere. *Weight* is the gravitational force on that mass, measured in newtons, and changes with the gravitational field strength g of the location.
- **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.
- **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 spreads the same weight over a large area and gives a small pressure.

- **Energy resources:** Useful energy is obtained from fossil fuels, biofuels, wind, waves, hydroelectric, and solar cells and panels, all 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 Moon's and Sun's gravity).
- **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 equals its volume). An object *sinks* in a liquid if it is denser than the liquid and *floats* if it is less dense, so floating depends on the relative densities.
- **Newton's first law, friction and drag:** *Newton's first law* states that an object stays at rest or keeps moving at constant velocity unless a resultant force acts. *Friction* opposes relative motion between surfaces and causes heating; *drag* is the friction of a fluid, such as air resistance, and it increases with speed. When drag grows to balance the weight of a falling object the resultant force is zero and the object falls at constant *terminal velocity*.

EXAM TIPS

TIP The phrases "constant speed", "constant velocity", "moving steadily" and "at rest" are all code for a *resultant force of zero*. Whenever you read them, balance the forces at once: a steady speed does not mean no forces, it means the forces cancel.

TIP An object falling freely near the Earth accelerates downward at $g \approx 9.8 \text{ m/s}^2$, the same value for every mass. Treat a *deceleration* as a negative acceleration: keep the minus sign in $a = \frac{\Delta v}{t}$ so that braking is handled by the arithmetic rather than by guesswork.

TIP On a speed-time graph the *gradient* answers "how quickly is the speed changing?" and the *area* answers "how far has it gone?". Decide which the question wants before using the numbers. Split the area into triangles and rectangles to find the distance.

TIP In $E_k = \frac{1}{2}mv^2$ the speed is squared, so doubling the speed multiplies the kinetic energy by four and trebling it multiplies by nine. Always square the speed *before* multiplying by the mass, and square only the speed, not the whole expression.

20 Movement into and out of cells

KEY FORMULAS

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 in a range of sucrose concentrations. A *positive* value means water moved in; a *negative* value means water moved out; a value near *zero* means the solution's water potential matches the tissue's. Percentage change is used, not raw change, so pieces of unequal starting mass can be compared fairly.

Surface area of a cube

$$\text{surface area} = 6L^2$$

Use to find the total exchange surface of a cube-shaped model (such as an agar cube) of side L . A cube has six identical square faces, each of area L^2 , so the surface area is $6L^2$. Combine with the volume to obtain the surface-area-to-volume ratio.

Surface-area-to-volume ratio of a cube

$$\text{surface area} : \text{volume} = \frac{6L^2}{L^3} = \frac{6}{L}$$

Use to show why small objects exchange substances by diffusion faster than large ones. For a cube of side L the ratio simplifies to $\frac{6}{L}$, so it *falls* as the cube grows: a 1 cm cube gives 6 : 1 but a 4 cm cube only 1.5 : 1. A large ratio means a short diffusion path relative to volume.

KEY CONCEPTS

- **Definition of active transport:** Active transport is the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration, *against* the concentration gradient, using energy from respiration. Its two defining features are the direction (low to high) and the need for energy.
- **Definition of diffusion:** Diffusion is the *net* movement of particles from a region of their higher concentration to a region of their lower concentration, down a concentration gradient, as a result of their random movement. The word *net* is essential: individual particles move in every direction, but overall more move from the crowded region to the sparse region than return.
- **Definition of osmosis:** Osmosis is the net movement of water molecules from a region of higher water potential to a region of lower water potential, through a *partially permeable* membrane. Only water crosses, because the membrane holds back the larger dissolved solute molecules.
- **Diffusion is a passive process:** Diffusion needs no energy input from the cell. It is driven only by the particles' own random *kinetic energy*, which is why it is described as *passive*. This is the key contrast with active transport, which does require energy from respiration.
- **Water potential:** Water potential is a measure of how free the water molecules in a solution are to move. Pure water has the *highest* water potential; dissolving a solute *lowers* it, because less water is free. Water always moves down the water potential gradient, from high to low.
- **Factors that affect the rate of diffusion:** Four factors change how fast diffusion occurs: a *steeper* concentration gradient speeds it up; a *higher* temperature gives particles more kinetic energy so they move faster; a *larger* surface-area-to-volume ratio allows more particles to cross per unit of volume supplied; and a *shorter* distance lets each particle complete its crossing sooner.
- **Importance of active transport: ion uptake by root hair cells:** Soil water is very *dilute* in mineral ions such as nitrate, while a root hair cell already holds these ions at a *higher* concentration. To absorb more, the cell must move ions against the gradient, so it uses *active transport* powered by respiration. This is why root hair cells contain *many mitochondria*, the site of most respiration, to supply the energy continuously.

- **Osmosis stated in terms of concentration:** Osmosis can also be defined as the net movement of water from a *dilute* solution (higher water potential) to a *more concentrated* solution (lower water potential), through a partially permeable membrane. The two definitions agree because a dilute solution has more free water and therefore a higher water potential.
- **Turgid, flaccid and plasmolysed:** A plant cell in a solution of *higher* water potential takes in water and becomes *turgid*: its contents press firmly on the rigid cell wall, which resists and stops the cell bursting. A cell that loses some water becomes soft, or *flaccid*. A cell in a *much* lower water potential loses so much water that the cell membrane pulls away from the cell wall; it is then *plasmolysed*.

EXAM TIPS

TIP An osmosis statement is correct only if all three features are right: it is *water* that moves (not solute), it moves from *dilute to concentrated* (down the water potential gradient), and it crosses a *partially permeable* membrane. Run each option past all three before choosing.

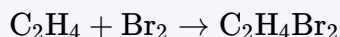
TIP A common trap names *active transport* but then describes it as moving *down* the gradient. The name alone earns nothing; the mark depends on the direction. Always confirm that active transport is described as moving particles from *lower to higher* concentration, against the gradient, using energy from respiration.

TIP When a question asks *why* diffusion happens, two marking points are almost always required: the *random movement* of the particles, and the *net movement down the concentration gradient*. Give the mechanism and the direction together; one without the other usually drops a mark.

TIP In a plant cell always name the *cell membrane* as the partially permeable barrier that controls osmosis. The cell wall is fully permeable and does not control water movement, so writing that water is controlled by the cell wall is a common wrong answer.

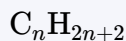
KEY FORMULAS

Addition of bromine to an alkene



Use for the reaction behind the bromine test. Bromine adds *across* the carbon-carbon double bond of ethene to give a single product, dibromoethane, with nothing else released. Because two reactants join to form one product, it is an *addition* reaction, and the orange-brown colour disappears.

General formula of the alkanes



Use to write or check the molecular formula of any alkane from its number of carbon atoms n . Methane is CH_4 ($n = 1$), ethane is C_2H_6 ($n = 2$) and propane is C_3H_8 ($n = 3$). A formula that does not fit $2n + 2$ hydrogens cannot be an alkane.

General formula of the alkenes



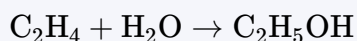
Use to write or check the molecular formula of any alkene from its number of carbon atoms n . Ethene is C_2H_4 ($n = 2$) and propene is C_3H_6 ($n = 3$). An alkene always has two fewer hydrogens than the alkane with the same number of carbons, because of its carbon-carbon double bond.

Complete combustion of a hydrocarbon fuel



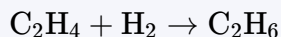
Use for the complete combustion of a hydrocarbon in a *plentiful* supply of oxygen, shown here for methane. The only products are *carbon dioxide* and *water*. In a limited supply of oxygen, incomplete combustion instead gives carbon monoxide and carbon (soot).

Hydration of an alkene to make ethanol



Use for the reaction of an alkene with *steam* in the presence of an *acid* catalyst (phosphoric acid). Water adds across the double bond of ethene to form ethanol in a single-product addition reaction. Remember the pairing: hydrogen needs a nickel catalyst, steam needs an acid catalyst.

Hydrogenation of an alkene



Use for the addition of *hydrogen* to an alkene in the presence of a *nickel* catalyst. Hydrogen adds across the double bond of ethene to form ethane, an alkane. It is an addition reaction because two molecules join to make a single product.

KEY CONCEPTS

- **Bonding and reactivity of alkanes:** In alkanes the bonding is *single covalent* throughout, so alkanes are *saturated* hydrocarbons. They are generally *unreactive*, except in terms of combustion: they burn in a plentiful supply of oxygen. This is why an alkane such as hexane does not react with dilute acids or with aqueous bromine.

- **Fossil fuels and hydrocarbons:** The three fossil fuels are *coal*, *natural gas* and *petroleum*. *Methane* is the main constituent of natural gas. A *hydrocarbon* is a compound that contains hydrogen and carbon only; petroleum is a *mixture* of hydrocarbons. A compound containing any other element, such as ethanol, is not a hydrocarbon.
- **Fractional distillation of petroleum:** Petroleum is separated into useful *fractions* by *fractional distillation*. The mixture is heated to vaporise it and fed into a fractionating column that is hot at the bottom and cooler at the top. Each fraction is a group of hydrocarbons with boiling points in a similar range; it condenses at the height where the temperature matches its boiling point.
- **Homologous series:** A *homologous series* is a family of similar compounds with similar chemical properties. Its members share the same *general formula*, differ from the next member by CH_2 , and show a steady trend in physical properties such as a rising boiling point as the chain gets longer.
- **Polymers and monomers:** A *polymer* is a large molecule built up from many smaller molecules called *monomers*. Poly(ethene) is a polymer made when many ethene molecules join together. The small repeating molecules are the monomers; the long molecule they build is the polymer.
- **Saturated and unsaturated compounds:** A *saturated* compound has molecules in which all carbon-carbon bonds are single bonds. An *unsaturated* compound has molecules in which one or more carbon-carbon bonds are not single bonds, that is, at least one carbon-carbon double bond is present. Saturated means the molecule holds as many hydrogen atoms as possible; unsaturated means it could add more.
- **The bromine test for unsaturation:** *Aqueous bromine* (bromine water) distinguishes a saturated from an unsaturated hydrocarbon. Added to an unsaturated hydrocarbon (an alkene) and shaken, the orange-brown bromine water is *decolourised*, turning from orange-brown to colourless. A saturated hydrocarbon (an alkane) leaves it orange-brown, because it has no double bond to react with.
- **The carbon-carbon double bond:** Every alkene molecule contains a *double* carbon-carbon covalent bond, written $\text{C} = \text{C}$. This double bond makes alkenes *unsaturated* hydrocarbons and is the reactive site: it can open up so that new atoms add across it. Ethene, C_2H_4 , is the simplest alkene.
- **Addition polymerisation of ethene:** The formation of poly(ethene) is an example of *addition polymerisation* using ethene (an alkene) monomers. Many ethene molecules join together as their carbon-carbon *double bonds open up*, with *no other product* formed. Only unsaturated monomers, which have a double bond, can polymerise this way.
- **Cracking:** *Cracking* is the breaking down of larger *alkane* molecules into smaller, more useful molecules, using a *high temperature* and a *catalyst*. It produces smaller alkanes plus *alkenes* (and hydrogen). Cracking matches supply to demand: it converts long-chain fractions that are in surplus into shorter-chain fuels and into alkenes needed as a feedstock.
- **General characteristics of a homologous series:** The members of a homologous series share the *same general formula*, so consecutive members differ by CH_2 . They show a *trend in physical properties*, most usefully a boiling point that rises steadily as the chain lengthens. They also have *similar chemical properties*, because every member has the same reactive feature. A single formula fitting the general formula is not enough on its own; the trend and shared chemistry complete the definition.
- **Trends from the bottom to the top of the column:** Moving *up* the fractionating column, the fractions have *shorter* hydrocarbon chains and *lower* boiling points, so they condense higher up where it is cooler. Moving *down*, the chains are longer and the boiling points higher. The longest, densest fractions that do not vaporise leave at the very bottom.

EXAM TIPS

TIP For a hydrocarbon with n carbon atoms, $2n + 2$ hydrogens means an alkane (saturated) and $2n$ hydrogens means an alkene (unsaturated). So C_4H_{10} is an alkane but C_4H_8 is an alkene. Always compare the hydrogen count with the saturated value $2n + 2$ before naming the family.

TIP In this course an alkane's only reaction is *combustion*. It does not add bromine, does not react with acids and does not undergo addition. So the bromine test never changes with an alkane. The one thing an alkane reliably does is burn, giving carbon dioxide and water when oxygen is plentiful.

TIP The examinable uses are: *refinery gas* for heating and cooking; *gasoline* (petrol) for cars; *naphtha* as a chemical feedstock; *diesel oil* (gas oil) for diesel engines; and *bitumen* for making

roads. Refinery gas sits at the top of the column and bitumen at the bottom, matching the shortest and longest chains.

TIP Alkenes are reactants in *addition* reactions. Fix the three conditions: bromine adds at room temperature and decolourises the orange-brown (not turning it orange); hydrogen adds with a *nickel* catalyst; steam adds with an *acid* catalyst. A statement that an alkene reacts with hydrogen or steam without a catalyst is wrong.

22 Organisms and their environment

KEY CONCEPTS

- **A food chain shows the transfer of energy:** 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 (prey → predator).
- **Carbon is recycled through five processes:** Unlike energy, *carbon is recycled* endlessly between the atmosphere and living organisms. The syllabus limits the carbon cycle to 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: 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 → producers → consumers → environment. Energy is not recycled, so new energy must keep arriving from the Sun.
- **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 through *photosynthesis*, using energy from light; 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 energy, not about being a plant or an animal: a producer makes food, a consumer takes food.
- **The Sun is the principal source of energy:** The *Sun* is the principal source of energy input to biological systems. Sunlight is not eaten directly; it is captured by producers during *photosynthesis*, which converts light energy into chemical energy stored in organic nutrients such as glucose. Read "principal source" as where the energy originally came from, so even the energy in a lion traces back through its prey to sunlight.
- **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 (it is a herbivore); a *secondary consumer* eats the primary consumer; a *tertiary consumer* eats the secondary consumer. For example, in grass → grasshopper → bluebird → snake, the grass is the producer, the grasshopper is the primary consumer, the bluebird is the secondary consumer and the snake is the tertiary consumer.
- **A food web is a network of food chains:** In a real habitat most animals eat more than one kind of food and most organisms are eaten by more than one predator, so a single straight-line chain is a simplification. A *food web* is a network of interconnected food chains, showing all the feeding relationships in a community at once. One producer usually supports many consumers, and one predator usually feeds on several prey species.
- **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 matter is recycled.
- **What each carbon-cycle 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. This is why deforestation raises atmospheric carbon dioxide: fewer trees means less photosynthesis removing it.

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 Herbivores, carnivores and the primary, secondary and tertiary levels are all *kinds* of consumer. Do not treat "consumer" and "carnivore" as interchangeable: every carnivore is a consumer, but not every consumer is a carnivore. An animal can even feed as a herbivore in one relationship and a carnivore in another, because the terms describe a feeding relationship rather than a fixed identity.

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. A sealed system with no sunlight cannot keep going indefinitely, because energy is still lost to the surroundings and no new energy arrives to replace it.

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 secondary consumer in one chain and a tertiary consumer in another, depending on what it is eating. When an animal appears in several chains within a web, trace each separate chain back to the producer and count the steps for that chain specifically.

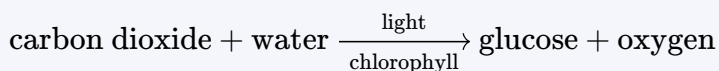
KEY FORMULAS

Balanced symbol equation for photosynthesis



Use at Extended level when a symbol equation is asked for. Glucose has 6 carbon and 12 hydrogen atoms, so 6 carbon dioxide and 6 water molecules are needed; 6 oxygen molecules are released. Every atom balances, obeying conservation of mass.

Word equation for photosynthesis



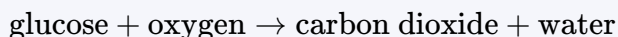
Use to state the reaction in words. Carbon dioxide and water are the reactants on the left; glucose and oxygen are the products on the right. Light and chlorophyll are conditions written on the arrow, never listed as reactants. Reversing the equation gives respiration.

Rate of photosynthesis from gas collected

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

Use in the pondweed experiment, where the volume of oxygen collected in a fixed time measures the rate. A larger volume in the same time means a faster rate. Keep the time interval the same when comparing conditions such as lamp distance.

Respiration is the reverse of photosynthesis



Use to check the direction of the photosynthesis equation. This reversed equation is aerobic respiration. If an answer choice has glucose and oxygen on the left, it describes respiration, not photosynthesis.

KEY CONCEPTS

- **Chlorophyll and chloroplasts:** *Chlorophyll* is a green pigment found inside *chloroplasts* that absorbs light energy and *transfers* it into chemical energy for the synthesis of carbohydrates. It is not used up and does not become part of the glucose. The chlorophyll is the pigment; the chloroplast is the organelle that contains it.
- **Definition, raw materials and products:** *Photosynthesis* is the process by which plants synthesise carbohydrates from the raw materials carbon dioxide and water, using energy from light. The raw materials are *carbon dioxide* (from the air) and *water* (from the roots). The products are *glucose*, a carbohydrate that stores energy and is the plant's food, and *oxygen*, released as a by-product.
- **Tissues of a dicotyledonous leaf, top to bottom:** From the upper surface down: *waxy cuticle* (thin, transparent, waterproof, reduces water loss); *upper epidermis* (single transparent layer, no chloroplasts); *palisade mesophyll* (tall column cells with the most chloroplasts, most photosynthesis); *spongy mesophyll* (rounded cells with large air spaces for gas exchange); *vascular bundles* containing xylem and phloem; *lower epidermis* with many *stomata*, each controlled by a pair of *guard cells*.
- **Limiting factors control the rate:** The rate of photosynthesis is affected by *light intensity*, *carbon dioxide concentration* and *temperature*. At any moment the rate is set by whichever factor is in shortest supply, the *limiting factor*. Raising the limiting factor increases the rate; raising a factor already in plentiful supply has little effect. Temperature has an *optimum*, above which the rate falls as the enzymes are disrupted by heat.
- **Palisade and spongy mesophyll compared:** The *palisade mesophyll* has tall, tightly packed cells with the most chloroplasts, placed just under the transparent upper surface to absorb the strongest

light. The *spongy mesophyll* has rounded, loosely packed cells with large air spaces that give a short diffusion path and a large internal surface area for gas exchange. Both layers contain chloroplasts and can produce oxygen in light.

- **Testing a leaf for starch:** A photosynthesising leaf converts glucose to starch, so the starch test shows where photosynthesis has occurred. First *destarch* the plant by keeping it in the dark for 24 to 48 hours, so any starch found afterwards was made during the experiment. To test: dip the leaf in boiling water to kill it, boil it in ethanol to remove the green chlorophyll, rinse it, then add iodine solution. A blue-black colour shows starch is present.
- **Xylem and phloem in a leaf vein:** A vascular bundle, or vein, contains two transport tissues. The *xylem* carries water and mineral ions *up* to the leaf, supplying a raw material for photosynthesis, and usually lies on the upper side of the bundle. The *phloem* carries the sugars made in photosynthesis *away* to the rest of the plant for use and storage.

EXAM TIPS

TIP When a question asks for the *raw materials*, give carbon dioxide and water, never light or chlorophyll. Light is the energy source and chlorophyll is the pigment that captures it; neither is used up nor built into the glucose, so neither is a raw material.

TIP Energy cannot be created, only transferred. Chlorophyll *absorbs* light energy and *transfers* it into chemical energy for building carbohydrates. Answers such as "chlorophyll makes energy" or "gives the plant energy" do not score; the mark is for the verb *transfer*.

TIP Write light above the arrow and chlorophyll below it. They are needed for the reaction but are neither used up nor produced, so they must not appear among the reactants. An examiner will not accept an equation with light written as a reactant on the left.

TIP Stomata sit mainly in the lower epidermis because the underside of the leaf is cooler and shaded. Gas exchange can still occur there while less water is lost by evaporation than would be lost from the brightly lit, warmer upper surface.

KEY CONCEPTS

- **Parts of an insect-pollinated flower:** The male part is the *stamen*, made of an *anther* (makes and releases pollen grains) on a *filament* (a stalk that holds the anther where an insect brushes it). The female part is the *carpel*: a *stigma* (sticky top that receives pollen), a *style* (stalk the pollen tube grows down) and an *ovary* (holds the ovules). *Petals* and *nectaries* attract insects; *sepals* protect the bud.
- **The female reproductive system:** The *ovary* produces and releases egg cells (the female gametes). The *oviduct* carries the 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; its lining thickens each cycle. 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 body that keeps it slightly cool. The *sperm duct* carries sperm towards the urethra. The *prostate gland* adds fluid; sperm plus fluid 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: the pollen grain grows a *pollen tube* down the style to an ovule, then the nuclei fuse. The fertilised 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*. It normally takes place in the *oviduct*: sperm swim up through the uterus into the oviduct, where one sperm nucleus fuses with the egg nucleus to form a single cell called a *zygote*, which divides to form an embryo.
- **What pollination is:** *Pollination* is the transfer of pollen grains from an *anther* to a *stigma*. It is only a *movement* of pollen: it says nothing about fertilisation, seeds or the pollen being the right species. Pollen simply has to arrive at a stigma.
- **Conditions a seed needs to germinate:** *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 aerobic respiration to release energy) and a *suitable warm temperature* (so the enzymes work fast enough). *Light is not needed*, because the seedling lives on the seed's own food store until it reaches the light.
- **Insect-pollinated versus wind-pollinated flowers:** An *insect-pollinated* flower is built to be found and brushed: large brightly coloured petals, scent, nectar, and anthers and sticky stigmas held *inside*, with large sticky pollen grains. A *wind-pollinated* flower is built for exposure: small dull petals or none, no scent or nectar, anthers and large feathery stigmas held *outside*, with small light smooth pollen made in huge amounts because most is wasted.
- **The menstrual cycle:** The menstrual cycle is a roughly *28-day* cycle. At Extended level describe the changes in the *ovary* and the *uterus lining*. Days 1 to 5: the lining breaks down and is shed as a period (thinnest). 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, then breaks down again if no fertilisation occurs.

EXAM TIPS

TIP These are the easiest marks in the chapter to lose by reversing them. The *anther* is the male part that *makes and releases* pollen; the *stigma* is the female part that *receives* it. Anther to stigma is the direction of every pollination.

TIP Keep the three female "places" 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 the pollen is the wrong species or the ovule is destroyed, no seed forms. Never treat "pollinated" as proof that a seed will follow.

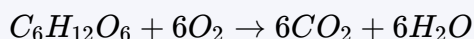
TIP Day 1 of the cycle is the first day of the period, when the lining is already breaking down. So across a cycle the uterus lining *decreases first, then increases*: it thins during menstruation, then

thickens ready to receive a fertilised egg. Reading it as "thickens first" is a common trap.

25 Respiration

KEY FORMULAS

Balanced symbol equation for aerobic respiration



Use for the Extended chemical form of aerobic respiration. Glucose is $C_6H_{12}O_6$ and oxygen is O_2 . The coefficients 1 : 6 : 6 : 6 balance the atoms and set the reacting ratios used in every calculation.

Word equation for aerobic respiration



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

Converting an amount in moles to a mass

$$\text{mass} = \text{moles} \times M_r$$

Use after finding the moles of a product to convert to a mass in grams. M_r is the mass of one mole; for water $M_r = 18$ and for carbon dioxide $M_r = 44$. Find the moles from the equation ratio first, then multiply by M_r .

Finding the amount of a product from the balanced equation

$$\text{moles of product} = \text{moles of glucose} \times \text{coefficient ratio}$$

Use to find how much carbon dioxide or water forms when a known amount of glucose is respired. Read the ratio straight from the coefficients: glucose to carbon dioxide and glucose to water are both 1 : 6, so multiply the moles of glucose by 6.

KEY CONCEPTS

- **Aerobic respiration and its site:** Aerobic respiration is the series of reactions that use *oxygen* to break down nutrient molecules, releasing energy and producing carbon dioxide and water. Its main site is the *mitochondria*. It is a continuous series of reactions, not a single event, so a cell is respiring at all times while it is alive.
- **Definition of respiration:** Respiration is the set of chemical reactions in cells that break down nutrient molecules to release energy. The fuel broken down is a nutrient molecule, most importantly *glucose*; oxygen is a reactant used to do the breaking down, and carbon dioxide and water are products, not fuels. Respiration happens continuously inside every living cell.
- **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.
- **Uses of the energy released by respiration:** The energy released by respiration is used for: *muscle contraction* to produce movement; *building large molecules from smaller ones*, for example joining amino acids into proteins during growth; *active transport* of substances against a concentration gradient; and *maintaining a constant body temperature* in mammals and birds by releasing heat.
- **Respiration compared with photosynthesis:** Respiration and photosynthesis are near opposites. Respiration *uses up* oxygen and glucose and *releases* energy, happening in all living cells at all times. Photosynthesis *produces* oxygen and glucose and *stores* energy, happening only in cells with chloroplasts and only in the light.

- **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 muscle cells, sperm cells and liver cells are packed with mitochondria: more mitochondria mean more respiration and so more energy released.

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 diffusion of oxygen and carbon dioxide across a surface. A question that asks what is *broken down* in respiration wants nutrient molecules such as glucose, never oxygen.

TIP Respiration *uses up* glucose and oxygen and *makes* carbon dioxide and water. Writing "carbon dioxide and water make glucose and oxygen" gives photosynthesis instead. Fix the direction by saying "glucose and oxygen make carbon dioxide and water, releasing energy" in that fixed order every time.

TIP To find a product from the balanced equation, *multiply* the moles of glucose by the coefficient ratio. A common error is to divide: 0.5 mol of glucose gives $0.5 \times 6 = 3$ mol of carbon dioxide, not $0.5 \div 6$. Match the known amount to the amount you want, then scale up by the ratio.

TIP Diffusion and osmosis are passive and need no energy from respiration. Only *active transport*, which moves substances against a concentration gradient, is powered by the energy respiration releases. A question describing movement down a gradient is testing whether you will wrongly credit respiration.

KEY FORMULAS

Orbital period

$$T = \frac{2\pi r}{v}$$

Rearrangement of the orbital-speed equation used when the orbital speed v and radius r are known and the period is required. If r is in km and v in km/s the kilometres cancel and T comes out directly in seconds.

Orbital speed

$$v = \frac{2\pi r}{T}$$

Use to find the speed of an object in a circular orbit, where r is the orbital radius and T the orbital period. In one period the object travels one full circumference $2\pi r$. Work in SI units (m, s, m/s) unless the data are given in consistent km and km/s.

Distance travelled in one orbit

$$\text{circumference} = 2\pi r$$

Use to find the distance an orbiting object covers in one complete period. Dividing this circumference by the period T gives the orbital speed, which is why $v = 2\pi r/T$ and not $v = r/T$.

Orbital radius

$$r = \frac{vT}{2\pi}$$

Rearrangement used when the orbital speed v and period T are known and the radius is required. The result is measured from the centre of the central body; subtract the body's radius to obtain a height above its surface.

KEY CONCEPTS

- **Classifying objects by what they orbit:** Classify a 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, because 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 four inner planets are small and rocky and the four outer planets are large gas giants. The *asteroid belt* lies between Mars and Jupiter.
- **The life cycle of a star:** Every star begins the same way: gravity pulls an interstellar cloud of gas and dust (a *nebula*) into a *protostar*, which becomes a stable star when fusion begins. The ending depends on 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* held together by its own gravity. It radiates most of its energy in the *infrared, visible and ultraviolet* regions. Its energy comes from *nuclear fusion* in the core, in which hydrogen nuclei join to form helium.
- **What the Solar System contains:** The Solar System is the Sun together with everything held in orbit around it by the Sun's gravity. It contains exactly *one star*, the Sun; *eight planets*; *minor planets* that orbit the Sun directly, namely dwarf planets (such as Pluto) and the asteroids of the asteroid belt; and *moons* that orbit the planets.

- **Why the planets orbit the Sun:** The Sun contains most of the mass of the Solar System, so it produces a strong gravitational field. The force that keeps each planet in orbit is the *gravitational attraction of the Sun*, which always points from the planet towards the Sun. Because the Sun's mass so dominates, the planets orbit the almost-stationary Sun. A moon orbits its planet by the same mechanism, using the gravitational attraction of the planet.
- **Field strength and orbital speed change with distance:** The Sun's gravitational field strength *decreases* with distance from the Sun. A weaker field provides a smaller inward pull, which can only sustain a *lower* orbital speed for a stable orbit. So moving outward from the Sun, both the gravitational field strength and the orbital speed decrease: Mercury orbits fastest, Neptune slowest.
- **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*, which is about *100 000 light-years* across and is one of many billions of galaxies in the Universe. Every other star in the Milky Way is much further from Earth than the Sun.
- **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, between Mars and Jupiter, marks the boundary between the rocky inner planets and the gaseous outer planets.
- **Nuclear fusion versus nuclear fission:** In *fusion*, small nuclei join to form a larger nucleus, as when hydrogen forms helium in the Sun's core; it needs extreme temperature and pressure. In *fission*, a large unstable nucleus such as uranium splits into smaller nuclei, as in a nuclear power station. Fusion joins, fission splits.
- **The Big Bang and the expanding Universe:** The *Big Bang Theory*, supported by many astronomical observations, states that the Universe expanded from a single point of very high density and temperature, is *still expanding* today, and is about *13.8 billion years* old. The observation that distant galaxies are moving apart is the key evidence for this expansion.
- **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. It is not a time. Light-travel time equals the distance in light-years, so a star 50 light-years away is seen as it was 50 years ago. Because light travels at a constant speed, travel time is directly proportional to distance.

EXAM TIPS

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

TIP In every orbital calculation, write the rearranged formula first, substitute with units, then evaluate. The orbital radius r is measured from the *centre* of the central body, so subtract the body's radius to find a height above its surface. Convert hours to seconds ($\times 3600$) and kilometres to metres ($\times 1000$) before substituting.

TIP To keep the two nuclear processes apart, remember *fuSe* = *join* and *fISSion* = *split* (picture a nucleus splitting into pieces). The Sun is powered by fusion; a nuclear power station on Earth by fission.

KEY CONCEPTS

- **Particle model of the three states:** Describe every state by *separation*, *arrangement* and *motion*. Solid: particles very close in a regular, ordered pattern, only vibrating about fixed positions. Liquid: particles close together but randomly arranged, sliding past one another. Gas: particles far apart and randomly arranged, moving quickly in all directions. Liquid and solid particles are about equally close; the large jump in separation is between liquid and gas.
- **Temperature, kinetic energy and forces of attraction:** *Temperature* measures the average kinetic energy of the particles, so a higher temperature means the particles move faster on average. *Forces of attraction* hold particles together; they are strong in a solid and a liquid, where particles are close, and negligible in a gas, where particles are far apart. A change of state happens when the particles gain or lose enough energy to overcome, or be captured by, these forces.
- **The five changes of state:** *Melting* is solid to liquid on heating, at the melting point. *Freezing* is liquid to solid on cooling. *Boiling* is liquid to gas throughout the whole liquid, at the boiling point. *Condensing* is gas to liquid on cooling. *Evaporating* is liquid to gas from the surface only, at any temperature below the boiling point. Heating adds energy to the particles; cooling removes it.
- **The three states of matter and their properties:** A *solid* has a fixed shape and a fixed volume and cannot be poured or compressed. A *liquid* has a fixed volume but no fixed shape, so it flows and takes the shape of its container, yet like a solid it barely compresses. A *gas* has neither a fixed shape nor a fixed volume; it spreads to fill any container and can be compressed considerably. Fixed volume separates a liquid from a gas; fixed shape separates a solid from a liquid.
- **Why a gas exerts pressure:** The particles of a gas move constantly and rapidly in random directions, so they collide with the walls of the container many times each second. Each collision exerts a small force on the wall, and the combined effect of an enormous number of collisions is the overall *pressure* of the gas. Pressure is caused by these collisions, not by particles attracting the walls.
- **Boiling compared with evaporating:** Both are changes from liquid to gas, but they differ in three ways. Boiling happens throughout the whole liquid, with bubbles forming inside it, only at the boiling point, and is fast. Evaporating happens only at the surface, at any temperature below the boiling point, and is slow. A puddle drying on a cool day is evaporation from the surface, not boiling.
- **Effect of temperature and pressure on the volume of a gas:** Heating a fixed mass of gas at constant pressure increases its volume: the faster particles need more room, so the gas expands to keep the collision rate per unit wall area constant. Increasing the pressure on a fixed mass of gas at constant temperature decreases its volume: the same particles are squeezed into a smaller space. Heating a gas in a rigid, constant-volume container instead raises its pressure.
- **State symbols in chemical equations:** 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. So NaCl(s) is solid sodium chloride and NaCl(aq) is salt dissolved in water. The symbol (aq) is not a fourth state of matter; it labels a substance dissolved in water.

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. Likewise boiling and condensing occur at the boiling point. Cross the melting point and the substance swaps between solid and liquid; cross the boiling point and it swaps between liquid and gas.

TIP Do not write that liquid particles are spread out. Melting barely changes the particle spacing, so a liquid is nearly as dense as its solid. The big increase in separation occurs only when a liquid boils into a gas, which is why boiling needs much more energy than melting.

KEY FORMULAS

Charge balance in an ionic compound

total positive charge = total negative charge

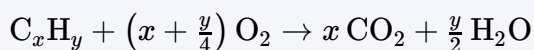
Use to build the formula of an ionic compound from its ions. Multiply each ion's charge by the number of that ion present, then choose the smallest whole numbers that make the two totals equal. For Ca^{2+} and OH^- this needs two hydroxide ions per calcium, giving $\text{Ca}(\text{OH})_2$.

Conservation of mass in a reaction

total mass of reactants = total mass of products

Use to check a reaction or find an unknown mass. Since the atoms are only rearranged, the total mass in a sealed flask does not change during a reaction. This is the same rule that forces a symbol equation to have equal atom counts on each side.

Balancing the combustion of a hydrocarbon



Use to balance the complete combustion of a hydrocarbon. Balance carbon first, then hydrogen, then oxygen last because oxygen is the only element appearing in both products. Double every coefficient at the end if a fraction remains, so that all coefficients are whole numbers.

Partner swap in double decomposition



Use to predict the products when two compounds in solution exchange partners, as in a precipitation or a neutralisation. The two positive parts swap their negative partners. Silver nitrate plus sodium chloride gives silver chloride plus sodium nitrate.

KEY CONCEPTS

- **Balancing a symbol equation:** A *symbol equation* replaces names with formulas and must have the same number of atoms of every element on both sides, because atoms are never created or destroyed. You balance only by placing *coefficients*, the large numbers in front of formulas; you may never change a subscript inside a formula. Changing H_2O to H_2O_2 makes a different substance rather than balancing the equation.
- **Formulas you are expected to know on sight:** Some formulas are vocabulary and have no derivation: water H_2O , carbon dioxide CO_2 , carbon monoxide CO , ammonia NH_3 and methane CH_4 ; the acids hydrochloric HCl , nitric HNO_3 and sulfuric H_2SO_4 ; and the *diatomic* elements H_2 , O_2 , N_2 and Cl_2 . You use these to build equations throughout the Chemistry strand, so learn them cold.
- **State symbols:** A *state symbol* in brackets after a formula gives the physical state of that substance: (s) solid, (l) pure liquid, (g) gas, (aq) aqueous, meaning dissolved in water. They are added after the equation is balanced. For magnesium ribbon burning in oxygen: $2\text{Mg}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{MgO}(\text{s})$.
- **What a molecular formula tells you:** The *molecular formula* states the number and type of atoms in one molecule. It is a headcount only: C_3H_8 means one molecule holds 3 carbon atoms and 8 hydrogen atoms bonded together. It does not state a mass, a mixture or a charge. A subscript applies only to the symbol directly in front of it, and a subscript of 1 is never written.
- **Word equations:** A *word equation* names the reactants and products and shows the direction of change with an arrow. Reactants, the starting substances, go on the left; products, the substances formed, go on the right. There is no balancing and no formulas: you are only naming substances and placing them on the correct side of the arrow.

- **Deducing a formula from a diagram:** When a model shows balls joined by sticks, count how many atoms of each type appear in *one* molecule and write each symbol with its count as a subscript. The trap is a diagram that draws two or more separate molecules side by side: a molecular formula describes one molecule only, so count a single molecule and ignore the identical copies. Two separate CCl_4 molecules are still CCl_4 , never C_2Cl_8 .
- **Ionic equations and spectator ions:** An *ionic equation* shows only the ions that actually take part in the reaction. A *spectator ion* is one that is present as (aq) on both sides of the full equation and is left unchanged, so it is cancelled. What remains is the real chemical change, usually two ions joining to form an insoluble solid, as in $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$.

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. A large share of balancing errors come from writing a single O instead of O_2 , which makes the equation impossible to balance correctly.

TIP A subscript written immediately outside a bracket multiplies *every* atom inside that bracket, not just the last one. In $\text{Ca}(\text{OH})_2$ the 2 gives two oxygen and two hydrogen atoms, so the unit is 1 Ca, 2 O, 2 H. Multiply the bracket out fully before counting; $\text{Al}_2(\text{SO}_4)_3$ is 2 Al, 3 S and 12 O.

TIP A subscript defines the identity of a substance, so altering it produces a different compound rather than a balanced equation. Balance only by adding coefficients in front of whole formulas. Writing Cu_2O_2 instead of using the coefficient 2CuO invents a substance that does not exist.

KEY FORMULAS

Displacement of a less reactive halogen



Use when a more reactive halogen is added to a halide of a less reactive one; here chlorine displaces bromine from potassium bromide. The displaced bromine dissolves to give an *orange* solution of aqueous bromine, the visible sign of reaction. A halogen can only displace one *below* it in the group, never one above.

Reaction of a Group I metal with water



Use for the reaction of an alkali metal with water; sodium is shown here. The products are always the metal hydroxide (an alkali) plus hydrogen gas, and the reaction grows more vigorous down the group. Balance both atoms and charge: two metal atoms are needed to match the two hydroxides and release one H_2 molecule.

Reaction of potassium with water



Use for potassium, the most reactive of the three named alkali metals, reacting with water. It gives potassium hydroxide and hydrogen, and reacts fast enough to ignite the hydrogen with a *lilac* flame. The equation has the same shape as for any Group I metal: two metal atoms per two water molecules, one H_2 released.

The halogens are diatomic molecules



Use to write any halogen as an element: each exists as a *diatomic* molecule of two atoms, shown by the subscript 2. Carry the subscript through every equation, for example in displacement reactions, so the atoms balance. Writing a bare Cl or I for the free element is a common lost mark.

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.
- **Metallic to non-metallic character across a period:** Moving left to right across a period, the elements change steadily from *metallic* to *non-metallic* character. Reactive metals sit on the left, non-metals on the right, and semi-metals of intermediate character lie between them. Electrical conductivity falls across the period: metals conduct well, semi-metals only weakly, non-metals essentially not at all. A clean anchor is Period 3, running sodium (metal) to silicon (semi-metal) to chlorine (non-metal).
- **Order and layout of the Periodic Table:** Elements are arranged in order of *increasing proton number* (atomic 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 therefore share 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 that are good electrical conductors. Going *down* the group three trends hold: melting point *decreases*, density *increases*, and reactivity with water *increases*. Each reacts with water to give a metal hydroxide (an alkali) and hydrogen gas, 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.
- **The four Group VII trends and the displacement rule:** Four trends run down Group VII. Three point the same way, one is opposite: density *increases*, melting point *increases*, colour *darkens*, but reactivity *decreases*. Reactivity falling down the group gives the halogens their signature reaction: a *more reactive halogen displaces a less reactive one from a solution of its halide*. Chlorine displaces bromine and iodine, bromine displaces iodine only, and iodine displaces neither.

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 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 Because elements in a group share the same number of outer electrons, their properties change gradually down the column, so an unfamiliar element can be predicted by extending a known trend. Work *position first, property second*: locate the element in its group and period, identify the direction of the trend (write it as an arrow), then extend it one step further by a comparable amount.

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, melting point and colour-intensity all rise down both groups, so only reactivity flips direction. The halogens react by *gaining* an electron, and lower down the group that electron is added further from the nucleus and attracted less strongly, so reaction is harder.

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 occur in solids. Fluid near the heat source is warmed and expands, becoming *less dense* than the fluid around it, so it rises. Cooler, denser fluid sinks to take its place and is warmed in turn, setting up a circulating *convection current* that carries energy through the whole fluid.
- **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 of those left behind falls, so the temperature of the remaining liquid falls. This is why evaporation has a cooling effect, as with sweat on skin.
- **How a gas exerts pressure:** The particles of a gas move quickly in random directions and continually collide with the walls of the container. Each collision exerts a small force on the wall, and the total force of all these collisions per unit area of wall is the *pressure* of the gas. The pressure is caused by the collisions, not by the weight of the gas pressing down.
- **Temperature and the motion of particles:** *Temperature* is a measure of the average kinetic energy of the particles. Heating a substance increases that average kinetic energy, so the particles move faster on average: in a solid they vibrate more vigorously about fixed positions, and in a liquid or gas they move around more quickly. The particles themselves do not grow or gain temperature; they simply move faster and, on average, spread a little further apart.
- **The three states and the particle model:** Describe every state by *separation*, *arrangement* and *motion*. A solid has particles very close in a regular pattern, vibrating about fixed positions, giving a fixed shape and fixed volume. A liquid has particles close together but irregularly arranged, sliding past one another, giving a fixed volume but no fixed shape. A gas has particles far apart and randomly arranged, moving quickly in all directions, so it fills its container and is easily compressed. Solid and liquid particles are about equally close; the large jump in separation is between liquid and gas.
- **Thermal conduction in metals:** *Conduction* is the transfer of thermal energy through a material without the material itself moving, and it is the main way energy travels through solids. In all solids, heated particles vibrate more and pass energy to their neighbours by collisions. In metals there is a second, much faster route: *free (delocalised) electrons* gain energy at the hot end, move through the metal and carry energy quickly to the cooler end. These free electrons are why metals are such good thermal conductors.
- **Thermal expansion of solids, liquids and gases:** When matter is heated its particles move faster and, on average, take up a little more room, so the material expands; cooling makes it contract. For the same rise in temperature a gas expands the most and a solid the least, because the forces between particles are weakest in a gas and strongest in a solid. Different solids expand by different amounts, which is why a bimetallic strip bends when heated.
- **Thermal radiation and the surface:** *Thermal radiation* is the transfer of thermal energy by electromagnetic waves, mainly *infrared*, and it needs no medium, so it can travel through a vacuum. The surface controls how well an object emits, absorbs and reflects it: dull, black surfaces are good absorbers and good emitters, while shiny, light surfaces are poor absorbers and emitters and so are good reflectors. The same dull black surface is both the best absorber and the best emitter.
- **Changing the pressure of a fixed mass of gas:** For a fixed mass of gas the pressure can be changed two ways. Heating at constant volume gives the particles more energy so they move faster, hitting the walls more often and harder, which raises the pressure. Compressing at constant temperature does not change the particle speed, but the same particles in a smaller volume hit the walls more often, which also raises the pressure. Be precise about which mechanism applies: only heating changes the particle speed.
- **Emitters, absorbers and reflectors of radiation:** The best absorbers and emitters of thermal radiation are *dull, black* surfaces; the best reflectors are *shiny, light* surfaces, which are poor absorbers and emitters. A good emitter loses thermal energy quickly, so a dull black object cools faster than a shiny one, while a good absorber warms quickly under a heater. To compare two surfaces fairly, keep everything except the surface identical.
- **Factors affecting the rate of evaporation:** Three factors increase the rate of evaporation, all by helping more energetic particles escape from the surface each second. A higher *temperature* means more surface particles have enough energy to escape. A larger *surface area* exposes more particles

able to escape. Greater *air movement* over the surface carries escaped vapour away, so fewer particles return. A puddle therefore dries fastest when it is warm, spread thin and in a breeze.

- **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. Two different routes turn a liquid into a gas: *boiling* happens throughout the whole liquid, only at the boiling point, while *evaporation* happens only at the surface and at any temperature below the boiling point. Heating supplies the energy that lets particles break free; cooling removes energy so they come back together.

EXAM TIPS

TIP For any question that asks you to describe 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 three-mark habit and stops you losing marks for a partial description.

TIP When explaining why evaporation cools a liquid, say that the *fastest* or *most energetic* particles escape, 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 A complete convection answer is a chain: the fluid *expands*, becomes *less dense*, then *rises*, and cooler denser fluid *sinks* to replace it. Missing the density step is the most common way to drop the mark, so always link expansion to a fall in density before saying the fluid rises.

KEY CONCEPTS

- **Comparing arteries, veins and capillaries:** The three vessel types are compared using three structural features: *wall thickness*, *lumen diameter* and the *presence of valves*. An *artery* has a thick muscular wall, a narrow lumen and no valves. A *vein* has a thinner wall, a wide lumen and valves. A *capillary* has a wall one cell thick and a tiny lumen for exchange.
- **Direction rule for arteries and veins:** *Arteries carry blood away from the heart; veins carry blood back to the heart*. The rule is set by direction, not by oxygen: the pulmonary artery is still an artery even though it carries deoxygenated blood, because it carries that blood away from the heart.
- **Red and white blood cells:** A *red blood cell* is a biconcave disc with *no nucleus*, leaving maximum room for *haemoglobin*, the protein that binds oxygen in the lungs and releases it in the tissues. A *white blood cell* is larger, less numerous and *has a nucleus*; it defends the body by phagocytosis and by producing antibodies.
- **Structure of the mammalian heart:** The heart is a muscular double pump with *four chambers*: two upper *atria* receive blood returning to the heart and two lower *ventricles* pump blood out. The *left ventricle* has the thickest wall because it pumps blood at high pressure all the way around the body. *Coronary arteries* branch across the outer surface and supply the heart muscle itself with oxygenated blood.
- **The circulatory system: vessels, a pump and valves:** A circulatory system is described using three structures working together: *blood vessels* form the pathway around which blood travels, 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.
- **Vessel structure matches blood pressure:** Each vessel feature follows from the pressure of the blood it carries. An artery carries blood at *high pressure*, so its thick, muscular, elastic wall withstands the pressure and its narrow lumen keeps it high. A vein carries blood at *low pressure*, so a wide lumen lowers resistance and valves stop the blood falling backward under gravity.
- **Coronary heart disease:** In coronary heart disease a coronary artery becomes *narrowed or blocked*, usually by a build-up of fatty material in its wall. Because the coronary arteries supply the heart muscle itself, less blood and less oxygen then reach that muscle, so it cannot contract as well; a complete blockage can kill the muscle beyond it.
- **Effect of physical activity on heart rate:** During physical activity the muscles respire faster and need more oxygen and glucose, so the *heart rate increases*. A faster heart pumps more blood each minute, which *increases the blood flow to the muscles*, delivering the extra oxygen and glucose and removing waste. When the activity stops, the heart rate falls back to its resting value.
- **How a valve opens and closes:** A valve is a passive flap with no muscle of its own; it responds to the *pressure difference* across it. When the pressure behind is higher the flap is pushed open and blood passes forward; when the pressure ahead becomes higher the flap is pushed shut, sealing the vessel against backflow. A valve that stayed permanently closed would block the circulation entirely.
- **Plasma and platelets:** *Plasma* is the liquid medium 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. *Platelets* are cell fragments that trigger *clotting* at a wound, sealing the break in the vessel wall.

EXAM TIPS

TIP The "lub-dub" heard through a stethoscope is made by the heart *valves snapping shut*, not by the muscle contracting. Answers that credit the sound to the chamber muscle are wrong.

TIP A pump and vessels alone would let blood slosh backward whenever the pressure drops. The mark for describing a circulatory system needs all three: *vessels, a pump and valves*. Leaving out the valves loses the one-way-flow idea.

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

valves, because their high pressure keeps blood moving forward.

TIP The fastest way to tell the two cells apart in a photomicrograph is the *nucleus*: a red blood cell has *none*, a white blood cell has *one*. Do not rely on size alone, and remember haemoglobin is a molecule inside red cells, not a component of blood in its own right.

TIP Heart activity can be monitored by an *ECG* (a trace of the electrical activity), the *pulse rate* (the pressure wave felt along an artery for each beat), and the *valve sounds* heard with a stethoscope. Name any of these three when asked how heart activity is monitored.

KEY CONCEPTS

- **Large surface area increases uptake:** The long, thin extension of a root hair cell gives it a *large surface area* in contact with the soil water. A larger surface area means more membrane across which water and mineral ions can enter at once, so it increases the *rate* of uptake.
- **Phloem and the substances it transports:** Phloem transports *sucrose* and *amino acids*, the dissolved products the plant moves to where they are used for growth or stored. Phloem can carry these substances in *either direction*, up or down the plant.
- **Positions of xylem and phloem in root, stem and leaf:** In a *root*, xylem lies in the centre, often as a star shape, with phloem in patches around it. In a *stem*, the vascular tissue forms a ring of bundles, with xylem on the inner side of each bundle and phloem on the outer side. In a *leaf* vein, xylem is 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 a gap that cannot change its own size; a pair of curved *guard cells* around it changes shape to widen or narrow the pore, controlling how fast water vapour diffuses out.
- **The pathway of water through the plant:** Once absorbed, water follows a fixed pathway in order: *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 to the mesophyll cells, where it evaporates.
- **The root hair cell:** A *root hair cell* is a cell in the epidermis of a young root with a long, thin extension that pushes out between the soil particles. It absorbs most of the plant's water and mineral ions. It has no chloroplasts, because it is underground and does no photosynthesis.
- **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).
- **Xylem and the substances it transports:** 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*. State both substances when two are asked for: water alone is only half the answer.
- **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 rate of mass loss = $\frac{\text{mass lost}}{\text{time taken}}$, where mass lost is starting mass minus final mass. A rate is given in grams per hour, so divide grams by hours.
- **Temperature and the rate of transpiration:** A higher temperature gives water molecules more energy, so water evaporates faster from the mesophyll surfaces and the vapour diffuses out faster. Higher temperature therefore increases the rate of transpiration.
- **The inner-xylem general rule:** Across a root, a stem and a leaf the same pattern holds: xylem sits on the *centre-facing, inner side* of the vascular tissue and phloem on the outer side. Find the centre of the organ and the xylem is the tissue facing it. This is why "xylem is always at the exact geometric centre" is wrong: it is central in the root but not in the stem or leaf.
- **Why water must cross the cortex first:** The xylem lies at the centre of a root, so water absorbed at the surface root hair must pass inward through the *cortex* cells before it reaches the xylem. The cortex is a compulsory middle stage: if it is destroyed over a region, water from the root hairs there can no longer reach the xylem.
- **Wind speed and the rate of transpiration:** Still air lets water vapour build up just outside the stomata, which slows further loss. Moving air carries this vapour away, keeping the outside air dry and the concentration gradient steep, so water vapour diffuses out faster. As wind speed keeps rising the rate eventually *levels off*, because once vapour is removed as fast as it forms, faster wind can do no more.

EXAM TIPS

TIP For a "describe the shape" mark on a graph of transpiration rate (y-axis) against wind speed (x-axis), state two things: the rate *increases* as wind speed increases, *then levels off*. Both halves of the shape are needed for full marks.

TIP Any "explain the adaptation" question wants three linked steps: *feature, then property, then benefit*. For a root hair cell: long thin extension (feature) gives a large surface area (property) which increases the rate of uptake of water and mineral ions (benefit). Give all three links and the mark is secure.

TIP If asked to name *two* substances carried by xylem, answer *water* and *mineral ions*, two items; "water" alone scores one mark where two were available. The same discipline applies to phloem: *sucrose* and *amino acids*. Learn each tissue with its pair of substances as one indivisible fact.

TIP When a cross-section is not labelled by organ, use the giveaway shapes: a *central star* means a root; a *ring of separate bundles* means a stem; a flat section with a distinct upper and lower surface means a leaf. Then apply the inner-xylem rule to identify each tissue.

TIP Two variables increase how fast a root hair cell absorbs water: a *larger surface area* and a *higher temperature*, which gives water molecules more energy. If a question changes both at once, the fastest cell is the one that is warmest *and* has the largest surface area; do not settle for an option that maximises only one factor.

KEY FORMULAS

Speed of electromagnetic waves in a vacuum

$$c = 3.0 \times 10^8 \text{ m/s}$$

Use as the wave speed v in $v = f\lambda$ for any electromagnetic wave in a vacuum (or approximately in air). Every region, from radio to gamma, travels at this same speed, so two EM waves sent the same distance arrive together whatever their frequency.

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; wavelength must be in metres for the speed to come out in m/s.

Wave speed from distance and time

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

Use to find a wave speed from a timed journey, for example a pulse crossing a known distance. The result feeds straight into $v = f\lambda$ when a frequency or wavelength is also needed.

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. Divide the speed by the wavelength to find the frequency, or by the frequency to find the wavelength; keep the speed and wavelength in matching units.

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 fixed positions and pass the disturbance to their neighbours, but they are not carried along. A cork on a pond bobs up and down as ripples pass yet stays over the same spot.
- **How sound is made and why it needs a medium:** Sound is produced by a *vibrating source* and travels as a longitudinal wave of compressions and rarefactions. It needs a *medium* of particles to pass the vibration on, so it travels through solids, liquids and gases but *not* through a vacuum. A bell ringing in a jar falls silent as the air is pumped out.
- **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, laterally inverted, upright and *virtual* (the 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 eye detects.
- **Refraction of light:** Refraction is the change in direction of a ray when its speed changes at a boundary. Entering a *denser* medium (air to glass) the light slows and bends *towards* the normal; entering a *less dense* medium it speeds up and bends *away* from the normal. A ray along the normal passes straight through.
- **Transverse and longitudinal waves:** In a *transverse* wave the particles vibrate at right angles to the direction of travel; examples are electromagnetic radiation, water waves and seismic S-waves. In a

longitudinal wave the particles vibrate parallel to the direction of travel, forming compressions and rarefactions; examples are sound and seismic P-waves.

- **Amplitude, wavelength and frequency:** *Amplitude* is the maximum displacement of a point from its rest position, in metres. *Wavelength* is the distance between two corresponding points on adjacent waves, such as crest to next crest, in metres. *Frequency* is the number of complete waves passing a fixed point each second, in hertz (Hz).
- **Reflection and refraction of waves:** All waves can reflect off a barrier and refract when their speed changes at a boundary. On reflection the speed and wavelength are unchanged because the wave stays in the same medium; only the direction changes. On refraction into a slower medium at fixed frequency, the wavelength shortens, because $v = f\lambda$ with f constant.
- **Refraction through a rectangular glass block:** A ray entering a glass block bends *towards* the normal (it slows) and, on leaving, bends *away* from the normal by the same amount. Because the two faces are parallel, the emergent ray is *parallel* to the incident ray but shifted sideways (a lateral displacement).
- **Speed of sound in solids, liquids and gases:** Sound travels *fastest in solids, slower in liquids and slowest in gases*, because the particles in a solid are packed most closely and pass a disturbance on most quickly. In air it is roughly 330 to 340 m/s. A measured speed near 1500 m/s indicates a liquid such as water.
- **Thin converging lens:** A converging (convex) lens brings rays parallel to the principal axis to a point called the *principal focus*; the distance from the lens to that point is the *focal length*. Light from a very distant object arrives parallel, so its image forms at the principal focus. Locate other images with a ray parallel to the axis (bending through F) and a ray straight through the centre.
- **Uses of the electromagnetic regions:** Radio waves: broadcasting and communication. Microwaves: mobile phone and satellite links, and cooking. Infrared: heating, thermal imaging, remote controls and optical-fibre communication. Visible light: vision and illumination. Ultraviolet: sterilising and security marking. X-rays: imaging bones and security scanners. Gamma rays: sterilising equipment and radiotherapy.

EXAM TIPS

TIP Amplitude is the maximum displacement from the rest position to *one* extreme, measured from the middle line to a crest or to a trough. The crest-to-trough distance is *twice* the amplitude, and the crest to the next trough is *half* a wavelength; examiners quote these doubled or halved values on purpose.

TIP When a wave refracts, its *frequency never changes*, since it is set by the source. Whatever happens to the speed, the wavelength follows it (both fall together or both rise together) so that $f = v/\lambda$ stays constant. Do not let a changing wavelength tempt you into changing the frequency.



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