



Combined Science (0653)

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Compact Cheat Sheet

The Practice Book
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1 Acids, bases and salts

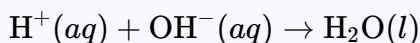
KEY FORMULAS

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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*.

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*.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

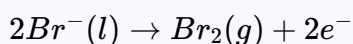
EXAM TIPS

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.

12 Electrochemistry

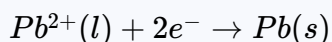
KEY FORMULAS

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.

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.

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).

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

KEY CONCEPTS

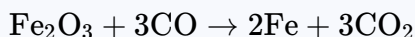
- **Physical and chemical digestion:** *Physical* (mechanical) digestion breaks food into smaller pieces, for example by the teeth and by churning in the stomach, without changing the molecules. *Chemical* digestion uses enzymes to break large insoluble molecules into small soluble ones. Physical digestion 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.

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.

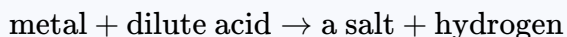
KEY FORMULAS

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 $\text{Zn} + \text{H}_2\text{SO}_4 \rightarrow \text{ZnSO}_4 + \text{H}_2$.

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.

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.

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.

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.

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.

KEY CONCEPTS

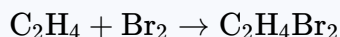
- **Definition of active transport:** Active transport is the movement of particles through a cell membrane from a region of lower concentration to a region of higher concentration, *against* the concentration gradient, using energy from respiration. Its two defining features are the direction (low to 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.

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.

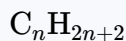
KEY FORMULAS

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.

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 $C = C$. 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.

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.

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 $\rightarrow$ 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 $\rightarrow$ producers $\rightarrow$ consumers $\rightarrow$ 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 $\rightarrow$ grasshopper $\rightarrow$ bluebird $\rightarrow$ 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.

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.

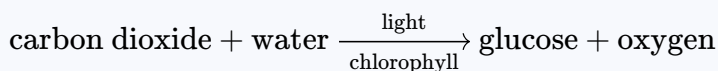
KEY FORMULAS

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.

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*.

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.

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.

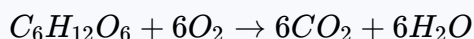
EXAM TIPS

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

KEY CONCEPTS

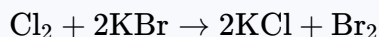
- **Balancing a symbol equation:** A *symbol equation* replaces names with formulas and must have the same number of atoms of every element on both sides, because atoms are never created or destroyed. You balance only by placing *coefficients*, the large numbers in front of formulas; you may never change 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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.

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.



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