Combined Science (0653)

IGCSE • Core • CAIE

Compact Cheat Sheet

The Practice Book
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1 Acids, bases and salts

KEY FORMULAS

Neutralisation as an ionic equation

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

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

KEY CONCEPTS

- **Acid, base and alkali defined**: An *acid* is a substance whose aqueous solution has a pH below 7 and turns litmus red; its formula almost always begins with hydrogen, as in HCl, H_2SO_4 and HNO_3. A *base* is an oxide or hydroxide of a metal that reacts with an acid to form a salt and water. An *alkali* is a base that is soluble in water, such as sodium hydroxide, potassium hydroxide or aqueous ammonia; every alkali is a base, but not every base is an alkali.
- **Classifying an oxide as acidic or basic**: An oxide is classified from the character of the element joined to the oxygen. *Basic oxides* are the oxides of *metals*, such as CuO, CaO and Na_2O; they react with acids to form a salt and water. *Acidic oxides* are the oxides of *non-metals*, such as SO_2 and CO_2; they dissolve in water to give an acidic solution and react with bases. The single question is whether the element is a metal or a non-metal.
- **Indicators and the pH scale**: An *indicator* shows a different colour in an acid than in an alkali. Litmus is *red* in acid and *blue* in alkali. To read an actual value, *universal indicator* is matched to a colour chart giving a pH: below 7 is acidic, exactly 7 is neutral (green), and above 7 is alkaline. The lower the pH the more strongly acidic, and the higher the pH the more strongly alkaline.
- **The master decision: soluble or insoluble**: How a salt is made is decided by one question: is the target salt *soluble* or *insoluble* in water? A *soluble* salt is made by reacting a dilute acid with a suitable reactant, then crystallising the salt from the filtrate. An *insoluble* salt is made by *precipitation*: mixing two soluble solutions so the salt forms as a solid, which is filtered, washed and dried.
- **The three characteristic reactions of a dilute acid**: A dilute acid reacts in three ways, each giving a salt. With a *metal* it gives a salt and *hydrogen*, which pops with a lit splint; calcium and dilute hydrochloric acid react this way to give calcium chloride and hydrogen. With a *base* it gives a salt and *water* only, with no gas. With a *carbonate* it gives a salt, *water* and *carbon dioxide*, which turns limewater milky. Only the metal and carbonate reactions release a gas, and the two gases are different.

EXAM TIPS

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

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

2 Atoms, elements and compounds

KEY FORMULAS

Nucleon (mass) number

$$A = Z + N$$

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

Number of neutrons

$$N = A - Z$$

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

KEY CONCEPTS

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

3 Biological molecules

KEY CONCEPTS

- **Building blocks of the three food groups**: A carbohydrate is built from many *glucose* molecules. A protein is built from many *amino acids* joined in a chain. A fat or oil is built from *fatty acids and glycerol*. A molecule is classed by what it is built from, not by its role.
- **Elements in carbohydrates, fats and proteins**: Carbohydrates and fats contain only *carbon, hydrogen and oxygen* (C, H, O). Proteins contain *carbon, hydrogen, oxygen and nitrogen* (C, H, O, N). Nitrogen is the element that identifies protein among the three food groups.
- **Starch, glycogen and cellulose are all made from glucose**: Starch (stores energy in plants), glycogen (stores energy in animals) and cellulose (forms plant cell walls) are all carbohydrates built from the single building block *glucose*. Three different roles, one shared building block.
- **The four food tests: reagent and positive result**: Iodine test for starch: iodine solution, no heating, browny-orange to *blue-black*. Benedict's test for reducing sugar: Benedict's solution, *heat* in a water bath, blue to a *brick-red* precipitate. Biuret test for protein: biuret solution, no heating, blue to *purple*. Emulsion test for fats and oils: dissolve in *ethanol* then add to water, clear to a *cloudy white* layer.

EXAM TIPS

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

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

4 Cells

KEY FORMULAS

Magnification equation

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

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

Magnification has no unit

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

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

KEY CONCEPTS

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

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 of substances in excess of requirements. This covers wastes the body itself made, such as carbon dioxide from respiration and urea from the breakdown of excess protein, together with useful substances taken in or made in amounts greater than the body needs.
- **Growth**: Growth is a permanent increase in size and dry mass. *Dry mass* is the mass of an organism once all its water has been removed, so growth means an organism has made new living material, not simply taken up water.
- **Nutrition**: Nutrition is the taking in of materials for energy, growth and development. Animals take in and digest food; plants take in carbon dioxide, water and mineral ions and use them, with light, to build their own food.
- **Respiration**: Respiration is the chemical reactions that break down nutrients to release energy. It is a *chemical* process that goes on continuously inside every living cell, not a physical process in the lungs.
- **The seven characteristics of living organisms (MRS GREN)**: Every living organism shows seven characteristics, remembered by the mnemonic *MRS GREN*: Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion and Nutrition. To count as living, an organism must be capable of showing all seven at some point in its life. The mnemonic itself earns no marks; marks are given only for reproducing the exact definition of each characteristic and applying it correctly.

EXAM TIPS

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

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

6 Chemical energetics

KEY CONCEPTS

- **Endothermic reactions**: An *endothermic* reaction takes in thermal energy from the surroundings, so the temperature of the surroundings falls. Dissolving certain salts, such as ammonium nitrate or ammonium chloride, in water is a common endothermic change.
- **Exothermic reactions**: An *exothermic* reaction transfers thermal energy to the surroundings, so the temperature of the surroundings rises. Combustion, neutralisation and the reaction of a reactive metal with an acid are all exothermic.
- **Measuring a temperature change**: A temperature change is found from two readings: the *initial* temperature, taken before the reactants are mixed, and the *highest* (exothermic) or *lowest* (endothermic) temperature reached once the reaction has happened. The change is the difference between these two readings, not the final reading alone.
- **What is meant by the surroundings**: The *surroundings* means everything outside the reacting chemicals themselves, such as the solution, the container and the air around it. Exothermic and endothermic are always defined by the temperature change of the surroundings, not by a change in the reacting chemicals directly.

EXAM TIPS

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

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

7 Chemical reactions

KEY FORMULAS

Rate of reaction from gas volume

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

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

KEY CONCEPTS

- **Chemical change**: A *chemical change* forms one or more new substances with different properties from the starting materials, and it is usually difficult to reverse. Burning and rusting are both chemical changes.
- **Four factors that change the rate**: Increasing the concentration of a solution, increasing the surface area of a solid (smaller pieces or powder), raising the temperature, and adding a suitable catalyst all *increase* the rate of reaction. Reversing any factor (diluting, using larger lumps, cooling, removing the catalyst) *decreases* the rate.
- **Oxidation and reduction in terms of oxygen**: At this tier, *oxidation is the gain of oxygen* and *reduction is the loss of oxygen*. When a metal oxide loses its oxygen to become the metal, it is reduced; the substance that takes that oxygen is oxidised.
- **Physical change**: A *physical change* alters only the state, shape or appearance of a substance; no new substance is formed, and the change can usually be reversed. Melting, boiling, freezing and dissolving are all physical changes.
- **Redox reaction**: A *redox reaction* is one in which oxidation and reduction happen at the same time. Whenever one substance gains oxygen, another substance must lose it, so the two changes always occur together in the same reaction.

EXAM TIPS

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

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

8 Chemistry of the environment

KEY CONCEPTS

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

EXAM TIPS

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

9 Diseases and immunity

KEY CONCEPTS

- **Direct contact transmission**: In *direct contact* transmission the pathogen passes straight from an infected host to an uninfected host, with nothing carrying it in between, for example skin touching infected skin or contact with infected body fluids.
- **Indirect transmission and its four routes**: In *indirect* transmission the pathogen passes between hosts by way of an intermediate carrier. The four routes are the *air* (droplets from a cough), *contaminated water*, *contaminated food*, and a *vector*, a separate organism such as a mosquito that carries the pathogen from host to host.
- **The body's defences against pathogens (overview)**: The body defends itself in layers: *barriers* keep pathogens out (skin, mucus and cilia in the airways, stomach acid), *clotting* seals a wound if the skin is broken, and *white blood cells* destroy pathogens that get in.
- **What a pathogen is**: A *pathogen* is a disease-causing organism. Pathogens fall into four groups: *bacteria* (e.g. cholera), *viruses* (e.g. influenza), *fungi* (e.g. athlete's foot) and *protozoa* (e.g. malaria). Not every disease is caused by a pathogen: a *deficiency* disease comes from a poor diet and an *inherited* disease passes through genes, and neither involves an infecting organism.
- **What a transmissible disease is**: A *transmissible disease* is one in which the pathogen can be passed from an infected host to an uninfected host. "Transmissible" describes only whether the pathogen can spread between hosts, not how severe the disease is or what type of organism causes it: cholera (bacterium), influenza (virus) and malaria (protozoan) are all transmissible because each pathogen can move from host to host.

EXAM TIPS

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

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

10 Drugs

KEY CONCEPTS

- **Antibiotic resistance and MRSA**: Some bacteria are *resistant* to an antibiotic: the antibiotic no longer kills them or stops their growth, so it becomes less effective against that strain. *MRSA* is a well-known strain of bacteria that has become resistant to many antibiotics and is therefore very difficult to treat, especially in hospitals.
- **Antibiotics have no effect on viruses**: Antibiotics kill bacteria or stop them growing, but they have *no effect on viruses*. Illnesses caused by viruses, such as a cold or influenza, cannot be treated with antibiotics because the drug has nothing to act on.
- **Definition of a drug**: A *drug* is any substance taken into the body that modifies or affects the chemical reactions taking place in the body. This definition makes no reference to benefit or harm, so a helpful medicine and a harmful substance are both drugs.
- **What an antibiotic is and does**: An *antibiotic* is a drug used to treat infections caused by bacteria. It works by killing the bacteria or by stopping them from growing and reproducing, which lets the body clear the infection. Penicillin is a well-known example.

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.

11 Electricity

KEY FORMULAS

Definition of resistance

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

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

Electrical power

$$P = IV$$

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

Resistors in series

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

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

- **Electric current and charge carriers**: *Electric current* is the flow of electric charge, measured in amperes (A). In a metal wire it is carried by *free electrons* drifting through the fixed lattice of positive ions, not by the ions themselves. A *conductor* such as copper lets charge flow through it freely; an *insulator* such as plastic does not.
- **Energy transfers in cells, generators and motors**: A *cell* or *battery* transfers *chemical energy to electrical energy*. A *generator* transfers *kinetic energy to electrical energy* when its shaft is turned. An *electric motor* transfers *electrical energy to kinetic energy* when supplied with current.
- **Fuse, earthing and double insulation**: A *fuse* is a thin wire, placed in the *live* wire, that melts and breaks the circuit if the current becomes too large. *Earthing* connects a metal case to the ground by an earth wire, so a fault current flows to earth and blows the fuse before a user is shocked. A *double-insulated* appliance has a non-conducting plastic case and needs no earth wire, since a user can never touch a live part through it.
- **Rules for a parallel circuit**: A *parallel circuit* has components connected on separate branches between the same two points, giving more than one path for the current. The *branch currents add* to give the larger source current, and *each branch has the full p.d.* of the supply. One branch can fail without breaking the others.
- **Rules for a series circuit**: A *series circuit* has components connected one after another in a single loop, giving only one path for the current. The *current is the same* at every point, since there is nowhere for it to split, and the source voltage is *shared*, so the component p.d.s add up to it. A break anywhere stops the current everywhere.

EXAM TIPS

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

12 Electrochemistry

KEY CONCEPTS

- **Anode, cathode and electrolyte**: The *anode* is the electrode connected to the *positive* terminal of the power supply; the *cathode* is the electrode connected to the *negative* terminal; the *electrolyte* is the molten or aqueous ionic substance that conducts the current and is decomposed. Name each part from its terminal connection, not from the products formed.
- **Cations and anions**: A *cation* is a positively charged ion; it moves towards the cathode during electrolysis. An *anion* is a negatively charged ion; it moves towards the anode. Each ion moves towards the electrode of opposite charge.
- **Definition of electrolysis**: Electrolysis is the *decomposition* of an ionic compound, when *molten or in aqueous solution*, by the passage of an *electric current*. The compound must be ionic and its ions must be free to move, so melting or dissolving it is a necessary first step, but a current must still be passed to force the decomposition.
- **Discharge of ions at the electrodes**: At the cathode, a positive ion *gains electrons* and becomes a neutral atom. At the anode, a negative ion *loses electrons* and becomes a neutral atom or molecule. This gain or loss of electrons that turns an ion into a neutral particle is called *discharge*.
- **Inert electrodes**: An *inert electrode*, made of platinum or carbon/graphite, conducts the current into and out of the electrolyte without reacting with the electrolyte or the products. Because the electrode itself takes no part in the reaction, whatever forms at it comes only from the ions already present in the electrolyte.
- **Why a solid ionic compound cannot be electrolysed**: In a solid, the ions are locked in a fixed lattice and cannot move, so no current can flow through it. Melting the compound, or dissolving it in water, frees the ions so they can move to the electrodes and be discharged. The charge on each ion does not change, only its freedom to move.

EXAM TIPS

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

13 Enzymes

KEY CONCEPTS

- **Denaturation**: To be *denatured* means an enzyme has been permanently changed, usually by a high temperature or an extreme pH, so that it can no longer work. Denaturation is permanent: cooling a heat-denatured enzyme back down does not restore its activity.
- **Effect of pH on enzyme activity**: Each enzyme has an *optimum pH*, the single pH value at which it works fastest. Moving away from the optimum pH, in either direction, lowers the rate of reaction, so a graph of activity against pH rises to a peak at the optimum and falls away on both sides of it.
- **Effect of temperature on enzyme activity**: As temperature rises from a low value, the rate of an enzyme-controlled reaction increases up to a maximum at the enzyme's *optimum temperature*, the single temperature at which it works fastest. Raising the temperature well beyond the optimum makes activity fall, because the enzyme becomes *denatured*.
- **Enzymes are biological catalysts**: An *enzyme* is a *protein* that works as a *biological catalyst*: it speeds up a chemical reaction inside a living cell without being used up or permanently changed. Because it is released unchanged at the end of the reaction, the same enzyme molecule can catalyse the same reaction again and again. Enzymes contain carbon, hydrogen, oxygen and nitrogen, the elements that confirm every enzyme is a protein.
- **What a catalyst does**: A *catalyst* is a substance that speeds up a chemical reaction without being used up or permanently changed by that reaction. A *biological catalyst* is a catalyst produced by a living organism, such as an enzyme, that speeds up a *metabolic* reaction taking place inside a cell.

EXAM TIPS

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

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

14 Experimental techniques and chemical analysis

KEY CONCEPTS

- **Choosing measuring apparatus**: Time is measured with a stop-watch, temperature with a thermometer and mass with a balance. For volume, a measuring cylinder gives an approximate reading, a volumetric pipette delivers one fixed volume precisely and a burette measures a variable volume delivered precisely. A gas syringe measures the volume of a gas produced.
- **Filtration and crystallisation**: *Filtration* separates an insoluble solid from a liquid: the solid stays on the filter paper as the residue, while the liquid passes through as the filtrate. *Crystallisation* obtains a soluble solid from its solution: the solution is warmed to evaporate some solvent, then left to cool slowly so that pure crystals grow as the solubility falls.
- **Key experimental terms**: A *solute* is the substance that dissolves; a *solvent* is the liquid it dissolves in; together they form a *solution*. A *saturated solution* holds the maximum mass of solute that will dissolve at a given temperature. In filtration, the insoluble solid trapped on the filter paper is the *residue*, and the liquid that passes through is the *filtrate*.
- **Paper chromatography**: Paper chromatography separates a mixture of soluble coloured substances. A spot of the mixture is placed on a pencil baseline, above the level of the solvent in the tank. The solvent rises up the paper, dissolving the substances and carrying them with it. A substance that is more soluble in the solvent travels further, so the components separate into individual spots.
- **Reading purity from a chromatogram**: A pure substance produces a single spot on a fully developed chromatogram. A mixture produces two or more spots, one for each coloured substance it contains. Counting the spots on a chromatogram is the standard way to show whether a sample is pure or a mixture of several substances.
- **Simple and fractional distillation**: *Simple distillation* obtains a pure solvent from a solution: the solvent evaporates, condenses in a condenser and is collected, while the dissolved solute stays behind. *Fractional distillation* separates two or more miscible liquids with different boiling points, using a fractionating column so that the liquid with the lower boiling point is collected first.
- **Testing cations with aqueous sodium hydroxide**: Adding aqueous sodium hydroxide gives a coloured metal hydroxide precipitate. Copper(II) gives a blue precipitate, iron(II) a green precipitate and iron(III) a red-brown precipitate, all insoluble in excess. Calcium gives a white precipitate insoluble in excess, while zinc gives a white precipitate that dissolves in excess. Ammonium ions give no precipitate but release ammonia gas on warming.
- **Tests for common gases**: Hydrogen gives a squeaky pop with a lighted splint. Oxygen relights a glowing splint. Carbon dioxide turns limewater milky. Ammonia turns damp red litmus paper blue. Chlorine bleaches damp litmus paper.

EXAM TIPS

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

15 Gas exchange in humans

KEY FORMULAS

Breathing rate from a timed count

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

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

Percentage increase

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

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

KEY CONCEPTS

- **Direction of gas exchange at the alveolus**: At the alveolus, *oxygen* diffuses from the alveolar air into the blood, and *carbon dioxide* diffuses from the blood into the alveolar air. Each gas moves in its own direction, oxygen in and carbon dioxide out.
- **How air is drawn into the lungs**: During inhalation the *intercostal muscles* contract to pull the rib cage up and out, and the *diaphragm* contracts and flattens. Together they increase the volume of the chest cavity, which lowers the pressure inside it below atmospheric pressure, so air flows in.
- **How breathing changes during exercise**: During exercise muscles respire faster, using oxygen and producing carbon dioxide more quickly. The body responds by increasing both the *rate* of breathing (more breaths per minute) and the *depth* of breathing (a bigger volume of air with each breath).
- **Route of air to the gas exchange surface**: Air passes from the *trachea* (the windpipe, held open by rings of cartilage) into two *bronchi*, one to each lung, then into many branching *bronchioles*, and finally into the *alveoli*, the tiny air sacs where gas exchange takes place.

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* or *overharvesting*, *pollution*, *introduced species*, or *climate change*. More than one cause can act on the same species at once.
- **Endangered and extinct species**: An *endangered* species is one whose population has fallen so low that it is at risk of becoming extinct. A species is *extinct* when all of its members have died and none remain alive anywhere.
- **Reasons for habitat destruction**: Humans destroy natural habitats to clear land for *farming* (crops and grazing livestock), to build *houses, roads and factories*, and to extract resources such as *timber and minerals*; pollution can also damage a habitat without any land being cleared.
- **The undesirable effects of deforestation**: Deforestation causes *loss of habitats and biodiversity*, *soil erosion*, *flooding*, and a *rise in atmospheric carbon dioxide*.
- **What an ecosystem is**: An *ecosystem* is a unit made up of a *community of organisms* together with the *non-living environment* in which they live and interact, including the soil, water, air and climate.
- **What biodiversity is**: *Biodiversity* is the number of *different species* that live in an area. It counts species, not individuals, so an area crowded with one species still has low biodiversity.

EXAM TIPS

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

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

17 Human nutrition

KEY FORMULAS

Energy released from a nutrient

$$E = m \times e$$

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

Standard energy values of the nutrients

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

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

KEY CONCEPTS

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

EXAM TIPS

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

18 Metals

KEY FORMULAS

Extracting a metal below carbon

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

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

Metal plus dilute acid

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

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

KEY CONCEPTS

- **Chemical reactions of metals**: Metals react with dilute acid, and the most reactive metals also react with cold water or steam. Metal plus dilute acid gives *a salt plus hydrogen*. Metal plus cold water gives *a metal hydroxide plus hydrogen*, and only potassium, sodium and calcium react this way. Metal plus steam gives *a metal oxide plus hydrogen*, shown by a less reactive metal such as magnesium.
- **Conditions for rusting and how to prevent it**: *Rusting* is the corrosion of iron, and it needs *oxygen and water present together*. Remove either one and iron does not rust, however long it is left. Rust is prevented by *barrier methods*: painting, greasing and coating with plastic all work the same way, by covering the surface so oxygen and water cannot reach the iron.
- **Every use is a property doing a job**: A metal is chosen for a use because a specific physical property suits the job. *Aluminium* has a low density and resists corrosion, so it is used for aircraft bodies and food containers. *Copper* is an excellent conductor of electricity and is ductile, so it is used for electrical wiring. To justify a use, name the property, not just the metal.
- **Physical properties of metals**: Most metals are good conductors of heat and electricity, shiny (lustrous), and *malleable* (can be hammered or pressed into shape) and *ductile* (can be drawn into a wire). They generally have high melting points, unlike most non-metals, which are poor conductors, dull, and often low-melting or gases.
- **Reactivity sets the extraction method**: How a metal is extracted from its ore is fixed by its reactivity. Very unreactive metals (silver, gold) are found *native*, as the uncombined element. Metals *below carbon* (zinc, iron, copper) are extracted by heating their oxide with carbon, which removes the oxygen. Metals *above carbon* (potassium to aluminium) are too reactive for carbon and must be extracted by *electrolysis*, for example aluminium from bauxite.
- **The reactivity series**: The reactivity series lists metals in order of decreasing reactivity, with the non-metals carbon and hydrogen included as reference points: potassium, sodium, calcium, magnesium, aluminium, (carbon), zinc, iron, (hydrogen), copper, silver, gold. The higher a metal sits, the more vigorously it reacts with water, steam and dilute acid.
- **What an alloy is**: An *alloy* is a mixture of a metal with one or more other elements, usually other metals, made by melting the components together and letting them solidify. An alloy is usually harder and stronger than the pure metal it is made from. The two syllabus examples are *brass* (copper and zinc) and *stainless steel* (iron with chromium, and often nickel and carbon), where the chromium resists corrosion.

EXAM TIPS

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

19 Motion, forces and energy

KEY FORMULAS

Average speed

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

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

Density

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

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

Power

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

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

Pressure

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

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

Speed

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

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

Weight

$$W = mg$$

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

Work done

$$W = Fd$$

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

KEY CONCEPTS

- **Energy stores and conservation of energy**: Energy is stored kinetically, gravitationally (as gravitational potential energy), chemically, elastically, nuclearly, electrostatically and internally (thermally), and is transferred mechanically, electrically, by heating or by waves. The *principle of conservation of energy* states that energy cannot be created or destroyed, only transferred from one store to another, so the total amount stays the same.
- **Force and resultant force**: A *force* is a push or a pull that can change an object's size, shape or motion. When forces act along one straight line, forces in the same direction add and forces in opposite directions subtract; the single *resultant force* that remains points the way of the larger force and decides how the motion changes.
- **Mass compared with weight**: *Mass* is the quantity of matter in an object, measured in kilograms, and stays the same wherever the object is. *Weight* is the gravitational force on that mass, measured in newtons, and changes with the gravitational field strength g of the location, for example becoming smaller on the Moon.
- **Measuring length, volume and time**: Length is measured with a *ruler* or metre rule, read to the nearest millimetre and viewed straight on to avoid *parallax* error. The volume of a liquid is measured with a *measuring cylinder*, reading the bottom of the meniscus at eye level. Time intervals are measured with a *stop-watch* or digital timer.
- **Reading distance-time and speed-time graphs**: On a *distance-time* graph the gradient is the *speed*: a horizontal line means the object is at rest and a steeper line means a greater speed. On a *speed-time* graph a horizontal line means a constant speed, a line sloping upward means the object is *accelerating*, and a line sloping downward means it is *decelerating*.

20 Movement into and out of cells

KEY FORMULAS

Mass change before converting to a percentage

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

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

Percentage change in mass

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

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

KEY CONCEPTS

- **Definition of diffusion**: Diffusion is the *net* movement of particles from a region of their higher concentration to a region of their lower concentration, down a concentration gradient, caused by the particles' own random movement. The word *net* matters: particles move in every direction, but overall more travel from the crowded region to the sparse region than the reverse.
- **Definition of osmosis**: Osmosis is the net movement of water molecules from a dilute solution to a more concentrated solution, through a *partially permeable* membrane. It is a special case of diffusion in which the only substance that moves is water.
- **Diffusion needs no energy**: Diffusion needs no energy input from the cell. It happens because of the particles' own constant random movement, which is why it is described as a *passive* process.
- **Partially permeable membrane**: A partially permeable membrane lets small water molecules pass through but holds back larger dissolved molecules such as sugar. Both conditions, a partially permeable membrane and a difference in water concentration across it, must be present for osmosis to occur.

EXAM TIPS

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

21 Organic chemistry

KEY FORMULAS

Complete combustion of a hydrocarbon

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

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

KEY CONCEPTS

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

EXAM TIPS

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

22 Organisms and their environment

KEY CONCEPTS

- **A food chain always begins with a producer**: A *food chain* shows the transfer of energy from one organism to the next, and always *begins with a producer* because energy must enter the living world through photosynthesis before any animal can feed. Each arrow points from the organism that is eaten to the organism that eats it, so the arrow shows the direction of energy flow.
- **Carbon is recycled through five processes**: Unlike energy, *carbon is recycled* endlessly between the atmosphere and living organisms. The cycle has five processes: *photosynthesis* removes carbon dioxide from the air; *respiration*, *decomposition* and *combustion* release carbon dioxide into the air; and *feeding* transfers carbon from one organism to the next without changing the amount in the atmosphere.
- **Energy flow is one-way**: Energy *flows through* living organisms rather than being stored forever: it enters producers as chemical energy, passes to consumers by feeding, and at every stage some is released by respiration and eventually transferred to the environment, mostly as *heat*. The overall path is Sun to producers to consumers to environment. Energy is never recycled, so a food chain depends on a constant new supply of light energy.
- **Herbivores, carnivores and decomposers**: A *herbivore* is an animal that gets its energy by eating plants. A *carnivore* is an animal that gets its energy by eating other animals. A *decomposer* is an organism that gets its energy from *dead or waste* organic material; bacteria and fungi are the main decomposers. The trigger words for a decomposer are dead, decaying or waste.
- **Producers and consumers**: A *producer* is an organism that makes its own organic nutrients, usually using light energy in *photosynthesis*; green plants and algae are producers. A *consumer* is an organism that gets its energy by *feeding on other organisms*. The distinction is about how the organism obtains its energy, not whether it is a plant or an animal.
- **The Sun is the principal source of energy**: The *Sun* is the principal source of energy input to biological systems. Sunlight is captured by producers during *photosynthesis*, which converts light energy into chemical energy stored in nutrients such as glucose. Even the energy in a consumer that never sees sunlight, such as a fox, traces back through what it eats to the Sun.
- **Trophic levels of consumers**: Consumers are numbered by how far along the chain they feed, counting from the producer. A *primary consumer* eats the producer; a *secondary consumer* eats the primary consumer; a *tertiary consumer* eats the secondary consumer. In a coral reef food web where phytoplankton (a producer) is eaten by zooplankton, the zooplankton is the primary consumer.

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.

23 Plant nutrition

KEY CONCEPTS

- **Chlorophyll is a green pigment in the chloroplasts**: *Chlorophyll* is a green pigment found inside *chloroplasts*. It absorbs the light energy that drives photosynthesis. Chlorophyll gives leaves their green colour, and chloroplasts are the structures within a plant cell that contain it.
- **Definition, raw materials and products**: *Photosynthesis* is the process by which plants make carbohydrates from simple raw materials using light energy. The raw materials are *carbon dioxide*, taken in from the air, and *water*, absorbed by the roots. The products are *glucose*, a carbohydrate the plant uses as food, and *oxygen*, released as a by-product.
- **Guard cells and stomata**: A *stoma* is a small pore in the lower epidermis. Each stoma is surrounded by a pair of *guard cells*, which change shape to open or close the pore, controlling the movement of gases and water vapour into and out of the leaf.
- **Palisade mesophyll**: The *palisade mesophyll* is a layer of tall, closely packed column cells directly beneath the upper epidermis. It contains most of the leaf's chloroplasts and is the main site of photosynthesis.
- **Spongy mesophyll**: The *spongy mesophyll* lies below the palisade mesophyll and is made of rounded, loosely packed cells with large air spaces between them. These spaces let carbon dioxide and oxygen diffuse easily to and from every cell.
- **Waxy cuticle**: The *waxy cuticle* is a thin, transparent, waterproof layer covering the upper surface of the leaf. It lets light through to the cells beneath while reducing water loss by evaporation from the epidermis.
- **Word equation for photosynthesis**: The word equation for photosynthesis is $\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{light}} \text{glucose} + \text{oxygen}$. Carbon dioxide and water are the reactants on the left; glucose and oxygen are the products on the right. Light and chlorophyll are conditions written on the arrow, never listed as raw materials.

EXAM TIPS

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

24 Reproduction

KEY CONCEPTS

- **Parts of an insect-pollinated flower**: The male part is the *stamen*, made of an *anther* (produces and releases pollen grains) on a *filament* (the stalk that holds the anther in position). The female part is the *carpel*: a *stigma* (sticky top that receives pollen), a *style* (stalk joining stigma to ovary) and an *ovary* (contains the ovules). *Petals* attract insects with colour and scent, *nectaries* reward them with nectar, and *sepals* protect the unopened bud. Core is scoped to this insect-pollinated flower only; no wind-pollinated flower is examined.
- **The female reproductive system**: The *ovary* produces and releases egg cells, the female gametes. The *oviduct* carries an egg towards the uterus and is the *site of fertilisation*. The *uterus* is the muscular organ in which a fertilised egg implants and the fetus develops. The *cervix* is the ring of muscle at its lower opening, leading to the *vagina*.
- **The male reproductive system**: The *testis* produces sperm cells, the male gametes, and is held in the *scrotum*, a sac of skin outside the main body that keeps it slightly cooler. The *sperm duct* carries sperm towards the urethra. The *prostate gland* adds fluid to the sperm to form *semen*. The *urethra* runs through the *penis*, which passes semen out of the body.
- **What fertilisation is in a plant**: *Fertilisation* in a flowering plant is the fusion of a *nucleus from a pollen grain* with a *nucleus in an ovule*. It follows pollination, once a pollen tube has grown down the style to reach an ovule. After fertilisation the *ovule becomes a seed* and the *ovary becomes a fruit*.
- **What fertilisation is in humans**: *Fertilisation* in humans is the fusion of the *nuclei from a sperm cell and an egg cell*. Sperm swim from the vagina, through the uterus, into the oviduct, where one sperm nucleus fuses with the egg nucleus to form a single cell called a *zygote*, which then divides to form an embryo.
- **What pollination is**: *Pollination* is the transfer of pollen grains from an *anther* to a *stigma*. It is defined by *direction* (anther to stigma), never by the agent that carries the pollen, so hand-pollination with a brush counts equally with insect-carried pollen. Pollination alone says nothing about fertilisation or a seed forming.

EXAM TIPS

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

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

25 Respiration

KEY FORMULAS

Word equation for aerobic respiration

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

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

KEY CONCEPTS

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

EXAM TIPS

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

26 Space physics

KEY FORMULAS

Distance from light-travel time

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

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

Time from distance and speed

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

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

KEY CONCEPTS

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

EXAM TIPS

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

27 States of matter

KEY CONCEPTS

- **Effect of heating a gas at constant pressure on its volume**: When a fixed mass of gas is heated at constant pressure, its particles gain energy and move faster. The gas expands to make room for them, so its volume increases.
- **Particle model of the three states**: Describe each state by the *separation*, *arrangement* and *motion* of its particles. Solid: particles close together in a regular pattern, only vibrating about fixed positions. Liquid: particles close together but randomly arranged, able to slide past one another. Gas: particles far apart and randomly arranged, moving quickly in every direction. Liquid and solid particles sit about equally close together; the big jump in separation is between liquid and gas.
- **The five changes of state**: *Melting* is solid to liquid on heating. *Freezing* is liquid to solid on cooling. *Boiling* is liquid to gas throughout the whole liquid, at the boiling point. *Evaporating* is liquid to gas from the surface only, at any temperature below the boiling point. *Condensing* is gas to liquid on cooling.
- **The three states of matter and their properties**: A *solid* has a fixed shape and a fixed volume; it cannot be poured or squashed. A *liquid* has a fixed volume but no fixed shape, so it flows and takes the shape of its container, and it also resists being squashed. A *gas* has neither a fixed shape nor a fixed volume; it fills any container and can be squashed considerably. A fixed volume separates a liquid from a gas; a fixed shape separates a solid from a liquid.
- **What causes the pressure of a gas**: A gas's particles move constantly and rapidly in every direction, so they collide with the walls of their container many times each second. Each collision exerts a small force on the wall, and the combined effect of billions of collisions every second is the overall pressure of the gas.

EXAM TIPS

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

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

28 Stoichiometry

KEY FORMULAS

Conservation of mass

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

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

KEY CONCEPTS

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

EXAM TIPS

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

29 The Periodic Table

KEY CONCEPTS

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

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.

30 Thermal physics

KEY CONCEPTS

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

EXAM TIPS

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

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

31 Transport in animals

KEY CONCEPTS

- **Comparing arteries, veins and capillaries**: The three vessel types are compared using three structural features: *wall thickness*, *lumen diameter* (the lumen is the central space blood flows through) and whether *valves* are present. An *artery* has a thick wall, a narrow lumen and no valves. A *vein* has a thinner wall, a wide lumen and valves. A *capillary* has a wall only one cell thick, with a lumen just wide enough for a red blood cell.
- **Direction rule: arteries away, veins back**: Blood is pumped *away* from the heart in *arteries* and returns to the heart in *veins*; the definition is by direction, not by the type of blood carried. The pulmonary artery still counts as an artery even though it carries deoxygenated blood, because it carries blood away from the heart. This direction rule does not change during exercise, only the rate does.
- **Structures of the mammalian heart**: The heart is a muscular double pump with *four chambers*: two upper *atria* receive blood entering the heart and two lower *ventricles* pump blood out. The wall of the *left ventricle* is the thickest, because it pumps blood all the way around the body. The *septum* is the wall of muscle separating the left and right sides, and internal *valves* give one-way flow through the heart.
- **The circulatory system: vessels, a pump and valves**: A circulatory system is described using three structures working together: *blood vessels* form the pathway blood travels along, a *pump* (the heart) contracts to push blood forward, and *valves* open to let blood pass and close to stop it flowing backward. Together they give *one-way flow* of blood around the body.
- **The four components of blood**: Blood has four components: *red blood cells* transport oxygen, *white blood cells* defend against pathogens, *platelets* help the blood clot, and *plasma* is the straw-coloured liquid that carries everything else. The first three are cells or cell fragments; plasma is the liquid they are suspended in.

EXAM TIPS

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

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

32 Transport in plants

KEY CONCEPTS

- **Functions of phloem**: Phloem transports *sucrose* and *amino acids*, the dissolved food substances a plant moves to wherever they are needed for growth or storage. Unlike xylem, phloem can carry these substances in *either direction* through the plant.
- **Functions of xylem**: Xylem transports *water* and *mineral ions* in one direction only, upward from the roots to the rest of the plant. Its cells have thick, strengthened walls, so xylem also gives the plant *support*.
- **Positions of xylem and phloem in root, stem and leaf**: In a *root*, xylem lies at the centre, often in a star-shaped pattern, with phloem in patches around it. In a *stem*, xylem and phloem sit together in vascular bundles arranged in a ring, xylem on the inner side of each bundle and phloem on the outer side. In a *leaf* vein, xylem lies toward the upper surface and phloem toward the lower surface.
- **Stomata and guard cells**: Water vapour leaves a leaf through tiny pores called *stomata* (singular: stoma), mainly on the lower surface. Each stoma is surrounded by a pair of *guard cells* that change shape to widen or narrow the pore, controlling how fast water vapour passes out.
- **The pathway of water through the plant**: Once absorbed, water follows a fixed order through the plant: *root hair cell*, then *cortex cells*, then *xylem*, then *mesophyll cells* of the leaf. Water crosses inward through the cortex to reach the central xylem, travels up the xylem to the leaf, then moves out into the mesophyll cells.
- **The root hair cell**: A *root hair cell* is a cell in the outer layer (epidermis) of a young root with a long, thin extension that grows out into the soil. It absorbs *water* and *mineral ions* from the soil, and has no chloroplasts because it is underground and does not photosynthesise.
- **What transpiration is**: *Transpiration* is the loss of water vapour from the leaves of a plant. Two details are separately examined: the water leaves as *water vapour*, not liquid, and it is lost from the *leaves*, not the roots.

33 Waves

KEY FORMULAS

Wave equation

$$v = f\lambda$$

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

KEY CONCEPTS

- **A wave transfers energy, not matter**: A wave is a travelling disturbance that transfers *energy* from one place to another without transferring *matter*. The particles of the medium oscillate about a fixed rest position and pass the disturbance to their neighbours, but are not carried along with it. Ripples spreading from a dropped pebble show this: the water mostly moves up and down, it does not travel outward with the ripples.
- **All electromagnetic waves travel at the same speed**: Every region of the electromagnetic spectrum travels at the same very high speed in a vacuum, and at approximately that same speed in air, whatever its frequency. Two electromagnetic signals sent the same distance, for example a radio wave and a gamma ray, always arrive together.
- **Audible range and ultrasound**: A typical human ear detects sound from about 20 Hz to $20\,000$ Hz. *Ultrasound* is any sound with a frequency above $20\,000$ Hz, so it is inaudible to humans even though it is still an ordinary sound wave.
- **How sound is made and why it needs a medium**: Sound is produced by a *vibrating source*. It needs a *medium* of particles to carry the vibration along, so it travels through solids, liquids and gases but *not* through a vacuum, since a vacuum has no particles to pass the disturbance on.
- **Law of reflection and the plane-mirror image**: At a plane surface the angle of incidence equals the angle of reflection, both measured from the *normal*, the line at right angles to the surface. The image in a plane mirror is the *same size* as the object, as far behind the mirror as the object is in front, and *virtual*, since the reflected rays only appear to come from behind the mirror.
- **Order of the electromagnetic spectrum**: In order of *increasing frequency* (and so *decreasing wavelength*): radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays. Radio waves have the longest wavelength and lowest frequency; gamma rays have the shortest wavelength and highest frequency. Visible light is the only region the human eye detects.
- **Refraction of light**: Refraction is the change in direction of a ray when its speed changes at a boundary between two media. Entering a *denser* medium such as glass the light slows down and bends *towards* the normal; leaving the denser medium it speeds up and bends *away* from the normal.

EXAM TIPS

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

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