Co-ordinated Sciences (0654)

IGCSE • Core • CAIE

Compact Cheat Sheet

The Practice Book
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1 Acids, bases and salts

KEY FORMULAS

Acid with a base: copper(II) oxide and sulfuric acid

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

Used whenever an acid reacts with a metal oxide or hydroxide, a base: the products are a salt and water only, with no gas released. Copper(II) oxide is a black solid that dissolves as it reacts, giving the blue solution of copper(II) sulfate as the visible sign. Write the acid as (aq), the oxide as (s), the salt as (aq) and water as (l).

Acid with a carbonate: calcium carbonate and hydrochloric acid

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

Used whenever an acid reacts with a carbonate: the products are a salt, water and carbon dioxide. The observation is vigorous effervescence, and bubbling the gas through limewater turns it milky, the standard test for carbon dioxide. The carbonate is added as a solid, (s), and the carbon dioxide escapes as a gas, (g).

Acid with a reactive metal: zinc and hydrochloric acid

$$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$$

Used whenever a reactive metal, one above hydrogen in the reactivity series such as magnesium, zinc or iron, meets a dilute acid. The state symbols carry marks of their own: the metal is added as a solid, the dilute acid is (aq), the soluble salt formed is (aq) and the hydrogen escapes as a gas, (g). The tell-tale observation is bubbles of a gas that gives a squeaky pop with a lit splint.

The three characteristic reactions of acids

$$acid + metal \rightarrow salt + hydrogen \cdot acid + base \rightarrow salt + water \cdot acid + carbonate \rightarrow salt + water + carbondioxide$$

Used to predict the products of any reaction of a dilute acid from what it meets. The three product patterns are fixed: a reactive metal gives a salt and hydrogen, a base gives a salt and water with no gas, a carbonate gives a salt, water and carbon dioxide. The salt's second name comes from the acid (hydrochloric gives chlorides, sulfuric gives sulfates, nitric gives nitrates); the first name comes from the metal, base or carbonate.

KEY CONCEPTS

- **Acid, base and alkali defined**: A *base* is a metal oxide or a metal hydroxide, and reacts with an acid to give a salt and water. An *alkali* is a base that is *soluble in water*. Every alkali is a base, but not every base is an alkali: sodium hydroxide is both, because it dissolves, while copper(II) oxide and magnesium oxide are bases but not alkalis, because they do not. Reacting with an acid to give a salt and water is a property of *all* bases, soluble or not, so that reaction alone never proves a substance is an alkali.
- **Hydrated and anhydrous defined**: A *hydrated* substance is one that is chemically combined with water, called water of crystallisation, built into its crystal structure. An *anhydrous* substance contains no water. Hydrated copper(II) sulfate is blue; anhydrous copper(II) sulfate is white. Heating a hydrated salt drives the water off as steam and leaves the anhydrous form behind, so the solid loses mass and changes colour; adding water reverses the change. Hydrated cobalt(II) chloride is pink and its anhydrous form is blue.
- **Indicator colours: litmus and methyl orange**: An *indicator* is a substance that is a different colour in acidic and alkaline solutions, so it reports which of the two a solution is. *Litmus*: red in acid, purple when neutral, blue in alkali. *Methyl orange*: red in acid, orange when neutral, yellow in alkali. The two changes worth locking in are "acid turns blue litmus red" and "alkali turns red litmus blue". Litmus does not give a reliable neutral reading, because its purple is hard to judge.

- **Metal oxides are basic, non-metal oxides are acidic**: An *oxide* is a compound of an element with oxygen, and its acid-base character follows the character of that element. *Metal oxides are basic*: they react with acids to give a salt and water. The syllabus names CuO and CaO; MgO and $\mathrm{Na_2O}$ behave the same way, and the soluble ones dissolve to give alkaline solutions. *Non-metal oxides are acidic*: they react with bases to give a salt and water, and the syllabus names $\mathrm{SO_2}$ and $\mathrm{CO_2}$. Classify from the element first: "basic, because magnesium is a metal and metal oxides are basic".
- **Neutralisation**: *Neutralisation* is the reaction of an acid with a base, including an alkali, to produce a *salt and water only*. There is no gas and the mixture warms up, so the absence of effervescence is itself an observation worth quoting. Followed with universal indicator, adding alkali to an acid moves the colour up the scale in order and gradually rather than in one jump: red, orange, yellow, green at pH 7, then blue and purple once the alkali is in excess.
- **The four routes to a soluble salt**: A soluble salt is made from an acid, which supplies the second part of its name, and a second reactant, which supplies the metal part. Reading the name backwards gives the two reactants: *nitrate* needs nitric acid, *chloride* needs hydrochloric acid. There are four routes, chosen by the second reactant: acid + excess reactive *metal*; acid + excess insoluble *base*; acid + excess insoluble *carbonate*; acid + an *alkali*, by titration. The first three add the solid *in excess* so all the acid is used up, then filter off the unreacted excess; titration is used instead for an alkali, because leftover alkali cannot be filtered out.
- **The pH scale and universal indicator**: The *pH scale* runs from 0 to 14 and shows how acidic or alkaline a solution is, not merely which. Below 7 is acidic, 7 is neutral, above 7 is alkaline. *Universal indicator* gives a continuous range of colours across the scale: red at the acidic end, strongly acidic, through orange and yellow, weakly acidic, green at pH 7, neutral, then blue through to purple at the alkaline end, strongly alkaline. The redder the solution, the lower the pH and the more acidic; the more purple, the higher the pH and the more alkaline.

EXAM TIPS

TIP The commonest lost mark in this chapter is the coefficient on the acid. Write the salt formula first from the charges, then count backwards to see how many acid molecules are needed. A metal ion carrying a $2+$ charge (Mg, Zn, Cu, Ca) needs *two* molecules of a monoprotic acid such as HCl or $\mathrm{HNO_3}$, because the salt takes two of the non-metal ions. Sulfuric acid, which supplies two hydrogens itself, usually needs no extra coefficient with a $2+$ metal. Check every element on both sides, then add the state symbols even when the question does not demand them.

TIP Every salt-preparation question is answered by one decision made before writing anything. Ask whether the second reactant is soluble. If it is *insoluble* (a metal, an insoluble base or a carbonate), use excess-then-filter, and say the excess ensures all the acid reacts and the excess is removed by filtration. If it is *soluble* (an alkali), the method must be *titration*: find the neutralising volume with an indicator, then repeat with the same volumes *without* indicator, so the dye does not contaminate the salt. Naming the wrong method loses every method mark that follows, however well the steps are described.

2 Atoms, elements and compounds

KEY FORMULAS

Electronic configuration of elements 1 to 20

$$\text{Na (proton number 11)}: \ 2,8,1 \qquad \text{Ca (proton number 20)}: \ 2,8,8,2$$

Use to write the configuration of any element with proton number 1 to 20. Fill shells from the nucleus outward, respecting the maxima 2, then 8, then 8, until the electrons run out; for a neutral atom the total equals the proton number.

Proton number and mass (nucleon) number

$$\text{mass number} = \text{proton number} + \text{number of neutrons}$$

Use to move between the proton number (the number of protons, which fixes the element) and the mass number (protons plus neutrons). Given any two, the third follows: an atom with proton number 12 and mass number 24 has $24 - 12 = 12$ neutrons.

KEY CONCEPTS

- **Cations and anions**: An *ion* is a charged particle formed when an atom loses or gains electrons. A metal atom loses electrons to form a positive ion, a *cation*: potassium $(2,8,8,1)$ loses one electron to become K^+. A non-metal atom gains electrons to form a negative ion, an *anion*: fluorine $(2,7)$ gains one electron to become F^-.
- **Diamond: a giant covalent structure**: *Diamond* is a giant covalent structure made only of carbon atoms. Every carbon atom is joined to four other carbon atoms by strong covalent bonds, repeated throughout the whole structure. Melting means breaking a huge number of strong covalent bonds, so diamond has an extremely high melting point and is extremely hard.
- **Element, compound and mixture defined**: An *element* is a substance made of only one type of atom. A *compound* is two or more different elements chemically bonded together in a fixed ratio, formed by a chemical reaction and separable only by chemical means. A *mixture* is two or more substances combined together with no chemical bond between them; the proportions can vary, each substance keeps its own properties, and physical methods separate it.
- **Isotopes defined**: *Isotopes* are different atoms of the same element that have the same number of protons but different numbers of neutrons. Same proton number means the same element; different neutron numbers mean different mass numbers. Chlorine exists as ${}^{35}_{17}\mathrm{Cl}$ and ${}^{37}_{17}\mathrm{Cl}$: both have 17 protons, but 18 and 20 neutrons respectively.
- **Relative charge and relative mass of the subatomic particles**: The *proton* has relative charge $+1$ and relative mass 1. The *neutron* has relative charge 0 and relative mass 1. The *electron* has relative charge -1 and a relative mass small enough to be treated as negligible. A neutral atom has equal numbers of protons and electrons, so its overall charge is zero.
- **The covalent bond: a shared pair of electrons**: A *covalent bond* forms when a pair of electrons is shared between two atoms, giving each atom a noble-gas electronic configuration. It forms between non-metal atoms. On this syllabus every covalent bond is a single shared pair, examined through six molecules: H_2, Cl_2, H_2O, CH_4, NH_3 and HCl.
- **The ionic bond: Group I meets Group VII**: An *ionic bond* is a strong electrostatic attraction between oppositely charged ions. It forms when a Group I metal transfers its one outer electron to a Group VII non-metal: lithium transfers its outer electron to fluorine, giving Li^+ and F^- in a $1:1$ ratio, held together in a giant lattice.
- **The nuclear atom**: Every atom has a central *nucleus*, containing *protons* and *neutrons*, surrounded by *electrons* arranged in *shells*. Almost all the mass of the atom is in the nucleus. For elements with proton number 1 to 20, the first shell holds a maximum of 2 electrons, and the second and third shells hold up to 8 each.

EXAM TIPS

TIP The classic trap is to reason that covalent bonds are strong, so a simple molecular compound must have a high melting point. That confuses two different forces: the covalent bonds *within* each molecule stay intact on melting; what breaks is the much *weaker forces between separate molecules*, which takes little energy. Name the force that is overcome, not the bond, and the mark follows.

3 Biological molecules

KEY CONCEPTS

- **Carbohydrates are built from glucose**: The small building block of carbohydrates is a simple sugar, *glucose*. Joining many glucose molecules into a chain produces a large carbohydrate: *starch* (the energy store of plants), *glycogen* (the energy store of animals) or *cellulose* (the material of plant cell walls). All three share the same single building block.
- **Elements of the three families**: Carbohydrates and fats are built from carbon (C), hydrogen (H) and oxygen (O) only. Proteins are built from those same three elements plus nitrogen (N). Testing which elements a pure molecule contains tells you which family it belongs to.
- **Fats are built from glycerol and fatty acids**: A fat molecule is built from two kinds of smaller unit: one molecule of *glycerol* and three molecules of *fatty acid*. Each fat is a fixed assembly of one glycerol to three fatty acids, never a variable "many" of one repeating unit as in a carbohydrate.
- **Nitrogen is the signature of protein**: Nitrogen is the one element that separates protein from the other two families: neither carbohydrates nor fats contain it. A pure molecule found to contain nitrogen must be a protein. A molecule found to contain only carbon, hydrogen and oxygen is a carbohydrate or a fat, and elements alone cannot decide which.
- **Proteins are chains of amino acids**: Proteins are built from *amino acids* joined into a long chain. Amino acids, and therefore proteins, always contain nitrogen in addition to carbon, hydrogen and oxygen, which is why proteins are the family identified by testing for nitrogen.
- **The four food tests at a glance**: Each biological molecule has one matching test: *iodine solution* for starch (orange-brown to blue-black, no heat), *Benedict's solution* for reducing sugar (blue to brick-red, with heat), *biuret solution* for protein (blue to purple, no heat), *ethanol then water* for fat (clear to cloudy white emulsion, no heat).

EXAM TIPS

TIP Iodine, biuret and the ethanol emulsion test are all added directly to the food sample with no heating. Benedict's solution is the exception: it must be heated, usually in a water bath, before the colour change appears. A described heating step in a food test always points to Benedict's test for reducing sugar.

TIP Give the *starting* colour and the *finishing* colour together, for example "orange-brown to blue-black", never the finishing colour alone. A vague description such as "it goes dark" loses the mark even when the correct test has clearly been identified.

4 Cells

KEY FORMULAS

Actual size from magnification

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

Used whenever a question gives a magnified image and its magnification and asks for the real size. This is a rearrangement of $M = \frac{\text{image size}}{\text{actual size}}$, obtained by multiplying both sides by actual size and then dividing by M.

Image size from actual size and magnification

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

Used whenever the real size and the magnification are known and the size of a drawing or photograph is needed. Give the answer in the same unit as the actual size.

Magnification

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

Used to find how many times larger, or smaller, an image is than the real specimen. Image size and actual size must be in the *same unit*, millimetres, before dividing; M has no units, since it is a ratio of two lengths.

Magnification has no unit

$$M = \times n$$

Magnification is a ratio of two lengths measured in the same unit, so the units cancel. Always write it as a plain number with a *times* sign, for example $\times 60$, never with mm attached.

KEY CONCEPTS

- **Bacterial cell structure**: A bacterial cell has a cell wall (not cellulose), a cell membrane, cytoplasm and ribosomes. Its genetic material is a single circular loop of *chromosomal DNA* free in the cytoplasm, often with one or more smaller loops called *plasmids*, so it has *no true nucleus*. It has no mitochondria, no chloroplasts and no permanent vacuole.
- **Mitosis makes identical cells**: New body cells are produced by *mitosis*, which gives two new cells genetically identical to the parent cell and to each other. Mitosis happens for *growth* (increasing the number of cells) and *repair and replacement* (replacing worn-out, damaged or dead cells), so division continues throughout life, not only in childhood.
- **Structures common to animal and plant cells**: Every animal and plant cell shares five structures. The *cell membrane* is a partially permeable boundary that controls which substances enter and leave. The *cytoplasm* is where most of the cell's chemical reactions happen. The *nucleus* holds the genetic material (DNA) and controls the cell's activities. *Mitochondria* are the site of aerobic respiration, releasing energy. *Ribosomes* are the site of protein synthesis.
- **The three plant-only extras**: A typical animal cell has none of these three structures. The *cell wall*, made of cellulose, lies outside the cell membrane and supports the cell, giving it a fixed shape. *Chloroplasts* contain chlorophyll and are the site of photosynthesis. The *permanent vacuole* is a large sac of cell sap that helps keep the cell firm.

EXAM TIPS

TIP Every cell, animal, plant or bacterial, has a cell *membrane*. What a typical animal cell lacks is the cell *wall*. The wall lies outside the membrane and is an extra layer, not a replacement for it, so "animal cells have no membrane" is always wrong.

5 Characteristics of living organisms

KEY CONCEPTS

- **Growth, reproduction, excretion and nutrition defined**: *Growth*: a permanent increase in size and dry mass. *Reproduction*: the processes that make more of the same kind of organism. *Excretion*: the removal of the waste products of metabolism and substances in excess of requirements. *Nutrition*: the taking in of materials for energy, growth and development.
- **Metabolism is the source of all seven characteristics**: *Metabolism* is the sum of all the chemical reactions taking place inside the cells of an organism. Each of the seven characteristics is a sign of metabolism at work: it releases the energy an organism uses (respiration), builds the new material an organism adds (growth), and produces the waste an organism must remove (excretion).
- **Movement, respiration and sensitivity defined**: *Movement*: an action by an organism, or part of an organism, that causes a change of position or place. *Respiration*: the chemical reactions in cells that break down nutrient molecules and release energy. *Sensitivity*: the ability to detect and respond to changes in the internal or external environment.
- **The seven characteristics of living organisms**: Every living organism shows seven characteristics, remembered by the mnemonic *MRS GREN*: Movement, Respiration, Sensitivity, Growth, Reproduction, Excretion, Nutrition. These describe what an organism is *able* to do over its lifetime, not what it must be doing at every single moment.
- **What counts as a waste product of metabolism**: Excretion removes waste that the organism's own chemical reactions produced, together with substances in excess of requirements. Urea from the breakdown of excess protein and carbon dioxide from respiration are both metabolic waste, so removing them is excretion. Undigested food that simply passes through the gut and out as faeces was never part of metabolism, so removing it is not excretion.

EXAM TIPS

TIP Where a question asks which characteristic is shown by *all* living organisms, excretion is a dependable answer: every organism has metabolism, so every organism produces metabolic waste that must be removed. It is a safer answer than movement or reproduction, since some organisms move very little and some individual organisms never reproduce.

TIP Marks are usually lost on a paraphrase, because a paraphrase drops the one word being credited. Growth is a *permanent* increase in size and *dry mass*; excretion removes the waste products of *metabolism*; reproduction makes *more of the same kind* of organism. Reproduce the wording above exactly rather than describing the idea in your own words.

6 Chemical energetics

KEY CONCEPTS

- **Classifying a reaction from the direction of the temperature change**: The direction of the change, not its size, decides the classification. If the temperature of the mixture *rises*, the reaction is *exothermic*; if it *falls*, the reaction is *endothermic*; if it shows *no change*, no net thermal energy has been transferred either way. A rise of 1 °C and a rise of 40 °C are both exothermic.
- **Endothermic reactions**: An *endothermic* reaction takes in thermal energy from the surroundings. Because that energy is drawn in, the temperature of the surroundings *decreases*. Thermal decomposition and the dissolving of certain salts, such as ammonium salts, are endothermic.
- **Everyday endothermic changes**: The thermal decomposition of a solid, such as heating copper carbonate to form copper oxide and carbon dioxide, is endothermic and needs a continuous supply of heat to keep going; it stops the moment heating stops. Dissolving certain salts, such as ammonium salts, in water is also endothermic and cools the solution.
- **Everyday exothermic changes**: Reactions that reliably transfer thermal energy out include combustion (a fuel burning in oxygen), the neutralisation of an acid by an alkali, and a reactive metal reacting with a dilute acid. All three warm the surroundings.
- **Exothermic reactions**: An *exothermic* reaction transfers thermal energy to the surroundings. Because that energy flows outward, the temperature of the surroundings *increases*. Combustion, neutralisation of an acid with an alkali, and a reactive metal reacting with an acid are all exothermic.

EXAM TIPS

TIP A bare number does not say which way thermal energy moved. Always state whether the change is a *rise* (temperature went up, exothermic) or a *fall* (temperature went down, endothermic), and record the starting and final temperatures to the same precision.

7 Chemical reactions

KEY FORMULAS

Average rate of reaction

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

Used to find the rate from a volume of gas, a mass loss or an amount of product, and the time it took. The units follow the quantity divided by time, giving $\mathrm{cm^3/s}$ or $\mathrm{g/s}$, so convert the time into the unit the answer asks for before dividing.

Instantaneous rate from the gradient of a tangent

$$\text{rate at a point} = \text{gradient of the tangent} = \frac{\Delta\text{volume}}{\Delta\text{time}}$$

Used when a question asks for the rate at one moment rather than over an interval. Draw a tangent touching the curve at that point and divide its rise by its run. The gradient falls from a maximum near the start of the reaction to zero once the curve is flat, which shows the rate falling to zero as the reaction finishes, not the reaction being at its fastest.

Reduction of lead(II) oxide by carbon

$$\mathrm{PbO + C \rightarrow Pb + CO_2}$$

Used to prove a reaction is redox from the equation alone, by tracking where the oxygen goes. The lead(II) oxide loses its oxygen to become lead, so it is reduced; the carbon gains that oxygen to become carbon dioxide, so it is oxidised. Both happen together, which is what makes the reaction redox, and the same reading applies to any metal extraction by carbon.

Thermal decomposition of calcium carbonate

$$\mathrm{CaCO_3 \rightarrow CaO + CO_2}$$

Used as the standard example of *thermal decomposition*, the breaking down of a single compound into two or more simpler substances using heat. One reactant splitting into two new products on heating is a chemical change, since new substances with different properties are formed.

KEY CONCEPTS

- **Comparing chemical properties is the strongest evidence**: A new substance has *different chemical properties* from the starting material, not just a different appearance or a different temperature. Testing whether rust reacts differently with dilute acid than iron does is stronger evidence of a chemical change than whether the rust can be scraped off, which is a physical property, or whether the metal feels warmer, which an energy change can also cause. Comparing chemical properties directly tests whether a new substance has formed.
- **Reading a volume-time graph**: A graph of volume of gas, or mass lost, against time is *steepest at the start*, where the rate is fastest, and *flattens* as the reactants are used up; once it becomes *horizontal* the reaction has finished, because a reactant has run out. Comparing two curves, the *steeper* curve had the faster rate, and the *height where each levels off* shows the total amount of product, which depends on the amount of reactant used, not on how fast the reaction went.
- **Redox is defined by oxygen alone on Core**: *Redox* is short for reduction and oxidation, and the two always happen *together*: if one substance gains oxygen, another must lose it. On Core, oxidation and reduction are defined only in terms of oxygen: *oxidation is the gain of oxygen* and *reduction is the loss of oxygen*. The Roman numeral in names such as iron(II), iron(III) and copper(II) is an oxidation number used only to *name* the ion; Core does not require working one out.
- **State symbols**: The state symbols (s), (l), (g) and (aq) mean solid, liquid, gas, and aqueous, meaning dissolved in water. They record what physically happens and carry no information about

whether a change is chemical: a reaction can produce an (aq) product and still be a chemical change, while $H_2O(l) \rightarrow H_2O(g)$ changes only the state symbol and is physical.

- **The five factors that speed up a reaction**: Five changes make a reaction faster, each in a single direction: increasing the *concentration* of a solution, increasing the *pressure* of a gas, increasing the *surface area* of a solid by using smaller pieces or a powder, increasing the *temperature*, and adding a *catalyst*. A higher concentration or pressure packs more particles into the same volume and a larger surface area exposes more particles to the other reactant, so all three raise how often particles meet; a higher temperature also gives the particles more energy.
- **The new-substance test**: One test decides whether a change is physical or chemical: *has a new substance been formed?* A physical change alters only the state or appearance of a substance and can usually be reversed, as in melting, dissolving or grinding. A chemical change, meaning a reaction, produces at least one new substance with different properties from the starting materials and is usually difficult to reverse. *Separating a mixture is always physical*, so filtering, dissolving and grinding never count as reactions even when the substance changes shape.
- **What a catalyst is**: A *catalyst* is a substance that increases the rate of a reaction and is chemically unchanged at the end of the reaction. Because it is not used up, weighing it before and after the reaction gives the same mass, and it changes only the *speed* of the reaction, not the total amount of product formed. Manganese(IV) oxide speeding up the decomposition of hydrogen peroxide into water and oxygen is the standard Core example.

EXAM TIPS

TIP Using a larger *volume* of a solution at the same concentration does not change the rate, because the concentration, the number of particles per unit volume, is unchanged. Only a genuinely more concentrated solution, or a change to one of the other four factors, speeds a reaction up. Using *larger pieces* of a solid is a rate-reducing change, not a rate-increasing one, because larger pieces expose less surface area.

TIP In the disappearing-cross method, and in any experiment where a *time* is the raw reading, a shorter recorded time means a *faster* reaction, not a slower one, which reads backwards until it is said aloud a few times. Always record the time to the nearest second, converting any reading given in minutes and seconds into seconds first.

8 Chemistry of the environment

KEY CONCEPTS

- **Adverse effects of the named air pollutants**: CO_2 and CH_4: higher levels lead to increased *global warming*, which leads to climate change. CO: a *toxic* gas that reduces the blood's ability to carry oxygen. Particulates: increased risk of *respiratory problems and cancer*. Oxides of nitrogen: *acid rain* and respiratory problems. SO_2: *acid rain*.
- **Composition of clean, dry air**: By volume, clean dry air is approximately *78% nitrogen* (N_2) and approximately *21% oxygen* (O_2). The remaining approximately *1%* is a mixture of the noble gases (mainly argon) and carbon dioxide (CO_2), not a single pure gas. *Dry* matters because real air also holds a variable amount of water vapour, left out of this standard composition.
- **Sources of the named air pollutants**: CO_2: *complete* combustion of carbon-containing fuels. CO and particulates: *incomplete* combustion, where the oxygen supply is limited. CH_4: decomposition of vegetation and waste gases from digestion in animals. Oxides of nitrogen: *car engines*. SO_2: combustion of fossil fuels that contain sulfur compounds.
- **Strategies to reduce the effects of climate change**: *Planting trees* removes carbon dioxide already in the atmosphere through photosynthesis. *Reducing livestock farming* cuts the methane released as a waste gas from digestion. *Decreasing fossil-fuel use* releases less carbon dioxide from combustion. *Increasing hydrogen and renewable energy* (for example wind and solar) generates energy without burning a carbon-containing fuel.
- **Testing whether a sample of water is pure**: Purity is judged by a *physical* property, not a colour change: a pure substance has a fixed, sharp melting point and boiling point. Pure water boils at *exactly 100 °C* and melts at *exactly 0 °C* at standard atmospheric pressure. Dissolving anything in the water raises the boiling point above 100 °C and lowers the melting point below 0 °C.
- **The four stages of domestic water treatment**: Raw water is made safe by a fixed sequence, one job per stage. *Sedimentation*: standing in tanks lets heavier insoluble solids settle out under gravity. *Filtration*: passing through a bed of sand traps the smaller insoluble solids that remain. *Carbon*: removes substances causing unpleasant tastes and odours. *Chlorination*: chlorine kills harmful microorganisms, making the water safe to drink.
- **Two chemical tests for the presence of water**: Anhydrous copper(II) sulfate is *white* and turns *blue* when water is added. Anhydrous cobalt(II) chloride is *blue* and turns *pink* when water is added. *Anhydrous* means without water; each solid takes water into its structure to form the coloured hydrated compound. Both changes are positive tests for the *presence* of water only.
- **Why distilled water is used in practical chemistry**: Tap water carries *dissolved chemical impurities* picked up from the ground and the supply system. Those impurities could react with the reagents being tested or add to the amount measured, giving a false result. *Distilled water* has been boiled and the steam condensed back to liquid, leaving the dissolved solids behind, so it contains far fewer chemical impurities.

EXAM TIPS

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

TIP The colour tests detect *water itself*; salty water, sugary water and pure water all turn anhydrous copper(II) sulfate blue, so they prove only that water is present. Purity is proved by boiling point and melting point alone. A liquid can turn cobalt(II) chloride pink *and* boil above 100 °C, meaning it contains water but is not pure.

9 Coordination and response

KEY CONCEPTS

- **Adrenaline and fight or flight**: *Adrenaline* is secreted by the adrenal glands in "fight or flight" situations, when the body is frightened, stressed or startled. Its effects are limited to three: increased breathing rate, increased heart rate, and increased pupil diameter.
- **Reflex action defined**: A *reflex action* automatically and rapidly integrates and coordinates a stimulus with the response of an effector. In plain terms: it is fast, it is automatic, and there is no conscious control by the brain. The effectors that carry out the response are muscles and glands.
- **Sense organs and their stimuli**: A *sense organ* is a group of receptor cells that responds to one specific stimulus. Learn the pairs: light is detected by the eye, sound by the ear, touch and temperature by the skin, and chemicals by the nose and tongue.
- **The central nervous system and its role**: The *central nervous system* (CNS) is the brain and the spinal cord, where information is processed and coordinated. The *peripheral nervous system* (PNS) is the nerves outside the brain and spinal cord, carrying impulses between the CNS and the rest of the body. Its role is the coordination and regulation of body functions, achieved by sending electrical impulses along neurones: stimulus, receptor, sensory neurone, CNS, motor neurone, effector, response.
- **The four glands and their hormones**: The Core syllabus names exactly four endocrine gland-and-hormone pairs, and the wording is "limited to" these: adrenal glands (one on top of each kidney) secrete adrenaline; the pancreas (in the abdomen, near the stomach) secretes insulin; the testes secrete testosterone; the ovaries secrete oestrogen.
- **The reflex arc sequence**: A *reflex arc* is the pathway an impulse follows during a reflex action: stimulus, receptor, sensory neurone, relay neurone (inside the CNS), motor neurone, effector, response, in that fixed order. The relay neurone's location inside the CNS, usually the spinal cord for a spinal reflex, is the fact most often tested.
- **The three neurones and the direction rule**: A *sensory neurone* carries impulses from a receptor to the CNS. A *relay neurone* lies entirely inside the CNS and connects a sensory neurone to a motor neurone. A *motor neurone* carries impulses from the CNS to an effector. Direction identifies each one: sensory neurones point inward to the CNS, motor neurones point outward to an effector, and the relay neurone never leaves the CNS.
- **What a hormone is**: A *hormone* is a chemical substance, produced by a gland, carried by the blood, that alters the activity of one or more specific target organs. The four load-bearing words, in order, are chemical, gland, blood, target; swapping a nervous-system word into any one of them, such as electrical, neurone or nerve, makes the whole statement wrong.

EXAM TIPS

TIP All three of adrenaline's syllabus effects increase: breathing rate up, heart rate up, pupil diameter up. Any option saying an effect decreases, narrows or slows contradicts the purpose of the fight-or-flight response and can be ruled out immediately.

TIP A receptor cell is the single cell that detects a stimulus; a sense organ is the whole structure built from a group of those cells. Writing "a receptor cell" where the question wants "a sense organ", or the reverse, is a common way to lose the mark.

Diseases and immunity

KEY CONCEPTS

- **Antibiotics treat bacterial infections, not viral ones**: Antibiotics are drugs used for the treatment of bacterial infections; they kill bacteria or stop them reproducing. Antibiotics do not affect viruses, so they do nothing for a disease such as influenza or measles. Some bacteria are resistant to antibiotics, which reduces how effective those antibiotics are.
- **Direct versus indirect transmission: the body-to-body test**: *Direct contact* is the pathogen passing straight from one body to another, including through blood and other body fluids. *Indirect* transmission is the pathogen travelling via something in between: a contaminated surface, contaminated food, an animal, or the air. The test that decides it: did the pathogen pass body-to-body, or did something carry it? If a surface, food, an animal or the air was involved at any point, the route is indirect, even when an infected person was the original source.
- **Five measures that control the spread of disease**: A clean water supply removes pathogens from drinking water. Hygienic food preparation stops pathogens being transferred onto food and stops those present from multiplying. Good personal hygiene, such as hand washing, removes pathogens from hands before they reach the mouth, food or another person. Waste disposal removes material pathogens grow in and that carries them back to food or water via animals. Sewage treatment keeps human waste, and the pathogens it carries, out of the water supply; the stages of sewage treatment are not required.
- **Pathogen and transmissible disease defined**: A *pathogen* is a disease-causing organism. A *transmissible disease* is a disease in which the pathogen can be passed from one host to another. Keep the two separate: the pathogen is the organism, the transmissible disease is the illness it produces and that illness is called transmissible because the pathogen behind it can move to a new host.
- **The body's five defences against pathogens**: Skin forms a physical barrier that stops pathogens entering the body. Hairs in the nose trap particles, including pathogens, in air that is breathed in. Mucus is a sticky layer in the airways that traps pathogens before they reach the lungs. Stomach acid kills many of the pathogens swallowed in food or drink. White blood cells carry out phagocytosis and produce antibodies that target pathogens.
- **Vaccinations are available for some pathogens**: Vaccinations are available for *some* pathogens to help control the spread of diseases, not for every pathogen that exists. Vaccination is given before a person meets the pathogen, so it is not a treatment for someone already ill.

EXAM TIPS

TIP An *antibiotic* is a drug, taken to treat an existing bacterial infection. An *antibody* is a substance that targets pathogens, produced by the body's own white blood cells. A *vaccine* is given before infection to help protect against a particular pathogen. Sort any option by asking whether it is a drug or a body product, and whether it acts before or after infection.

TIP Skin guards the outside of the body, nose hairs and mucus guard the airway, stomach acid guards the gut, and white blood cells act inside the body after something has already got past a barrier. A wrong option is usually a real defence with the wrong job attached to it, such as "stomach acid traps pathogens before the lungs" (that is mucus). Read the verb, not just the noun.

11 Drugs

KEY CONCEPTS

- **A drug is defined by mechanism, not by harm**: The definition of a drug says nothing about whether it is helpful or harmful. A life-saving medicine and a harmful substance can both be drugs, because "drug" is judged by what a substance does, not by whether it is good or bad for you.
- **Antibiotic resistance reduces effectiveness**: *Antibiotic resistance* is when some bacteria are able to survive an antibiotic that used to kill them. This reduces the effectiveness of the antibiotic against those bacteria; it does not mean the antibiotic stops working completely.
- **Antibiotics kill bacteria but do not affect viruses**: Antibiotics work against bacteria only. A viral illness such as a cold or flu is not affected by an antibiotic at all, no matter the dose.
- **Antibiotics treat bacterial infections**: An *antibiotic* is a drug used to treat bacterial infections: it kills bacteria or stops them multiplying, so the body's own defences can clear the rest. Penicillin is the standard named example.
- **The Daphnia caffeine test and the baseline idea**: To show a substance is a drug, compare its effect against an untreated baseline. Daphnia (small water fleas) have a normal heart rate in plain pond water, about 306 beats per minute; when moved into a caffeine solution the rate rises well above this baseline, showing caffeine has been taken in and has modified the chemical reactions that control heart rate.
- **The definition of a drug**: A *drug* is a substance taken into the body that modifies or affects chemical reactions in the body.

EXAM TIPS

TIP A drop in bacterial numbers, even a small one, shows the antibiotic has had some effect. Describing a sample as showing "no effect at all" is too strong unless the numbers genuinely did not change; a small drop means the antibiotic worked poorly against a mostly resistant sample, not that it did nothing.

TIP Keep the job of an antibiotic strict. It only treats bacterial infections; it does not relieve pain, does not act on viruses, and does not supply nutrients the way a food supplement does.

KEY FORMULAS

Combined resistance in series

$$R_{\text{total}} = R_1 + R_2 + \dots$$

Used to replace resistors connected one after another in a single loop by one resistance. The total is always larger than the largest individual resistor.

Current from power and voltage, for choosing a fuse

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

Used to find an appliance's normal operating current from its power rating P and the supply voltage V. Then choose the *smallest standard fuse rating above* that current (from 3 A, 5 A, 13 A, 30 A): too low and the fuse blows in normal use; too high and it will not blow soon enough to protect the appliance.

Electrical energy transferred

$$E = IVt$$

Used to find the electrical energy E transferred, in joules, when the time t is in seconds. Equivalent to $E = Pt$ once the power is already known.

Electrical power

$$P = IV$$

Used to find the power P in watts transferred by a component carrying current I in amperes across potential difference V in volts. Rearranges to $I = \frac{P}{V}$, the form used to find an appliance's normal operating current from its power rating and the mains voltage.

Resistance

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

Used to find the resistance R in ohms (Ω) from the potential difference V across a component in volts and the current I through it in amperes. Rearranges to $V = IR$ and $I = \frac{V}{R}$. A larger resistance means a smaller current for the same voltage.

KEY CONCEPTS

- **Current is a flow of charge, read from an ammeter**: An *electric current* is a flow of electric charge; in a metal wire the charges that move are *electrons*. Current is measured in *amperes (A)* with an *ammeter*, connected *in series* so it carries the very current it measures, and built with a *very low resistance* so adding it does not reduce that current.
- **Determining resistance experimentally**: Connect the component in *series* with a cell, a switch, an *ammeter* and a *variable resistor*; connect the *voltmeter in parallel* across the component only. Close the switch, set the variable resistor, and read the ammeter and voltmeter *at the same time*; calculate $R = V/I$. *Open the switch between readings* so the component does not heat up and drift, *repeat* for several settings, discard any *anomalous* reading, and take the *mean* of the calculated resistances.
- **Direct current and alternating current**: *Direct current (d.c.)* flows in *one direction only*; a cell or battery supplies d.c. *Alternating current (a.c.) repeatedly reverses direction*, many times each

second; the mains supply is a.c.

- **Fuses, trip switches, earthing and double insulation**: A *fuse* is a thin wire in the *live* wire that *melts and breaks the circuit* if the current exceeds its rating; it is one-shot and must be replaced. A *trip switch* does the same job automatically, faster, and can be *reset*. A *metal* casing is *earthed*, so a fault sends a large current to earth and blows the fuse. A *double-insulated* appliance has a plastic casing with no exposed metal, so it needs no earth wire.
- **Standard circuit symbols and what each component does**: *Cell* and *battery* (two or more cells) provide the voltage that drives the current; a *switch* completes or breaks the circuit; a *lamp* transfers energy to light and heat; a *fixed resistor* limits the current by a fixed amount, a *variable resistor* changes it smoothly; a *heater* transfers energy to heat the surroundings; a *motor* turns and drives something; an *ammeter* measures current *in series*; a *voltmeter* measures voltage *in parallel*; a *fuse* melts and breaks the circuit if the current is too large.
- **The heating effect of a current and the hazards**: A current passing through a wire makes it warm; a *thin* wire heats more than a thick one carrying the same current, because it has the greater resistance. The four hazards: *damaged insulation* (bare conductor gives a shock path), *overheating cables* (too much current melts the insulation and can start a fire), *damp conditions* (water conducts, giving current an easy path through a person) and *excess current from overloading* (too many appliances on one socket).
- **The law of electric charges and charging by friction**: There are two kinds of charge, *positive* and *negative*. *Like charges repel; unlike charges attract.* Charging by friction transfers *electrons* only: the material that gains electrons becomes negative, and the material that loses them becomes positive. Protons never transfer, because they are locked inside the nuclei of the atoms.
- **The law of magnetic poles and the test for a magnet**: Every magnet has a *north (N)* and a *south (S)* pole. *Like poles repel* (N with N, or S with S); *unlike poles attract* (N with S). Attraction alone never proves a bar is a magnet, because a magnet also attracts unmagnetised magnetic materials (*iron, steel, nickel, cobalt*). Only *repulsion* is decisive: only another magnet is pushed away when presented pole to like pole.
- **The parallel rules**: A parallel circuit has branches between the same two points. Each branch gets the *full source voltage*. The *branch currents add up to the source current*. The *combined resistance is less than the smallest branch resistance*, because the extra branch gives the current an extra route. If one branch fails, the others keep working.
- **The series rules**: A series circuit is a single loop with only one path for the current. The *current is the same at every point*. The *source voltage is shared* between the components. *Resistances add.* A break anywhere stops the current everywhere.
- **The source voltage causes the current and is shared**: The *voltage of the source* (cell, battery or power supply) *causes the current to flow*; without a source there is no current, however the components are arranged. Voltage is measured in *volts (V)*, also called *potential difference (p.d.)* across a component or *electromotive force (e.m.f.)* for a source, formal names for the same measured quantity on Core. In a *series* circuit the source voltage is *shared between the components*. A *voltmeter* measures voltage and is connected *in parallel* across the component, with a *very high resistance* so almost no current is diverted through it.

EXAM TIPS

TIP If a question asks for energy in *joules*, put the power in watts and the time in seconds. If it asks for a bill in *kilowatt-hours*, put the power in kilowatts and the time in hours: energy in kWh $=$ power in kW $\times$ time in hours, and cost $=$ energy in kWh $\times$ price per kWh. Mixing the two systems is the commonest way to lose these marks.

13 Electrochemistry

KEY FORMULAS

Molten lead(II) bromide: overall equation

$$\text{lead(II) bromide} \xrightarrow{\text{electrolysis}} \text{lead} + \text{bromine}$$

States the overall change for this named experiment. Electrolysis decomposes the ionic compound into its two elements, lead collecting at the cathode and bromine released at the anode.

Overall reaction: hydrogen and oxygen to water

$$\text{hydrogen} + \text{oxygen} \rightarrow \text{water}$$

States what a hydrogen-oxygen fuel cell actually does: the two gaseous reactants combine to give water and nothing else. Because no carbon is present anywhere in the reaction, no carbon dioxide can form.

KEY CONCEPTS

- **Concentrated aqueous sodium chloride: products and observations**: Concentrated aqueous sodium chloride (brine) is electrolysed with inert electrodes. At the *cathode*, *hydrogen* gas forms: colourless bubbles that burn with a squeaky pop when tested with a lighted splint. At the *anode*, *chlorine* gas forms: a pale yellow-green gas that bleaches damp litmus paper white.
- **Dilute sulfuric acid: products and observations**: Dilute sulfuric acid is electrolysed with inert electrodes. At the *cathode*, *hydrogen* gas forms, giving colourless bubbles that burn with a squeaky pop when a lighted splint is held to the gas. At the *anode*, *oxygen* gas forms, also colourless bubbles, but this gas relights a glowing splint. Both gases are colourless, so the splint tests are the only way to tell the two tubes apart.
- **Molten lead(II) bromide: products and observations**: Solid lead(II) bromide is heated until molten and electrolysed with inert carbon electrodes. At the *cathode*, positive lead ions are attracted there and *lead* forms, seen as a silvery-grey molten metal collecting at the electrode. At the *anode*, negative bromide ions are attracted there and *bromine* forms, seen as a red-brown vapour with a sharp choking smell.
- **The hydrogen-oxygen fuel cell**: A *hydrogen-oxygen fuel cell* uses hydrogen and oxygen to produce electricity, with *water as the only chemical product*. Hydrogen is fed to one electrode and oxygen, usually from the air, to the other; the two gases react through the cell and the energy is released as an electric current rather than as a flame.
- **The parts of an electrolytic cell**: The *anode* is the positive electrode, joined to the positive terminal of the power supply. The *cathode* is the negative electrode, joined to the negative terminal. The *electrolyte* is the molten or aqueous ionic substance being decomposed, the liquid the electrodes dip into; it is not an electrode and not the wire. In every experiment on this syllabus the electrodes are *inert*, made of platinum or carbon/graphite, and the power supply's job is to provide the direct current that drives the electrolysis.
- **What electrolysis is**: *Electrolysis* is the decomposition of an ionic compound, when molten or in aqueous solution, by the passage of an electric current. Three parts of that sentence carry the marks: *decomposition* means a chemical change that makes new substances, not simply dissolving; *ionic compound* means the substance must be built from ions, because ions are what move and carry the charge; and *molten or in aqueous solution* means the compound must be melted or dissolved, since a solid ionic compound does nothing at all.
- **Why the ions must be free to move**: In a solid ionic compound the ions are locked into fixed positions in a lattice, so no charge can flow and the compound does not conduct. Melting the compound, or dissolving it in water, breaks that fixed arrangement apart without removing the ions' charges, so the ions become *free to move* and a current can pass. No free-moving ions means no current and no electrolysis.

EXAM TIPS

TIP The commonest slip in this chapter is calling the electrolyte an electrode. The two rods dipping into the liquid are the electrodes; the liquid itself is the electrolyte. In a labelled diagram with four parts, the electrolyte is always the liquid, never the wire, the switch or the gap above the liquid.

TIP Learn the two tests as a pair, because the wording is nearly identical and easy to swap under pressure. A *lighted* splint that gives a *squeaky pop* identifies *hydrogen*. A *glowing* splint that *relights* identifies *oxygen*. Naming the wrong splint state, lighted instead of glowing, is the commonest way to lose this mark.

14 Enzymes

KEY CONCEPTS

- **Enzymes are protein catalysts that are not used up**: An *enzyme* is a *protein* that acts as a *biological catalyst*: it speeds up a chemical reaction and is not permanently changed or used up by it, so the same molecule catalyses reaction after reaction. Enzymes are involved in all the *metabolic reactions* of a living organism. The substance an enzyme acts on is its *substrate*; what the reaction produces is the *product*.
- **pH: every enzyme has an optimum, and it is not always 7**: Every enzyme has an *optimum pH* at which activity is greatest. Moving away from it in either direction, more acidic or more alkaline, reduces activity; moving far enough denatures the enzyme, exactly as with heat. The optimum is not always neutral: the protease in the stomach works best around pH 2.
- **Rate or time: read the column heading first**: Some result tables record a *rate*, such as volume of gas per minute, where a bigger number means a faster reaction. Others record a *time*, such as how long a colour change took, where a smaller number means a faster reaction. The optimum is the largest rate or the shortest time; always check the heading before picking a value.
- **Specificity: each enzyme has its own substrate**: Each enzyme normally acts on only one substrate, or one narrow group of similar substrates, a property called *specific*. Learn the four pairs: *amylase* acts on starch, *protease* on protein, *lipase* on fats and oils, *catalase* on hydrogen peroxide. An enzyme having no effect on a substance it is not specific to is not a fault, the wrong conditions, or being used up, it is simply not that enzyme's substrate.
- **Temperature: rises to a peak, then crashes to zero**: As temperature rises from cold, enzyme activity increases up to the *optimum temperature*, the temperature at which activity is greatest (about 37°C for human enzymes). Above the optimum, activity falls sharply to zero because the enzyme is *denatured*: strong heat permanently changes the protein's shape, and a denatured enzyme cannot work again.
- **The temperature and pH graphs share one shape**: A graph of activity against temperature and a graph of activity against pH both rise to a single peak, the optimum, and then fall, because each variable has exactly one optimum. For temperature the fall is steep and reaches zero because of denaturation; for pH the curve is usually a symmetrical bell either side of the optimum.

EXAM TIPS

TIP Temperature, pH and substrate concentration each affect enzyme rate independently, so an investigation into one must keep the other two fixed, for example with a *water bath* for temperature and a *buffer solution* for pH. If two variables differ between trials, any difference in rate cannot be attributed to either alone, and the result is invalid.

TIP A denatured enzyme has a permanently changed shape and does not work again, even on cooling; an enzyme merely slowed by cold is undamaged and recovers fully on warming. Enzymes are molecules, not organisms, so never describe heat as "killing" them, and never describe a catalyst as being "used up".

15 Experimental techniques and chemical analysis

KEY FORMULAS

Solubility scaled to 100 g of solvent

$$\text{solubility (g per 100 g water)} = \text{mass of solute (g)} \times \frac{100}{\text{mass of water (g)}}$$

Used whenever a solubility is quoted per $100\ \text{g}$ of solvent but the experiment used a different mass of water. Scale the mass of water up (or down) to $100\ \text{g}$ and scale the dissolved mass of solute by the *same* factor. E.g. $18\ \text{g}$ dissolving in $50\ \text{g}$ of water scales to $18 \times \frac{100}{50} = 36\ \text{g}$ per $100\ \text{g}$ of water.

Titre from the two burette readings

$$\text{titre} = \text{final burette reading} - \text{initial burette reading}$$

Used to find the volume of acid actually run in from the burette, which is never read straight off the final mark alone, because the burette rarely starts at zero. Both readings are taken to the nearest $0.05\ \text{cm}^3$, reading the bottom of the meniscus at eye level.

KEY CONCEPTS

- **Choosing a separation technique**: Match the technique to the mixture. *Filtration* removes an insoluble solid from a liquid, exploiting particle size: the solid stays on the paper as the *residue*, the liquid passes through as the *filtrate*. *Crystallisation* obtains a soluble solid from its solution by evaporating some solvent, then cooling slowly so pure crystals grow. *Simple distillation* obtains a pure solvent from a solution. *Fractional distillation* separates two or more miscible liquids with different boiling points, using a fractionating column. Filtration can never separate two miscible liquids, since there is no insoluble solid for it to trap.
- **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 both collects a gas and reads its volume directly from the position of its plunger.
- **How paper chromatography separates a mixture**: A spot of the mixture is placed on a *pencil* baseline near the bottom of the paper, and the solvent in the tank must start *below* that baseline, or the spot would dissolve straight into the solvent instead of being carried up the paper. As the solvent rises it dissolves each substance and carries it up the paper; a substance that is more soluble in the solvent travels further, so the components of the mixture separate into a line of spots.
- **Key experimental terms**: A *solvent* is the liquid that does the dissolving; a *solute* is the substance that dissolves in it; a *solution* is the mixture the two form together. A *saturated solution* holds the maximum mass of solute that will dissolve at that temperature; adding more leaves solid undissolved however long it is stirred. In filtration, the insoluble solid trapped on the filter paper is the *residue*, and the liquid that passes through is the *filtrate*.
- **Purity from melting and boiling points**: A *pure* substance melts at one sharp, fixed temperature and boils at one sharp, fixed temperature, rather than over a range. An impurity *lowers and broadens* the melting point, so an impure solid melts gradually over a range instead of at one value, and it *raises* the boiling point above the pure value.
- **Reading purity and identity 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. An unknown substance is identified by running it alongside known reference substances, on the same paper, in the same solvent, under identical conditions: an unknown spot that lines up at the *same height* as a reference spot is very likely the same substance.
- **Testing cations with sodium hydroxide and ammonia**: Add aqueous sodium hydroxide *drop by drop, then in excess*. 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; zinc gives a white precipitate that *dissolves* in excess to a colourless solution. Ammonium gives no

precipitate, but releases ammonia gas on warming. With aqueous ammonia the results match, except copper(II) dissolves in excess to a *deep blue* solution.

- **Tests for anions**: *Carbonate* CO_3^{2-}: add dilute acid, giving effervescence, and the gas turns limewater milky. *Chloride* Cl^-, *bromide* Br^- and *iodide* I^-: acidify with dilute nitric acid, then add aqueous silver nitrate, giving a *white*, *cream* and *yellow* precipitate respectively. *Sulfate* SO_4^{2-}: acidify with dilute nitric acid, then add aqueous barium nitrate, giving a white precipitate.
- **Tests for the five gases**: *Hydrogen*: a lighted splint gives a squeaky pop. *Oxygen*: a glowing splint relights. *Carbon dioxide*: bubbled through limewater, it turns the limewater milky. *Chlorine*: turns damp litmus paper red and then bleaches it white. *Ammonia*: turns damp *red* litmus paper blue, because it is alkaline.
- **The acid-base titration method**: The *alkali* is measured into the conical flask with a volumetric pipette, and indicator is added. The *acid* is run in from a burette, swirling the flask continuously so the acid mixes evenly with the alkali as it enters rather than reacting only where it lands. The *end-point* is the point at which the indicator just changes colour, showing the acid and alkali have exactly reacted.

EXAM TIPS

TIP Dip a *clean* wire in the sample and hold it in the edge of a hot, blue Bunsen flame. *Lithium* gives a red (crimson) flame, *sodium* a yellow flame, *potassium* a lilac flame and *copper(II)* a blue-green flame. An unclean wire can carry over a trace of sodium and mask a fainter colour, so the wire must be cleaned before each new sample.

16 Gas exchange in humans

KEY FORMULAS

Change in a gas's percentage

$$\text{Change} = \text{larger value} - \text{smaller value}$$

Used to find how far a gas's percentage moves between inspired and expired air; always subtract the smaller of the two values from the larger one, whichever direction the change runs.

Increase in breathing rate during exercise

$$\text{Increase in rate} = \text{rate during/after exercise} - \text{resting rate}$$

Used to find how much breathing rate rises because of exercise; subtract the resting (before) value from the exercise (during or shortly after) value.

KEY CONCEPTS

- **Breathing, gas exchange and respiration are three different processes**: *Breathing* is the mechanical movement of air into and out of the lungs. *Gas exchange* is the diffusion of oxygen and carbon dioxide across the alveoli. *Respiration* is the chemical release of energy from nutrients inside every living cell. The three words describe three different processes and must not be treated as synonyms.
- **Composition of inspired and expired air**: Oxygen falls from about 21% to about 17% (some is taken into the blood). Carbon dioxide rises from about 0.04% to about 4% (produced by respiration in the body's cells). Nitrogen stays at about 78% in both, since the body neither uses nor produces it. Water vapour rises from a low to a high level.
- **Protecting the airways: mucus and ciliated cells**: Sticky *mucus* lining the trachea and bronchi traps dust, particles and pathogens before they reach the alveoli. *Ciliated cells* alongside it carry beating *cilia* that sweep the trapped mucus upward toward the throat, where it is swallowed or coughed out.
- **Testing for carbon dioxide with limewater**: *Limewater* is a reagent that turns from clear to *cloudy* in the presence of carbon dioxide, and the more carbon dioxide present, the faster it clouds. Bubbling exhaled air and inhaled air through separate, identical volumes of limewater lets the two be compared.
- **The pathway of air from mouth to alveoli**: Air passes from the nose or mouth to the *larynx* (the voice box), then the *trachea* (the single windpipe), which divides into two *bronchi* (one per lung), which branch into narrower *bronchioles*, ending at the *alveoli*, tiny air sacs wrapped in blood capillaries where gas exchange happens. The *ribs*, *intercostal muscles* and *diaphragm* form the pump that moves air in and out.

EXAM TIPS

TIP Nitrogen stays at about 78% in both inspired and expired air, because the body neither uses it nor produces it. Where a question asks which gas does *not* change between inspired and expired air, nitrogen is the answer.

TIP On a labelled diagram, the *single* central tube at the top, before it divides, is always the *trachea*; one of the two tubes after the division, entering a lung, is a *bronchus*; a fine branch deep inside a lung is a *bronchiole*; and the dome-shaped sheet of muscle at the base of the chest is the *diaphragm*.

17 Human influences on ecosystems

KEY CONCEPTS

- **Biodiversity counts species, not individuals or mass**: *Biodiversity* is the number of different species that live in an area. It is not population size, the number of individual organisms, and not biomass, their total mass. A field of a million wheat plants has a huge population but a biodiversity of one.
- **Ecosystem: the three-part definition**: An *ecosystem* is a unit containing the community of organisms and their environment, interacting together. The *community* is every population of organism present; the *environment* is the non-living surroundings (water, air, soil, sunlight); *interacting* means the two affect each other. Leaving out either the non-living half or the interaction describes only a community, not an ecosystem.
- **Endangered and extinct defined**: A species is *endangered* when its numbers have fallen so low that it is at risk of dying out completely. A species is *extinct* when no individuals remain anywhere. The distinction matters for conservation questions: an endangered species can still be raised by conservation action, an extinct species cannot.
- **Five undesirable effects of deforestation, stated**: Clearing forests causes five undesirable effects: reduced biodiversity, extinction of species with nowhere left to survive, loss of soil, flooding, and an increase of carbon dioxide in the atmosphere. On Core these five are *stated* as a list; naming which one an option describes, and getting its direction right, is the skill tested.
- **Four conservation methods**: Conservation on Core is limited to four methods: monitoring and protecting species and habitats; education, to change human behaviour towards a species; captive breeding programmes, to raise numbers before release to the wild; and seed banks, storing the seeds of rare plants so the species can be regrown later.
- **Six reasons for endangerment or extinction**: A species becomes endangered or extinct for one or more of six reasons: climate change, habitat destruction, hunting, overharvesting, pollution, and introduced species. Identify which reason a scenario shows by matching its exact wording, not a general impression of harm.
- **Three reasons habitats are destroyed**: Humans destroy habitats for three reasons: increased area for housing, crop production and livestock production; extraction of natural resources such as mining, quarrying and drilling; and freshwater and marine pollution from untreated sewage and chemical waste. An option that protects or restores a habitat is never one of the three reasons.

EXAM TIPS

TIP A seed bank stores the seeds of rare *plants*, never animal material such as DNA, scales or feathers. An option offering to store animal material in a seed bank misapplies the method; the correct answer for a rare animal is captive breeding instead.

18 Human nutrition

KEY FORMULAS

Comparing nutrient percentages at equal total mass

$$\text{if total mass}_1 = \text{total mass}_2\text{, then } \%_1 > \%_2 \iff \text{mass}_1 > \text{mass}_2$$

Used when two portions of equal total mass are compared; because the denominator is the same for both, the portion with the higher percentage by mass always contains the greater actual mass of that nutrient.

Percentage of a nutrient by mass

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

Used whenever a question gives the mass of one nutrient in a stated portion mass and asks for its percentage by mass; divide the nutrient's mass by the total mass and multiply by 100.

KEY CONCEPTS

- **Chemical digestion: large insoluble to small soluble**: *Chemical digestion* is the breakdown of large, insoluble molecules into small, soluble molecules, carried out by enzymes. Starch becomes sugar, protein becomes amino acids, and fat becomes fatty acids and glycerol.
- **Deficiency diseases: keep the two pairings exact**: *Scurvy* is caused by a lack of *vitamin C* and gives swollen, bleeding gums and slow wound healing. *Rickets* is caused by a lack of *vitamin D* (and the calcium it helps absorb) and gives soft, weak bones that bend. Vitamin D is made in the skin in sunlight as well as taken in from oily fish and dairy foods, so low dietary calcium and low sunlight exposure combine to raise rickets risk.
- **Physical digestion: smaller pieces, no chemical change**: *Physical (mechanical) digestion* is the breakdown of food into smaller pieces without any chemical change to the food molecules. Chewing at the mouth and churning by the stomach's muscular walls change only the size of the pieces; every starch, protein or fat molecule inside is still the same molecule afterwards.
- **The alimentary canal in order**: Food travels, in order, through the *mouth* (chewed and mixed with saliva), the *oesophagus* (a muscular tube pushing food to the stomach), the *stomach* (a muscular sac that churns food), the *small intestine* (the duodenum and ileum, where digestion is completed and nutrients are absorbed), and the *large intestine* (the colon, rectum and anus, which absorbs water and stores undigested food before it is egested).
- **The four associated organs**: *Salivary glands* secrete saliva into the mouth. The *liver* makes bile. The *gall bladder* stores and concentrates bile, releasing it into the small intestine. The *pancreas* secretes digestive juice into the small intestine. None of these organs is part of the tube food actually passes through.
- **The role of chemical digestion**: The role of chemical digestion is to produce molecules small and soluble enough to be *absorbed*, crossing the wall of the small intestine into the blood. A molecule can fail to be absorbed because it is too large, or because it is insoluble; chemical digestion fixes both at once.
- **The seven components of a balanced diet**: *Carbohydrates* are the main energy source; *fats and oils* are a concentrated energy store and insulation; *protein* is for growth and repair; *vitamins* (the syllabus names C and D) are needed in small amounts for health; *mineral ions* (calcium for bones and teeth, iron for haemoglobin) support specific functions; *fibre* gives bulk that keeps food moving through the gut; *water* is the solvent for reactions and transport.
- **What a balanced diet means**: A *balanced diet* contains all the nutrient types the body needs (carbohydrates, fats and oils, protein, vitamins, mineral ions, fibre and water), in amounts and proportions correct for that individual. Both parts of the definition must be present, every nutrient type and quantities suited to the person; a diet is not balanced merely because it is plentiful or because it follows one fixed recipe.

EXAM TIPS

TIP The *liver* makes bile but no enzymes; the *pancreas* makes digestive juice but no bile; the *gall bladder* makes nothing at all, it only stores and releases the bile the liver has already made. Confusing these three costs marks on almost every paper that tests this chapter.

TIP A question about a nutrient asks for either its *dietary source* (where it comes from) or its *importance* (what the body uses it for), and sometimes both. Answering the wrong half, or only one half when two are asked for, is the commonest way to lose these marks.

19 Inheritance

KEY CONCEPTS

- **Chromosome, gene and allele: the three nested terms**: A *chromosome* is a length of DNA, found in the nucleus, that carries genetic information. A *gene* is a length of DNA that codes for a specific protein; a single chromosome carries many genes. An *allele* is an alternative form of a gene, for example a round-seed allele and a wrinkled-seed allele of the same seed-shape gene.
- **Dominant and recessive alleles**: A *dominant* allele is expressed whenever it is present in the genotype, written as a capital letter; it masks the effect of any recessive allele present alongside it. A *recessive* allele is only expressed when no dominant allele of that gene is present, written as a small letter.
- **Genotype versus phenotype**: *Genotype* is the genetic make-up of an organism, written as its alleles, for example *Rr*. *Phenotype* is the observable features of an organism, for example *red flowers*. A quick check: the genotype uses letters; the phenotype uses a description you could see.
- **Homozygous, heterozygous and pure-breeding**: *Homozygous* means having two identical alleles of a gene, for example BB or bb. *Heterozygous* means having two different alleles, for example Bb. A homozygous individual bred with an identical genotype is *pure-breeding*, always reproducing that same genotype; a heterozygous individual is not pure-breeding, since it produces a mixture of genotypes.
- **How sex is decided: XX and XY**: One pair of chromosomes is the sex chromosomes. A female is *XX*; a male is *XY*. A mother is XX, so every egg cell carries an X; a father is XY, so half his sperm carry an X and half carry a Y. An X-carrying sperm fertilising the egg gives XX (female); a Y-carrying sperm gives XY (male). The father's sperm decides the child's sex, and the expected ratio of male to female offspring is 1:1.
- **What inheritance means**: *Inheritance* is the transmission of genetic information from one generation to the next. Monohybrid inheritance is the inheritance of a single characteristic controlled by one gene.

EXAM TIPS

TIP Gene and allele are the most confused pair of terms in this chapter. Every plant has the seed-shape gene; round and wrinkled are its alleles. If a question asks for the alternative *forms* of a characteristic, the answer is allele, not gene; if it asks for the length of DNA responsible for the characteristic, the answer is gene, not allele.

TIP If two parents show no sign of a condition yet produce an affected child, the allele responsible must be recessive: each parent was a hidden, heterozygous carrier. An individual showing a recessive phenotype must be homozygous recessive, because a single dominant allele would have masked it; fix this individual's genotype first in any pedigree question, then work outwards.

20 Metals

KEY FORMULAS

General equations for a metal with water and with steam

$$\text{metal} + \text{water} \rightarrow \text{metal hydroxide} + \text{hydrogen} \text{ and } \text{metal} + \text{steam} \rightarrow \text{metal oxide} + \text{hydrogen}$$

Use the first for a very reactive metal in cold water, for example $Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$. Use the second for a moderately reactive metal heated in steam, for example $Mg + H_2O \rightarrow MgO + H_2$. Cold water gives a *hydroxide*; steam gives an *oxide*.

General reactions of a metal with oxygen and with dilute acid

$$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide} \text{ and } \text{metal} + \text{acid} \rightarrow \text{salt} + \text{hydrogen}$$

Use the first for any metal burning or tarnishing in air; a metal oxide is *basic* and neutralises an acid, unlike an acidic non-metal oxide. Use the second for a metal above hydrogen in the reactivity series added to a dilute acid, shown by fizzing that pops with a lit splint. A worked case: $2Mg + O_2 \rightarrow 2MgO$. Metals below hydrogen, such as copper, give no reaction with dilute acid.

Mass of one component in an alloy from a percentage composition

$$\text{mass of component} = \frac{\%\ \text{composition}}{100} \times \text{total mass}$$

Use whenever a percentage-by-mass composition is given for an alloy. For solder that is 37% lead and 63% tin by mass, the lead in a 4 kg sample is $0.37 \times 4 = 1.48$ kg. Always name which element the percentage belongs to before multiplying, since the two components' percentages are easy to swap.

KEY CONCEPTS

- **A metal atom loses electrons to form a positive ion**: When a metal reacts, whether with oxygen, acid, water or steam, the metal atom *loses its outer electrons* and becomes a *positive ion*. That single fact is examinable at Core in exactly this qualitative form: state that electrons are lost and a positive ion is formed, without the half-equation notation used to write it out symbolically.
- **Alloys are harder and stronger than the pure metal**: An alloy is generally *harder and stronger* than the pure metal it is made from, which is why alloys are used far more widely in engineering than pure metals. Brass is harder than pure copper; steel is harder than pure iron.
- **An alloy is a mixture, not a compound**: An *alloy* is a mixture of a metal with one or more other elements. Its atoms are simply mixed and not chemically joined in a fixed ratio, so the composition can vary from sample to sample, which is why an alloy is classed as a mixture rather than a compound.
- **Barrier methods prevent rusting by keeping out oxygen and water**: Painting, greasing or oiling, and coating with plastic are *barrier methods*. Each forms a physical layer over the iron that stops oxygen and water reaching the surface underneath. A barrier only protects where it is intact; a chip exposes bare iron and rust starts there.
- **Extracting aluminium: bauxite and electrolysis**: The main ore of aluminium is *bauxite*. Aluminium lies above carbon, so carbon cannot remove the oxygen from aluminium oxide, and aluminium is instead extracted by *electrolysis*, a far more expensive process used only where reduction with carbon will not work.
- **Extracting iron: hematite and the blast furnace**: The main ore of iron is *hematite*, which contains iron(III) oxide. Iron lies below carbon, so it is extracted by *reduction of iron(III) oxide in the blast furnace*; here reduction means removal of oxygen from the ore. Molten iron, being denser, collects below the molten slag at the base of the furnace and is tapped off separately.
- **How each band of the series reacts with water, steam and acid**: Potassium, sodium and calcium react with *cold water*, giving a metal hydroxide and hydrogen. Magnesium, zinc and iron react little with cold water but react with *steam*, and with *dilute acid*, both giving hydrogen. Copper, silver and

gold react with none of them. A metal above hydrogen fizzes with dilute acid; a metal below hydrogen does not react with it.

- **Matching a metal's property to its use**: Every "why is this metal used for this job" question is answered by matching one property to the requirement. *Copper* is used for electrical wiring because it conducts electricity well. *Aluminium* is used for aircraft manufacture (low density), for overhead electrical cables (low density *and* good electrical conductivity) and for food containers (resistance to corrosion).
- **Physical properties: metals compared with non-metals**: Metals generally *conduct heat and electricity well*, are *malleable* (hammered into shape without cracking) and *ductile* (drawn into wire), are shiny when freshly cut, sonorous, dense and have high melting points. Non-metals are generally the opposite: poor conductors, brittle rather than malleable, dull, and low melting. The two properties examiners test most often are good electrical conductivity and malleability, because a non-metal solid neither conducts nor bends.
- **Reactivity decides how easily a metal is extracted**: The more reactive a metal, the more *stable* the compound it forms, so the *harder* it is to extract from its ore. Carbon is the dividing line: metals above carbon (potassium to aluminium) cannot have their oxide reduced by carbon and are extracted by *electrolysis*; metals below carbon (zinc, iron, copper) are extracted by *heating with carbon*; the least reactive metals, silver and gold, are so unreactive they are found *native*, needing little or no extraction.
- **Rusting needs both oxygen and water**: *Corrosion* is the gradual reaction of a metal with substances in its surroundings; for iron and steel the process is *rusting*. Rusting requires *both* oxygen and water. Remove either one and rusting stops.
- **The named alloys and their elements**: *Brass* is a mixture of copper and zinc. *Stainless steel* is a mixture of iron with other elements such as chromium, nickel and carbon; it is used for cutlery because it is hard and resists rusting.
- **The reactivity series in order**: The *reactivity series* lists metals in order of how readily they react, most reactive first: potassium, sodium, calcium, magnesium, aluminium, (carbon), zinc, iron, (hydrogen), copper, silver, gold. Carbon and hydrogen are included as reference points because a metal's position relative to each one decides how it behaves with acid and how it is extracted.

21 Motion, forces and energy

KEY FORMULAS

Average speed

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

Used to find the average speed of a journey from the total distance travelled and the total time taken, or rearranged to $s = vt$ and $t = s/v$. It gives the average over the whole journey, not the speed at any one instant.

Density

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

Used to find the density of a substance from its mass and volume, or rearranged to $m = \rho V$ and $V = m/\rho$. Report it in g/cm^3 when the mass is in grams and the volume in cm^3, or in kg/m^3 when both are in base units. Never mix the two.

Mechanical work

$$W = Fd$$

Used to find the work done when a force moves an object through a distance *in the direction of the force*, or rearranged to $F = W/d$. It is measured in joules, and 1 J = 1 N m. The work done is equal to the energy transferred.

Moment of a force

$$M = F \times d$$

Used to find the turning effect of a force about a pivot, where d is the *perpendicular* distance from the pivot to the line of the force. The unit is the newton metre (N m). The same force applied further from the pivot produces a larger moment, which is why a door opens more easily when pushed at its edge.

Power

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

Used to find the rate at which energy is transferred, or equivalently $P = W/t$, the rate of doing work. It is measured in watts, and 1 W = 1 J/s. Rearranges to $E = Pt$ and $t = E/P$. Convert any time given in minutes to seconds before substituting.

Pressure

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

Used to find the pressure a force exerts over a contact area, or rearranged to $F = pA$ and $A = F/p$. It is measured in pascals, and 1 Pa = 1 N/m^2. The area must be in m^2 for the answer to be in pascals.

Weight from mass

$$W = mg$$

Used to find the weight in newtons from a mass in kilograms and the gravitational field strength g in N/kg, or rearranged to $g = W/m$. Near the Earth's surface $g \approx 9.8$ N/kg. Convert any mass given in grams to kilograms before substituting.

KEY CONCEPTS

- **Choosing the right instrument for length, volume and time**: A *ruler* measures a straight length, read at eye level to avoid a parallax error. A *measuring cylinder* measures the volume of a liquid, read at the bottom of the meniscus. A *clock* or *digital timer* measures a time interval. Match the instrument to the quantity being measured, not the other way round.
- **Energy stores and the conservation of energy**: Energy is held in *stores*: kinetic, gravitational potential, chemical, elastic (strain), nuclear, electrostatic and internal (thermal). The principle of *conservation of energy* states that energy cannot be created or destroyed, only transferred from one store to another, so the total energy is always the same before and after an event.
- **Measuring the density of an irregular solid by displacement**: The volume of an irregular solid cannot be measured with a ruler, so it is found by *displacement*. Find the mass on a balance. Part-fill a measuring cylinder with water, read the level, lower the solid in until it is fully submerged and read the new level. The volume of the solid is the *rise* in level, the difference between the two readings, not the final reading. Then apply $\rho = m/V$.
- **Resultant force and Newton's first law**: The *resultant* force is the single force with the same effect as all the forces acting together. Along a line, add forces pointing the same way and subtract those pointing in the opposite direction; the resultant acts in the direction of the larger force. A force can change an object's size, shape or motion. Newton's first law states that when the resultant force on an object is zero, it stays at rest or continues to move at a constant speed in a straight line.

EXAM TIPS

TIP A single swing of a pendulum is too short to time accurately, because the reaction time at the start and the stop is a large fraction of the reading. Time *20* complete oscillations and divide by 20: the same reaction-time error is spread across 20 readings, so the error in one period is 20 times smaller. State the number timed in the answer. The same reasoning applies to any small distance or short repeated event, average it over many.

22 Movement into and out of cells

KEY FORMULAS

Percentage change in mass

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

Used in the potato-cylinder osmosis practical to compare cylinders of slightly different starting sizes fairly. A positive value means the tissue gained water (was in a more dilute solution); a negative value means it lost water (was in a more concentrated solution).

Surface area to volume ratio and organism size

$$\text{surface area to volume ratio} = \frac{\text{surface area}}{\text{volume}}$$

Everything an organism takes in by diffusion enters through its surface, but every cell needing supply sits in its volume. As an organism gets bigger this ratio falls, so diffusion alone becomes too slow and the organism needs a specialised exchange surface plus a transport system.

KEY CONCEPTS

- **Active transport defined**: *Active transport* is the movement of particles through a cell membrane from a region of their lower concentration to a region of their higher concentration, that is against a concentration gradient, using energy from respiration. Both features must be true together: a statement with only one of them describes diffusion or osmosis instead.
- **Diffusion defined**: *Diffusion* is the net movement of particles from a region of their higher concentration to a region of their lower concentration, that is down a concentration gradient, as a result of the random motion of the particles. Both halves of a correct statement must agree: higher to lower concentration and down the gradient; reversing either half describes active transport instead.
- **Diffusion through the cell membrane**: Some substances move into and out of cells by diffusion through the cell membrane, which is *partially permeable*: small particles such as oxygen, carbon dioxide and water cross it freely, while large molecules such as proteins are held back. Before naming a movement as diffusion, check two things: is there a concentration gradient, and is the particle small enough to cross?
- **Osmosis defined**: *Osmosis* is the diffusion of water through a *partially permeable membrane*, from a dilute solution (more water) to a concentrated solution (less water). Only water moves; the dissolved solute stays behind because the membrane holds it back.
- **Which structure controls osmosis**: In a plant cell, water moves into and out of the cell by osmosis through the *cell membrane*, not the cell wall. The cell wall is fully permeable, so it lets everything through and controls nothing; the cell membrane, just inside it, is the partially permeable boundary.
- **Why diffusion matters**: Diffusion carries the essential traffic of living organisms. *Gases*: in the lungs oxygen diffuses from the air into the blood and carbon dioxide diffuses the other way; in a leaf carbon dioxide diffuses in through the stomata. *Solutes*: digested food such as glucose is at a higher concentration in the small intestine than in the blood, so it diffuses in and is absorbed.

23 Nuclear physics

KEY FORMULAS

Count rate

$$\text{count rate} = \frac{\text{number of counts}}{\text{time}}$$

Use whenever a detector connected to a counter gives a number of counts over a stated time. Divide counts by time, in counts/s or counts/minute. For 150 counts in 30 s, that is $150 \div 30 = 5$ counts/s. Multiplying instead of dividing is the classic error.

Fraction remaining after n half-lives

$$\text{fraction remaining} = \left(\frac{1}{2}\right)^n$$

Use for any whole number of half-lives n. It applies equally to mass, activity and count rate, since all are proportional to the number of undecayed nuclei. Three half-lives leave $\left(\frac{1}{2}\right)^3 = \frac{1}{8}$ of the original amount.

Nuclide notation

$${}^{A}_{Z}\mathrm{X}$$

Use to read or write a nucleus. X is the element symbol, the *nucleon number* A sits on top and the *proton number* Z sits underneath. Read ${}^{20}_{10}\mathrm{Ne}$ as 10 protons and $20 - 10 = 10$ neutrons. The larger number is always the nucleon number, and it always goes on top.

Number of neutrons in a nucleus

$$\text{number of neutrons} = A - Z$$

Use whenever a question gives the nucleon number A (the big number) and the proton number Z (the small number) and asks for neutrons. Subtract the small number from the big one. For magnesium ${}^{24}_{12}\mathrm{Mg}$, that is $24 - 12 = 12$ neutrons. The distractors offered are almost always A and Z themselves, so read carefully for which total the question wants.

KEY CONCEPTS

- **Decay is spontaneous and random**: *Radioactive decay* is an unstable nucleus emitting radiation to become more stable. It is *spontaneous*: it happens on its own, with nothing outside the nucleus causing it, so heating or compressing a source never changes the rate. It is *random*: which nucleus decays next, and exactly when, cannot be predicted.
- **Ionising radiation and background radiation**: Nuclear radiation is *ionising* because it can knock electrons out of atoms. *Background radiation* is the low-level radiation always present, even with no source nearby. The four natural sources to know by name are radon gas in the air, rocks and buildings, food and drink, and cosmic rays from space. Waste from nuclear power and medical X-rays are man-made, not natural, sources.
- **Isotopes**: *Isotopes* are atoms of the same element, so with the same proton number, that have different numbers of neutrons. An element can have more than one isotope, and some isotopes are radioactive while others are not: carbon-12 is stable, carbon-14 is radioactive, and both are carbon because both have 6 protons.
- **Match the radiation to the job**: *Alpha* sources are used in smoke alarms. *Gamma* sources sterilise sealed equipment, irradiate food to kill bacteria, and are used to diagnose and treat cancer, because gamma penetrates deep enough to reach what it needs to. *Beta* is used to measure and control the thickness of thin materials such as foil, because it is only partly absorbed.

- **Nature and charge of alpha, beta and gamma**: *Alpha* is a helium nucleus, 2 protons and 2 neutrons, with charge $+2$. *Beta* is a fast-moving electron, with charge -1. *Gamma* is a high-frequency electromagnetic wave, with no charge and no mass. Only alpha and beta carry mass; only alpha and beta carry charge.
- **Penetration and ionising power**: *Alpha* is stopped by paper (or a few cm of air) and is the most ionising. *Beta* is stopped by a few mm of aluminium and is moderately ionising. *Gamma* needs several cm of lead to be reduced substantially and is the least ionising. The two properties run opposite ways: the type that is easiest to stop is the most ionising.
- **What half-life means**: The *half-life* of a radioactive isotope is the time taken for half of the undecayed nuclei in any sample to decay, which is the same as the time for the count rate to fall to half its value. It is a fixed property of the isotope: every successive halving takes the same time.
- **What the nucleus contains**: The *nucleus* is the small, central part of an atom. It contains *protons* and *neutrons*, together called *nucleons*. The *electrons* orbit outside the nucleus, not inside it. A question asking what is found inside the nucleus should always be answered with protons and neutrons only.

EXAM TIPS

TIP *Alpha* emission lowers the proton number by 2 and the nucleon number by 4. *Beta* emission raises the proton number by 1 (a neutron turns into a proton and an electron, and only the electron leaves) while the nucleon number stays the same. *Gamma* changes neither. Both alpha and beta decay turn the nucleus into a different element; gamma does not.

TIP Ionising radiation can kill cells, cause mutations and cause cancer, and the risk grows with the dose received. Radioactive materials are moved, used and stored safely by cutting three things: *time* spent near the source, kept as short as possible; *distance* from the source, kept as large as practical; and *shielding*, placing an absorbing material such as lead between the source and people.

24 Organic chemistry

KEY FORMULAS

Addition polymerisation of ethene to poly(ethene)

$$n\,CH_2{=}CH_2 \rightarrow -[CH_2{-}CH_2]_n-$$

Used to write the formation of poly(ethene) from its monomer ethene. The carbon-to-carbon double bond in each monomer opens up, each freed bond joins to a neighbouring monomer, and no other product is formed.

Complete combustion of an alkane

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

Used whenever an alkane burns in a plentiful supply of oxygen: all the carbon becomes carbon dioxide and all the hydrogen becomes water. The same word-equation pattern applies to any alkane fuel.

Complete combustion of ethanol

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

Used when ethanol burns in a plentiful supply of oxygen, giving the same two products as any complete combustion of an organic fuel. With a restricted air supply, ethanol behaves like any other organic fuel: a smoky flame, soot and carbon monoxide, and less energy released.

The four molecules you must name and draw

$$CH_4 \quad C_2H_6 \quad C_2H_4 \quad C_2H_5OH$$

Used to identify and draw methane, ethane, ethene and ethanol, the only four organic molecules examinable on Core. Know each name, its formula and whether it is saturated or unsaturated.

KEY CONCEPTS

- **Alkanes are saturated and generally unreactive except in combustion**: The bonding in alkanes is single covalent throughout, so alkanes are saturated hydrocarbons. Alkanes are generally unreactive except in terms of combustion: they do not react with aqueous bromine, and they do not form polymers.
- **Alkenes contain a carbon-to-carbon double bond and are unsaturated**: The bonding in alkenes includes a double carbon-to-carbon covalent bond, $C=C$, so alkenes are unsaturated hydrocarbons. Ethene, C_2H_4, is the alkene named and drawn at Core: two carbons joined by a double bond, each carrying two hydrogens.
- **Displayed formula: every atom and every bond**: A *displayed formula* shows all the atoms and all the bonds in a molecule, drawn out individually, unlike a molecular formula such as C_2H_6 which only counts atoms. Every carbon atom must have exactly four lines coming out of it (a double bond counts as two of them), every hydrogen has one, and every oxygen has two.
- **Ethanol is an alcohol, not a hydrocarbon**: Ethanol, C_2H_5OH, is the alcohol studied at Core. Its name ends in *-ol* and its displayed formula carries the $-OH$ group; it is not a hydrocarbon because of the oxygen atom.
- **Fractional distillation separates by boiling point**: Crude oil is heated until it vaporises and fed into a tall fractionating column that is hot at the bottom and cooler towards the top. The vapour rises and cools; a fraction condenses back to a liquid at the level where the column has cooled below that fraction's boiling point, and the liquid fractions are collected at their different levels.
- **Hydrocarbon defined**: A *hydrocarbon* is a compound that contains hydrogen and carbon *only*. Ethanol is not a hydrocarbon, because as well as carbon and hydrogen it contains oxygen, even though it is organic and burns as a fuel.

- **Petroleum is a mixture of hydrocarbons**: Petroleum is not one substance but a mixture of thousands of different hydrocarbon molecules of different chain lengths, jumbled together as it comes out of the ground. It must be separated before its parts are useful.
- **Polymer and monomer defined**: A *polymer* is a large molecule built up from many smaller molecules called *monomers*, joined by covalent bonds. One polymer molecule contains thousands of monomer units.
- **Saturated and unsaturated are decided by carbon-to-carbon bonds only**: A *saturated* compound has molecules in which all the carbon-to-carbon bonds are single bonds. An *unsaturated* compound has molecules with at least one carbon-to-carbon double bond, $\mathrm{C=C}$. The decision is made entirely by the bonding between carbon atoms; it says nothing about which elements are present or about the bonds to hydrogen.
- **The five named fractions and their uses**: *Refinery gas* is used for heating and cooking, *gasoline (petrol)* fuels cars, *naphtha* is a chemical feedstock (a raw material for making chemicals), *diesel oil (gas oil)* fuels diesel engines, and *bitumen* is used for making roads. Naphtha is the one fraction that is not burned as a fuel.
- **The stem counts carbons, the ending names the family**: An organic name is a stem plus an ending. The stem counts the carbon atoms: *meth-* is 1, *eth-* is 2. The ending names the family: *-ane* is an alkane (single carbon-to-carbon bonds only), *-ene* is an alkene (contains $\mathrm{C=C}$), *-ol* is an alcohol (contains $-\mathrm{OH}$). Core names and draws exactly four molecules: methane, ethane, ethene and ethanol.
- **The three fossil fuels, and natural gas is mainly methane**: The three fossil fuels, formed underground over millions of years from the remains of dead organisms, are *coal*, *natural gas* and *petroleum* (crude oil). Natural gas is mainly *methane*, $\mathrm{CH_4}$.

EXAM TIPS

> TIP *Saturated versus unsaturated* is decided by the type of carbon-to-carbon bond. *Hydrocarbon versus not* is decided by which elements are present. Ethanol is saturated but is not a hydrocarbon; propene is a hydrocarbon but is not saturated. Decide which question is being asked before writing an answer.

> TIP "Plentiful supply of oxygen" or a "clean blue flame" means *complete* combustion (carbon dioxide and water only). "Limited air supply", a "closed air hole", a "yellow smoky flame" or "soot" means *incomplete* combustion (carbon monoxide and/or carbon (soot) also form, and less energy is released).

25 Organisms and their environment

KEY CONCEPTS

- **A food chain shows energy transfer, starting with a producer**: A *food chain* shows the transfer of energy from one organism to the next, beginning with a producer: producer, then primary consumer, then secondary consumer, then tertiary consumer. It describes feeding relationships, not the distance between predator and prey or the number of species in a habitat.
- **Classes of consumer: primary, secondary and tertiary, by what they eat**: Consumers are classed by their position in a food chain. A *primary consumer* feeds directly on the producer. A *secondary consumer* feeds on a primary consumer. A *tertiary consumer* feeds on a secondary consumer. The class is decided by what an organism eats, never by its size or how fierce a predator it looks.
- **Energy flows one way and ends up in the environment as heat**: Energy flows through living organisms by feeding and is eventually transferred to the environment; most of it is lost, for example as heat released during respiration. Because this energy is gone for good, it is called energy *flow*, not an energy cycle, and the Sun must keep resupplying it.
- **Producer, consumer, herbivore, carnivore and decomposer defined**: A *producer* makes its own organic nutrients, usually using energy from sunlight in photosynthesis. A *consumer* gets its energy by feeding on other organisms. 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* gets its energy from dead or waste organic material.
- **The carbon cycle: photosynthesis removes carbon dioxide, several processes return it**: The *carbon cycle* describes how carbon moves between the atmosphere, as carbon dioxide, and living organisms. *Photosynthesis* is the only major process that removes carbon dioxide from the air, converting it into carbon compounds in plants. *Respiration*, *feeding*, *decomposition* and *combustion* all play a part in the cycle, and several of them return carbon dioxide to the atmosphere.
- **The Sun as principal energy source; producers capture it by photosynthesis**: The *Sun* is the principal source of energy entering almost all food chains. Only *producers* (green plants and algae) capture it directly: photosynthesis converts light energy into chemical energy stored in glucose, the form energy must take before it can pass along a food chain by feeding.

EXAM TIPS

TIP Most organisms eat more than one kind of food and are eaten by more than one predator, so several food chains interconnect into a *food web*. Reading one: an organism that makes its own food is a producer regardless of where it is drawn, and every arrow still points from the eaten to the eater.

TIP In a food chain, each arrow points from the organism that is eaten to the organism that eats it, the direction energy flows. To build a chain, find the producer first, then follow "is eaten by" one step at a time; drawing the arrows backwards is the most common wrong answer.

26 Plant nutrition

KEY CONCEPTS

- **Chlorophyll is the pigment; the chloroplast is the structure**: A *chloroplast* is the small green structure inside a plant cell. *Chlorophyll* is the green pigment held inside it, and it absorbs the light photosynthesis needs. "Which structure?" wants chloroplast; "which pigment?" wants chlorophyll; the wrong word usually scores zero. Chloroplasts are packed into the cells near the top of a leaf, where light is strongest; root cells have none, because no light reaches them.
- **Definition of photosynthesis**: Photosynthesis is the process by which plants synthesise carbohydrates from raw materials, using energy from light. A full-mark answer names all three parts: the *raw materials* (carbon dioxide and water), the *product* (glucose) and the *energy source* (light). Dropping any one part loses marks.
- **Destarch before an experiment**: Before testing what photosynthesis needs, leave the plant in the dark for 24 to 48 hours. With no light it cannot photosynthesise, so it uses up any starch already in its leaves, leaving them *destarched*. Any starch found at the end of the experiment must then have been made *during* it, which is what makes the result mean something. Skipping this step makes a positive iodine test prove nothing.
- **Leaf cross-section, top to bottom**: A leaf's cross-section runs, from the top: *waxy cuticle* (waterproof, not cells), *upper epidermis* (transparent, no chloroplasts), *palisade mesophyll* (tall packed cells, most chloroplasts, main photosynthesis site), *spongy mesophyll* (loosely packed cells with large *air spaces* between them), *lower epidermis* (holds most of the *stomata*), and a *vascular bundle* (vein) containing xylem and phloem. You need to identify each of these on a diagram.
- **Testing for photosynthesis means testing for starch**: You cannot see photosynthesis happen, but you can see what it leaves behind. A plant turns spare glucose into *starch*, and starch turns *blue-black* with iodine solution; no starch stays *orange-brown*. So every experiment in this chapter ends with the same test: boil the leaf in water (kills it), boil it in ethanol in a hot water bath (removes the chlorophyll so a colour change is visible), rinse, then add iodine.
- **The two adaptations: large surface area and thin**: Your syllabus names exactly two leaf features to explain. *Large surface area*: a big flat leaf faces more light, so more light is absorbed by the chlorophyll beneath, so more photosynthesis; it also exposes more stomata, admitting more carbon dioxide. *Thin*: carbon dioxide only has a short distance to travel from a stoma to a mesophyll cell, so it arrives quickly.
- **The word equation for photosynthesis**: $\text{carbon dioxide} + \text{water} \xrightarrow{\text{light energy}} \text{glucose} + \text{oxygen}$. The left side is what goes in, the right side is what is made. *Light energy* (and chlorophyll) are written above the arrow because both are needed but neither ends up inside the glucose. Written the other way round it is the word equation for respiration; examiners regularly offer one as a trap for the other.
- **Xylem and phloem carry materials in opposite directions**: The vascular bundle (vein) in a leaf contains two transport tissues. *Xylem* carries water and mineral ions *to* the leaf, from the roots. *Phloem* carries the sucrose and amino acids photosynthesis produces *away* from the leaf, to the rest of the plant. Keep the pairing exact: water and minerals go with xylem; sugars and amino acids go with phloem.

EXAM TIPS

TIP A leaf-adaptation answer scores by chain, not by naming the feature alone: "the leaf has a large surface area, so more light falls on it, so more light is absorbed for photosynthesis." Stopping at "large surface area" with no consequence and no benefit typically scores about half the available marks.

27 Reproduction

KEY CONCEPTS

- **Conditions needed for germination**: A seed needs exactly three conditions to germinate: *water*, *oxygen*, and a *suitable warm temperature*. Light is *not* required; the young seedling lives off its own food store until it reaches light.
- **Defining a sexually transmitted infection**: A *sexually transmitted infection (STI)* is *an infection that is transmitted through sexual contact.*
- **Definition of asexual reproduction**: *Asexual reproduction is a process resulting in the production of genetically identical offspring from one parent.* Two conditions score marks: there is only *one parent*, and there is *no fusion of gametes*.
- **Definition of sexual reproduction**: *Sexual reproduction is a process involving the fusion of the nuclei of two gametes (sex cells) to form a zygote, and the production of offspring that are genetically different from each other.* Two parents, fusion, varied offspring; the exact opposite of asexual reproduction on all three counts.
- **Fertilisation in plants: the fusion of nuclei**: *Fertilisation occurs when a pollen nucleus fuses with a nucleus in an ovule*, inside the ovary. Pollination *moves* pollen to the stigma; fertilisation *fuses* nuclei inside the ovary, a separate, later event.
- **Flower structure: stamen and carpel**: A flower's male parts form the *stamen*: *anther* (produces and releases pollen grains) plus *filament* (the stalk that holds the anther up). Its female parts form the *carpel*: *stigma* (sticky surface that receives pollen) plus *style* plus *ovary* (contains the *ovules*, each of which becomes a seed after fertilisation). *Petals* attract insects and *sepals* protect the unopened bud.
- **HIV: the pathogen and its link to AIDS**: *HIV* (human immunodeficiency virus) is a *pathogen*, specifically a *virus*, that causes an STI. Untreated HIV infection may progress over time to cause *AIDS* (acquired immune deficiency syndrome).
- **Human fertilisation: definition and location**: Human *fertilisation* is *the fusion of the nucleus of a sperm cell with the nucleus of an egg cell*, forming a single new nucleus. It normally happens in the *oviduct*, not the uterus.
- **Pollination: the transfer of pollen**: *Pollination is the transfer of pollen grains from an anther to a stigma.* It is defined narrowly as the transfer step only: not the pollen tube growing, and not any fusion of nuclei.
- **The definition of a species**: A species is *a group of organisms that can reproduce to produce fertile offspring.* The word *fertile* carries the definition: two organisms may look alike and even mate, but if their offspring cannot themselves reproduce, the two organisms belong to different species.
- **The human female reproductive system**: *Ovaries* produce egg cells, usually releasing one about every month. *Oviducts* carry an egg from an ovary towards the uterus and are the usual site of fertilisation. The *uterus* is a muscular organ in which a fertilised egg implants and develops. The *cervix* is the narrow lower part of the uterus, opening into the *vagina*.
- **The human male reproductive system**: *Testes* produce sperm cells, held in the *scrotum* outside the main body, slightly cooler than body temperature. *Sperm ducts* carry sperm towards the urethra. The *prostate gland* adds fluid to sperm to make *semen*. The *urethra* carries semen through the *penis* out of the body.

EXAM TIPS

TIP The anther *makes* pollen; the stigma *receives* it. They sit on opposite teams (male stamen, female carpel), so a question that swaps their jobs has swapped the two teams.

TIP A pathogen counts as sexually transmitted if sexual contact is *one* of its routes; it need not be the *only* route. HIV also spreads through infected blood and from mother to child, and that does not stop it being an STI.

TIP *Binary fission* in bacteria (one cell divides into two identical cells), *budding* in yeast (a small outgrowth grows and separates), *runners* in plants such as the strawberry or spider plant (a horizontal stem roots to form an identical new plant), and *tubers* in plants such as the potato (new plants grow directly from the parent's tuber, with no seeds or pollination). A classification question tests the two conditions, not the organism's name.

TIP *Testosterone*, mainly from the testes, brings about *male* secondary sexual characteristics at puberty (for example facial hair, a deeper voice). *Oestrogen*, mainly from the ovaries, brings about *female* secondary sexual characteristics (for example breast development) and starts the menstrual cycle.

28 Respiration

KEY FORMULAS

Word equation for aerobic respiration

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

Used to summarise aerobic respiration: glucose and oxygen are the reactants used up; carbon dioxide and water are the products. Energy is released alongside the reaction but, since it is not a substance, it never appears inside the equation itself.

KEY CONCEPTS

- **Aerobic respiration: definition and site**: *Aerobic respiration* is the chemical reactions in cells that use *oxygen* to break down *nutrient molecules* to release *energy*. All three parts, oxygen use, breakdown of a nutrient molecule, and the release of energy, must be present for a complete definition; the word "oxygen" is the one most often left out. Most aerobic respiration takes place in the *mitochondria*, so a cell with a high energy demand, such as a muscle cell, contains very many of them.
- **Respiration is continuous**: Respiration happens all the time, in *every* living cell of *every* living organism, whether the organism is resting or active, because every cell needs a constant supply of energy. A person sitting completely still is still respiring; so is a plant in the dark, since respiration, unlike photosynthesis, needs no light.
- **Respiration is not breathing**: *Respiration* is the chemical release of energy from nutrient molecules inside every living cell; it takes place continuously, whether or not the organism is visibly active. *Breathing*, the mechanical movement of air into and out of the lungs, only supplies the oxygen that aerobic respiration uses. An organism with no lungs, such as a plant, still respires in every cell.
- **Testing for the products of respiration**: *Limewater* turns milky in the presence of carbon dioxide, so bubbling exhaled air, or air from a flask of respiring organisms, through limewater and watching it turn milky detects the carbon dioxide that aerobic respiration produces. A rise in temperature detects the energy released, since some of it is lost as heat. These two observable changes are the standard evidence that respiration is taking place.
- **Uses of the energy released by respiration**: Living organisms use the energy released by respiration for *muscle contraction*, *protein synthesis*, *cell division*, *growth*, the *passage of nerve impulses*, and *maintaining a constant body temperature* in mammals and birds. *Active transport* against a concentration gradient also appears in exam stems as a further use. Each of these is an active process that would not occur without an input of energy.

EXAM TIPS

TIP Where a question offers *carbon dioxide + water -> glucose + oxygen* as an option for aerobic respiration, reject it: that is the reverse reaction, photosynthesis, not respiration. Aerobic respiration always has glucose and oxygen as reactants and carbon dioxide and water as products, never the other way round.

29 Space physics

KEY FORMULAS

Light-year to kilometre conversion

$$d_{\text{km}} = n_{\text{ly}} \times 9.5 \times 10^{12}$$

A light-year is a unit of distance, about 9.5×10^{12} km, the distance light travels through space in one year. Multiply the number of light-years by this value to convert to kilometres.

Speed of light

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

The constant speed of light in a vacuum. Use this value in every light-travel-time calculation in this chapter, and remember a light-year is defined as the distance light covers in one year at this speed.

Time for light to travel a distance

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

Rearranged speed equation, used to find how long light (or any signal) takes to cross a known distance d at speed v, for example from the Sun to a planet. Keep powers of ten separate: divide the leading numbers, then subtract the exponents.

KEY CONCEPTS

- **Dwarf planets**: A *dwarf planet* orbits the Sun directly and is round due to its own gravity, but unlike the eight planets it has not cleared other similarly sized objects from its orbital region. Pluto is the standard example.
- **How a star begins**: Every stable star begins as an *interstellar cloud of gas and dust*. Where the cloud is dense enough, gravitational attraction pulls the material together, so the cloud contracts and heats up.
- **Order of the eight planets**: In order of increasing distance from the Sun, the eight planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune. A common ordering mnemonic is "My Very Easy Method Just Speeds Up Naming."
- **The protostar**: As a collapsing cloud contracts under gravity, matter gathers at the centre and heats up, forming a hot, spinning body called a *protostar*. Once the protostar's centre is hot and dense enough, the collapse halts and it settles down as a stable star.
- **The Sun's size and composition**: The Sun is a star of *medium size*, made up mostly of the two lightest elements, hydrogen and helium. It radiates most of its energy in the infrared, visible and ultraviolet regions of the electromagnetic spectrum.
- **What a galaxy is**: A *galaxy* is a huge collection of many billions of stars, together with gas and dust, all held together by gravity. Our Sun is one ordinary star in a galaxy called the *Milky Way*.
- **What the Solar System is**: The *Solar System* is the Sun together with everything held in orbit around it by the Sun's gravity. At its centre is one star, the Sun. Dwarf planets and asteroids orbit the Sun *directly*, like the planets; moons orbit a planet rather than the Sun, so they orbit the Sun only *indirectly*.

30 States of matter

KEY CONCEPTS

- **Diffusion defined by kinetic particle theory**: *Diffusion* is the net movement of particles from a region of higher concentration to a region of lower concentration, caused by the random motion of the particles. It is a *net* movement: particles travel in all directions, but more leave the crowded region than enter it. It needs no stirring and no external force.
- **Diffusion is faster in a gas than in a liquid**: Diffusion happens fastest in gases, more slowly in liquids, and is negligible in solids. In a gas, particles move faster and are much further apart than in a liquid, so with fewer collisions in their way they spread through the available space more quickly. In a solid, the particles are fixed in position and cannot diffuse at all.
- **Particle arrangement, separation and motion in the three states**: *Solid*: particles are arranged in a regular, repeating pattern, touching, and vibrate about fixed positions. *Liquid*: particles are arranged randomly, still touching but with a little more space between them, and move around and slide past one another. *Gas*: particles are arranged randomly, far apart with large gaps between them, and move quickly and randomly in all directions. Going from solid to liquid to gas, both the separation and the speed of the particles increase.
- **Predicting the state of a substance from its melting and boiling point**: Below its melting point a pure substance is a *solid*; between the melting and boiling points it is a *liquid*; above its boiling point it is a *gas*. Place the given temperature on a number line between the two fixed points and read off the region it falls in. Take care comparing negative values, since the warmer temperature is the larger number: -40 °C is warmer than -95 °C.
- **The effect of temperature and pressure on the volume of a gas**: Heating a fixed mass of gas at constant pressure *increases* its volume. Increasing the pressure on a fixed mass of gas at constant temperature *decreases* its volume. A solid or a liquid barely responds to either change, because its particles are already touching.
- **The five changes of state**: *Melting* is solid to liquid and *freezing* is liquid to solid. *Evaporating* or *boiling* is liquid to gas and *condensing* is gas to liquid. Heating drives a substance towards the gas state as its particles gain energy; cooling drives it towards the solid state as they lose energy.
- **The three states and their distinguishing properties**: A *solid* has a fixed shape and a fixed volume, cannot flow and cannot be compressed. A *liquid* has a fixed volume but no fixed shape; it flows and takes the shape of its container, and it can barely be compressed. A *gas* has neither a fixed shape nor a fixed volume; it flows, fills its container completely and is easily compressed. Only a gas can be compressed easily, because only a gas has large gaps between its particles.
- **What happens to the particles when a solid melts**: When a solid melts, its particles gain enough energy to move out of their fixed positions and start sliding past one another. Their *separation* changes only slightly: they end up a little further apart, but *still touching*. This is why a liquid's volume is only a little greater than the same mass of solid. The large separation with big gaps belongs to a gas, not to a liquid.

EXAM TIPS

TIP Where a question asks which state has the most widely separated particles, or the greatest ability to flow and take the shape of a new container, the answer is always the *gas*. The ranking is fixed in both cases: solid, then liquid, then gas.

31 Stoichiometry

KEY FORMULAS

Concentration in g/dm3

$$\text{concentration (g/dm}^3) = \frac{\text{mass of solute (g)}}{\text{volume of solution (dm}^3)}$$

Use to find how concentrated a solution is, or rearrange to find a mass or a volume. Dissolving $20\ \mathrm{g}$ of solute to make $2.0\ \mathrm{dm}^3$ of solution gives a concentration of $20 \div 2.0 = 10\ \mathrm{g/dm}^3$.

Deducing a molecular formula from the number of bonds each atom forms

$$\mathrm{C}\ (4\ \text{bonds}) + \mathrm{H}\ (1\ \text{bond each})\ \rightarrow\ \mathrm{CH_4}$$

Use where a question gives the number of covalent bonds each atom forms and asks for the formula of a simple molecular compound. The atom that forms more bonds needs one partner atom for every bond it must complete: carbon forms four bonds and each hydrogen supplies only one, so four hydrogen atoms are needed, giving $\mathrm{CH_4}$. The same reasoning applies to atoms that share electrons to complete a stable outer shell: an atom needing four more electrons must bond to four atoms that each supply one.

Reacting mass by proportion using the balanced equation

$$\text{mass of B} = \text{mass of A} \times \frac{\text{coefficient of B} \times M_r(\mathrm{B})}{\text{coefficient of A} \times M_r(\mathrm{A})}$$

Use to find a reacting or product mass directly from A_r/M_r values and the balanced equation, without the mole concept. For $2\mathrm{Cu} + \mathrm{O_2} \rightarrow 2\mathrm{CuO}$ with A_r: Cu $= 64$, O $= 16$, one copper atom combines with one oxygen atom overall, so the mass ratio Cu : O is $64 : 16$; the mass of oxygen that reacts with $6.4\ \mathrm{g}$ of copper is $6.4 \times (16 \div 64) = 1.6\ \mathrm{g}$.

Relative molecular mass and relative formula mass

$$M_r = \sum A_r \text{ of every atom shown in the formula}$$

Add the A_r of every atom the formula shows, respecting subscripts, including repeats of the same element. For water, $\mathrm{H_2O}$, with A_r: H $= 1$, O $= 16$, $M_r = (2 \times 1) + 16 = 18$. Applied to an ionic compound the same sum is called the *relative formula mass*; the arithmetic is identical, and every atom shown, however many elements the formula has, must be counted.

KEY CONCEPTS

- **A word equation shows reactants forming products**: A *word equation* names every reactant on the left of an arrow and every product on the right, where the arrow means "react to form". Magnesium burning in oxygen to form magnesium oxide is written magnesium $+$ oxygen $\rightarrow$ magnesium oxide, never the other way round and never inventing a substance that was not actually named in the reaction.
- **Concentration measured in g/dm3**: On Core, this topic is used only for *concentration*: how much solute, in grams, is dissolved in every cubic decimetre of *solution*. Concentration measured this way is written in $\mathrm{g/dm}^3$. The volume used is always that of the whole finished solution, not just the water added before the solute dissolved.
- **Relative atomic mass, Ar, defined**: *Relative atomic mass*, A_r, is the average mass of the isotopes of an element compared with *one twelfth of the mass of one atom of carbon-12*. It has no units, because it is a ratio of two masses. Quote the standard in full: one twelfth of the mass of one atom of carbon-12, not one twelfth of a mole of carbon-12 and not the mass of a whole carbon-12 atom.
- **State symbols in a symbol equation**: A *state symbol* is written in brackets after each formula: (s) solid, (l) pure liquid, (g) gas, and (aq) aqueous, meaning dissolved in water. Assign it from what the

question actually states about each substance: a metal reacting is (s), a dilute acid is (aq) (never (l), which is reserved for a pure liquid), and a solution formed as a product is also (aq). Calcium reacting with dilute sulfuric acid to give a solution of calcium sulfate is $\mathrm{Ca(s)} + \mathrm{H_2SO_4(aq)} \rightarrow \mathrm{CaSO_4(aq)} + \mathrm{H_2(g)}$.

- **Stating the formulas of elements and compounds**: The formulas of the elements and compounds named in the subject content must be *recalled*, not derived. Seven elements exist as diatomic molecules and are always written with a subscript 2: hydrogen $\mathrm{H_2}$, nitrogen $\mathrm{N_2}$, oxygen $\mathrm{O_2}$, fluorine $\mathrm{F_2}$, chlorine $\mathrm{Cl_2}$, bromine $\mathrm{Br_2}$ and iodine $\mathrm{I_2}$. A compound such as sodium chloride, NaCl, or ammonia, $\mathrm{NH_3}$, is likewise a fixed formula to know, not one built by balancing ionic charges.
- **What a molecular formula shows**: A *molecular formula* uses element symbols and subscript numbers to show the number and type of atoms of each element present in *one molecule* of a compound. It does not say how many molecules are in a sample, and it says nothing about electron arrangement or physical state; those are shown separately. Reading $\mathrm{C_2H_6}$ (ethane), the subscript after each symbol is the atom count for that element: 2 carbon atoms and 6 hydrogen atoms.

EXAM TIPS

TIP A *coefficient* is the large number placed in front of a whole formula and may be changed freely to balance an equation. A *subscript* belongs to the formula itself and must never be changed, because changing it changes the substance. Propane burning completely is $\mathrm{C_3H_8(g)} + 5\mathrm{O_2(g)} \rightarrow 3\mathrm{CO_2(g)} + 4\mathrm{H_2O(l)}$: every number in front is a coefficient chosen to balance the atoms, and none of the subscripts inside $\mathrm{C_3H_8}$, $\mathrm{CO_2}$ or $\mathrm{H_2O}$ has been touched.

32 The Periodic Table

KEY FORMULAS

Alkali metal with cold water

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

Used for any Group I metal reacting with cold water, in the general form alkali metal + water $\rightarrow$ metal hydroxide + hydrogen. Swap in the metal for lithium, $2Li + 2H_2O \rightarrow 2LiOH + H_2$, or potassium, $2K + 2H_2O \rightarrow 2KOH + H_2$. The two products are always the metal hydroxide and hydrogen, never an oxide.

Diatomic halogen molecules

$$Cl_2,\ Br_2,\ I_2$$

Used whenever a halogen's formula is written. Each halogen atom has seven outer-shell electrons, one short of a full shell, so two atoms share a pair of electrons to complete both outer shells, giving a *diatomic* molecule rather than a single atom.

Outer-shell electron count across Period 3

$\mathrm{Na}=1,\ \mathrm{Mg}=2,\ \mathrm{Al}=3,\ \mathrm{Si}=4,\ \mathrm{P}=5,\ \mathrm{S}=6,\ \mathrm{Cl}=7,\ \mathrm{Ar}=8$ outer-shell electrons, left to right$

Used to read an element's outer-shell electron count straight from its column. The group number and this count are the same thing, and it climbs by one across each period from Group I to Group 0.

Position and electronic structure

$\text{group number} = \text{number of outer-shell electrons}$ and $\text{period number} = \text{number of occupied electron shells}$

Used to convert an element's position in the table into its electron arrangement, and back again. Read the two numbers off the table and the chemistry follows, because reactions are governed by the outer-shell electrons.

KEY CONCEPTS

- **Four characteristic properties of the transition elements**: The transition elements form the central block between Group II and Group III. Four properties characterise them: *high density* and *high melting points*, in contrast to the low-density, low-melting Group I metals; *coloured compounds*, copper compounds typically blue or green and iron(II) compounds pale green, where Group I and Group II compounds are usually white; and they *often act as catalysts*, as with iron in industry and manganese(IV) oxide speeding up the decomposition of hydrogen peroxide.
- **Full outer shell and unreactivity**: Group VIII, also written Group 0, holds the *noble gases*: helium, neon, argon and the rest. Each atom has a *full outer shell*, two electrons for helium and eight for the rest, so there is no driving force to gain, lose or share electrons and the atoms are *unreactive*. Having no reason to bond even to each other, they exist as single separate atoms, which is what *monatomic* means, and they are colourless gases at room temperature.
- **How the Periodic Table is arranged**: The elements are placed in one continuous sequence in order of increasing *proton number*, one proton at a time with no gaps. The horizontal rows are *periods*, and the period number equals the number of occupied electron shells in an atom. The vertical columns are *groups*, and for the main groups the group number equals the number of outer-shell electrons. Metals occupy the left and centre of the table, and non-metals are confined to the top right, separated from the metals by a rough diagonal staircase.
- **Metallic character across a period**: Moving from left to right across any period, the number of outer-shell electrons rises from one to eight, and the elements change from *metallic* to *non-metallic* in character. The oxides change in step: metal oxides on the left are *basic*, non-metal oxides on the

right are *acidic*. Metals on the left conduct electricity well; non-metals on the right conduct poorly or not at all.

- **The alkali metals: physical properties and storage**: Group I is the family of *alkali metals*, named lithium, sodium and potassium on this syllabus. Unlike everyday metals they are *relatively soft*, soft enough to cut with a knife, exposing a shiny surface that tarnishes within seconds in air. They have *low density*, so lithium, sodium and potassium all float on water, and their melting points are low for metals. Because they react readily with both air and water, they are stored under oil.
- **The halogens: appearance and trends down Group VII**: Group VII, the *halogens*, are reactive non-metals named chlorine, bromine and iodine on this syllabus; every atom has seven outer-shell electrons, one short of a full shell. Down the group the colour becomes *darker* and the density, melting point and boiling point all *increase*, so the state at r.t.p. passes from gas (pale yellow-green chlorine) through liquid (red-brown bromine) to solid (grey-black iodine). Reactivity *decreases* down the group, the opposite direction to Group I.
- **Trends down Group I**: Going down Group I from lithium to sodium to potassium, three properties change in a set direction: *melting point decreases* because the atoms get larger and the metallic bonding weakens, *density increases*, and *reactivity with water increases* because the outer electron is lost more easily. All three trends are limited on this syllabus to lithium, sodium and potassium, described rather than read from a data table.
- **Why elements in a group have similar chemical properties**: Every atom in a group has the *same number of outer-shell electrons*. Because chemical reactions are almost entirely about what the outer-shell electrons do, elements in a group react in the same general way: Group I atoms all have one outer electron to lose, Group VII atoms all have seven, one short of a full shell. "Similar" is the word to use, never "the same", because melting point, density and reactivity still change steadily down a group.

33 Thermal physics

KEY CONCEPTS

- **Convection transfers energy through fluids by the fluid moving**: *Convection* is the main way thermal energy travels through *liquids and gases*, and the fluid itself moves. Heat part of a fluid and it *expands*, becomes *less dense* and *rises*; cooler, *denser* fluid sinks to take its place, is heated in turn, and also rises, setting up a *convection current*. Convection cannot happen in a solid, because solid particles cannot flow.
- **Evaporation: the most energetic particles escape from the surface**: *Evaporation* is the escape of the *more energetic* particles from the *surface* of a liquid, and it can happen at any temperature, not only at the boiling point. Because it is always the fastest particles that leave, the average energy of the particles left behind falls, so the liquid *cools down*. This is why sweat, or perfume on skin, feels cool as it evaporates.
- **Gases expand most, solids expand least**: Heating gives particles more energy, so on average they sit slightly further apart and the substance expands; cooling reverses this. For the *same* temperature rise, the order is *gases* > *liquids* > *solids*. A gas expands most because its particles are already far apart with negligible forces between them; a solid expands least because strong bonds hold its particles in place, letting them only vibrate a little further.
- **Good and bad thermal conductors**: *Metals* (copper, aluminium, iron, steel, brass) are good thermal conductors. *Non-metals* (wood, plastic, glass, rubber, cloth, and air) are poor conductors, called *thermal insulators*. This is why a saucepan has a metal base but a plastic or wooden handle, and why oven gloves are made of thick cloth.
- **Melting and boiling temperatures of water**: For pure water at standard atmospheric pressure, *melting* happens at 0 °C and *boiling* happens at 100 °C. Use the two values to name the state: below 0 °C it is a solid, between 0 °C and 100 °C it is a liquid, above 100 °C it is a gas.
- **Random motion of smoke or pollen is evidence for moving particles**: Smoke viewed under a microscope, or pollen grains in water, move in continuous, random, jerky paths, even though nothing visible is pushing them. They are being *collided with* by particles of the surrounding air or water, far too small to see; the hits arrive unevenly from all directions, so the visible speck is knocked one way and then another. This random motion is the *evidence* that matter is made of moving particles.
- **Solid, liquid and gas in the particle model**: Three quantities describe every state: *spacing*, *arrangement* and *motion*. A *solid* has particles close together in a regular pattern, held by strong forces, only *vibrating* about fixed positions, giving it a fixed shape and a fixed volume. A *liquid* has particles close together but irregularly arranged, *sliding* past one another, giving it a fixed volume but no fixed shape. A *gas* has particles far apart, randomly arranged, moving quickly in all directions, giving it neither a fixed shape nor a fixed volume.
- **Surface colour and texture decide absorption, emission and reflection**: *Dull black* surfaces are the best *absorbers* and the best *emitters* of thermal radiation. *Shiny white or silver* surfaces are the worst absorbers and emitters, and the best *reflectors*. One rule captures it: a good absorber is also a good emitter, which is why refrigerator cooling pipes are dark and vacuum flasks are silvered.
- **Temperature is linked to particle motion**: Heating a substance transfers energy to its particles, so they move *faster*; cooling slows them down. In a gas that means faster flying between collisions, in a liquid more vigorous sliding, in a solid a *bigger vibration* about a fixed position. The particles never stop moving completely.
- **Temperature stays constant while a substance melts or boils**: While a pure substance is melting or boiling, its temperature does not change, even though energy is still being supplied. The energy is used to pull the particles apart, not to speed them up further, so on a temperature-time graph a change of state is a *flat, horizontal* section.
- **The four names for a change of state**: *Melting* is solid to liquid; *solidification* (freezing) is liquid to solid; *boiling* or *evaporation* is liquid to gas; *condensation* is gas to liquid. A change of state never changes the particles themselves, only their spacing, arrangement and motion.
- **Thermal radiation needs no medium**: Conduction and convection both need particles to carry energy. *Thermal radiation* does not: it is mainly *infrared*, travels as electromagnetic waves, and can cross a *vacuum*. This is the only way the Sun's energy reaches the Earth. Exam shortcut: if a question mentions a vacuum, empty space, or "no particles," the answer is radiation.

EXAM TIPS

TIP Every everyday application in this chapter is asking which of *conduction*, *convection* or *radiation* is being blocked or boosted, and marks are awarded for naming the right one. A vacuum flask blocks all three: the *vacuum* stops conduction and convection, the *silvered walls* cut radiation, and the *stopper* stops convection out of the top. Trapped air (loft insulation, wool, double glazing) is a poor conductor and its small pockets cannot circulate, so it blocks conduction and convection at once.

TIP Where a question says "in terms of the particles," never answer in terms of heat alone. Name the particles and state their *spacing*, their *arrangement* and their *motion*. Marks in this chapter are awarded for those three words, not for a general description of something becoming hotter.

34 Transport in animals

KEY FORMULAS

Percentage change in heart rate

$$\text{percentage change} = \frac{\text{change}}{\text{starting value}} \times 100\%$$

Used to quantify a rise or fall in heart rate. The "change" is the later reading minus the earlier one; the "starting value" is always the reading recorded *first*, before the activity or the recovery period being measured.

Turning a short count into a rate in bpm

$$\text{heart rate (bpm)} = \text{count} \times \frac{60}{\text{seconds counted}}$$

Used to scale up a pulse count taken over a short interval to a rate in beats per minute, e.g. count for 15 seconds and multiply by 4, or count for 30 seconds and multiply by 2.

KEY CONCEPTS

- **Arteries: thick, muscular wall, small lumen**: *Arteries* carry blood away from the heart at *high pressure*. Their walls are *thick and muscular* and the *lumen* (the hollow space blood flows through) is relatively small, and they carry no valves along their length.
- **Blood leaves in arteries, returns in veins**: Blood is pumped *away* from the heart in *arteries* and returns to the heart in *veins*. Artery means away. This is a rule about *direction*, not about what the blood contains.
- **Capillaries: a wall one cell thick**: *Capillaries* are the tiny vessels linking arteries to veins, reaching almost every cell. Their walls are only *one cell thick*, and their function is to *exchange substances* between the blood and the body cells.
- **Circulatory system defined**: A *circulatory system* is a system of *blood vessels* with a *pump* and *valves* that give blood a *one-way flow* around the body. All three parts, vessels, pump and valves, are required by the definition, and the valves are the part most often left out.
- **Coronary arteries supply the heart muscle**: The heart muscle cannot take oxygen from the blood passing through its own chambers, so it has a dedicated supply. The *coronary arteries* branch off the aorta and run over the surface of the heart, delivering oxygenated blood to the heart muscle itself.
- **One-way valves keep blood flowing forwards**: Valves sit between each atrium and the ventricle below it, and at the base of the main arteries leaving the heart. As a chamber contracts, rising pressure pushes blood through the next valve; once the blood is through, the valve *shuts* so it cannot flow back into the chamber it just left.
- **Red blood cell structure**: A *red blood cell* is a *biconcave disc* with *no nucleus*, packed with the red pigment *haemoglobin*. The biconcave shape and the missing nucleus both leave more room for haemoglobin, which is what makes oxygen transport efficient.
- **The four chambers of the heart**: The heart has four chambers. The two upper chambers, the *atria*, *receive* blood arriving at the heart. The two lower chambers, the *ventricles*, *pump* blood out. Blood always moves down through the heart, atrium first, ventricle second.
- **The four components of blood**: Blood has four components: *red blood cells*, *white blood cells*, *platelets* and *plasma*. Two are whole cells, one is a collection of cell fragments, and one is a liquid.
- **The left ventricle wall is thicker than the right**: The *left* ventricle wall is noticeably thicker than the right ventricle wall. The left side pumps blood at high pressure all the way around the whole body, while the right side only pumps blood the short distance to the nearby lungs.
- **The septum divides left from right**: The *septum* is a thick muscular wall running down the middle of the heart, separating the left side from the right. It is a solid wall, not a valve (a small flap) and not a ventricle (a chamber).
- **Veins: thin wall, wide lumen, valves**: *Veins* carry blood back to the heart at *low pressure*. Their walls are *thin*, the lumen is *wide*, and *valves* are spaced along their length to stop the low-pressure blood flowing backwards.

- **White blood cells defend the body**: *White blood cells* defend the body against pathogens in two ways: *phagocytosis* (engulfing and digesting pathogens) and *antibody production* (making proteins that target specific pathogens). White blood cells do not transport oxygen; that is the red cells' job.
- **Why a pump alone is not enough**: A pump on its own pushes blood forwards while it squeezes, then lets it slide back the moment it relaxes. *Valves* close as soon as blood has passed through them, so blood that was pushed forwards stays forwards. Without valves the blood would slosh to and fro with no net flow at all.

EXAM TIPS

TIP In a percentage-change question the denominator is always the value recorded *first*, before the change being measured happens. Dividing by the later (final) value instead is the single most common error in this calculation.

TIP Blood pressure is much higher in vessels near the heart than in vessels far away. A pressure difference like that cannot appear on its own, so something must be actively pushing at one end, which is the pump.

TIP B9.3 always tests the same three features: the relative *thickness of the wall*, the *diameter of the lumen*, and whether *valves* are present. Work through them in that order and every vessel question falls out.

35 Transport in plants

KEY CONCEPTS

- **Pathway of water from soil to leaf**: Learn the order and never reverse it: *root hair cell -> root cortex cells -> xylem -> leaf mesophyll cells*. The cortex is the short sideways crossing to reach the xylem in the middle of the root; the xylem does the long-distance vertical lift; the mesophyll is where most of the water is finally lost as transpiration.
- **Phloem: cargo, direction and cell type**: *Phloem* transports the plant's dissolved food, *sucrose and amino acids*. Movement can be in *either direction*, depending on where the food is needed. Phloem is made of *living* cells.
- **Position of xylem and phloem in root, stem and leaf**: *Root*: the vascular tissue forms a central *star*; xylem fills the arms, phloem sits between them. *Stem*: vascular bundles form a *ring* near the outer edge; within each bundle xylem lies toward the *inside*, phloem toward the *outside*. *Leaf vein*: xylem lies toward the *upper* side, phloem toward the *lower* side. The xylem is always the more central of the pair, and the one with thick walls and a hollow centre.
- **Root hair cell: sole job is absorption**: Water and mineral ions enter a plant almost entirely through *root hair cells*, epidermal cells near the root tip drawn out into one long, thin extension into the soil. Their function is one sentence: *root hair cells absorb water and mineral ions from the soil*, nothing else.
- **Stoma is the pore; guard cells open and close it**: A *stoma* (plural stomata) is the pore itself, the gap in the leaf's epidermis. A *guard cell* is one of the pair of curved cells around the pore that changes shape to open or close it. Calling the pore a guard cell is the commonest way to lose this mark. Stomata are far more numerous on the *lower* surface of a typical leaf than the upper.
- **Transpiration defined: evaporation then diffusion**: *Transpiration* is the loss of water vapour from the leaves of a plant. It happens in two stages: water *evaporates* from the mesophyll cells inside the leaf into the internal air spaces, then that vapour *diffuses* out of the leaf through the *stomata*. A full answer names both stages, in that order.
- **Water by osmosis, mineral ions by active transport**: *Water* enters the root hair cell by *osmosis*, because the soil solution outside is more dilute than the cell contents. *Mineral ions* usually enter against their own concentration gradient, by *active transport*, using *energy from respiration*, which is why root cells contain many mitochondria.
- **Xylem: cargo, direction and cell type**: *Xylem* transports *water and mineral ions*, one way, *upward*, from the roots to the stem and leaves. Xylem vessels are long, hollow tubes of *dead* cells joined end to end, with thickened walls, which is why the xylem also *supports* the plant.

EXAM TIPS

TIP Sort every claim by cargo first, not by direction. Mineral ions are dissolved in the water absorbed at the root, so they ride the *xylem*, never the phloem. Sucrose is made in the leaves, so it rides the *phloem*, in either direction: sugar stored in the roots over winter travels *upward* through the phloem to the buds in spring, so "phloem always goes down" is a trap.

TIP A *large surface area* of root hairs *increases* the rate of uptake of water and mineral ions; longer hairs or more hairs both raise the total absorbing surface. A surface-area answer only scores in full if it names what the extra area is *for*: not just "a bigger surface area" but "a bigger surface area, so it absorbs more water and mineral ions".

TIP The commonest wrong option for transpiration is *translocation*, and the two words are close enough to catch a fast reader. Transpiration is water vapour leaving the leaves; translocation, respiration and condensation are never the answer to "loss of water vapour from a leaf".

36 Variation and selection

KEY CONCEPTS

- **Continuous variation: a measured range between two extremes**: *Continuous variation* produces a range of phenotypes between two extremes, with every value in between possible; the syllabus example is body length (height). It is *measured* on a scale rather than sorted into named groups.
- **Discontinuous variation: a limited number of counted categories**: *Discontinuous variation* produces a limited number of phenotypes with no intermediates; the syllabus examples are ABO blood group and pea seed colour (green or yellow, never in between). It is *counted* into named groups rather than measured on a scale.
- **Mutation: a random change in the DNA base sequence**: A *mutation* is a genetic change: a change in the base sequence of DNA, most commonly one base swapped for a different base. A mutation is a *random* event; it is not produced to order by whatever the organism happens to need.
- **Natural selection: the five-step chain**: 1. *Genetic variation* exists within a population. 2. Organisms produce more *offspring* than the environment can support. 3. This causes a *struggle for survival*, including competition for resources. 4. Individuals better adapted to the environment have a *greater chance of surviving and reproducing*. 5. Survivors *pass on their alleles*, so advantageous alleles become more common over time. The chain must stay in this order.
- **Selective breeding: the three-step process**: *Selective breeding* (artificial selection) is the human-directed version of natural selection. 1. Humans *select* individuals showing a desired feature. 2. Those individuals are *crossed* to produce the next generation. 3. The offspring showing the desired feature are *selected* to be the next generation's parents. Repeating this over many generations improves crop plants and domesticated animals.
- **Species: a group that can produce fertile offspring**: A *species* is a group of organisms that can *reproduce to produce fertile offspring*. This is the definition tested directly: state both parts, *reproduce* and *fertile offspring*, to secure the mark.
- **Variation defined: differences within one species**: *Variation* is the differences between individuals of the same species; two different species, such as a cat and a dog, are never compared for variation. Variation comes from two sources: *genetic causes* (the alleles an individual inherits) and *environmental causes* (conditions such as diet or sunlight). Only the genetic part is passed on to offspring.

EXAM TIPS

TIP Mutation is the only process that forms a genuinely new allele. Selection, whether natural or artificial, only sorts variation that mutation has already supplied; it cannot invent an allele that was never there. Whenever a question asks how a *new* characteristic first appeared, the first cause is always a mutation, never the selecting agent.

TIP Natural selection and selective breeding share one mechanism: both increase the frequency of alleles already present in a population. They differ only in *who or what* is doing the choosing: the environment selects in natural selection, a human selects in selective breeding (also called artificial selection).

37 Waves

KEY FORMULAS

Focal length from u and v

$$f = \frac{u \times v}{u + v}$$

This relationship is always given in the question, so it need not be memorised, but its use must be fluent. Work out $u \times v$ and $u + v$ separately before dividing. The unit of the top line is cm² (a length times a length), and the unit of the bottom line is cm, so f comes out in cm.

p = u + v

$$p = u + v$$

The object-to-screen distance p is the sum of the object distance u and the image distance v, because all three are measured along the same ruler with the lens between the object and the screen. Use it to find v once p has been read from the ruler and u is known, by rearranging as $v = p - u$.

Speed of sound from an echo

$$\text{speed} = \frac{2d}{t}$$

An echo is sound reflected from a hard surface a distance d away; the sound travels there *and back*, so the path length is $2d$, and t is the time for the echo to return. This is the standard method for finding the speed of sound in air from a measured distance and time, giving about 340 m/s.

The law of reflection

$$i = r$$

The angle of incidence equals the angle of reflection, both measured from the normal. Use it for every plane-mirror calculation. If a question quotes the angle between the ray and the mirror *surface* instead, subtract it from 90° to get i before applying the law.

The wave equation

$$v = f\lambda$$

Wave speed v in m/s, frequency f in Hz and wavelength λ in m. Use it whenever a question supplies two of the three quantities, rearranged as $f = \frac{v}{\lambda}$ or $\lambda = \frac{v}{f}$. Frequency is set by the *source*, not by the material the wave travels through, so it stays fixed even when the wave crosses into a new medium.

KEY CONCEPTS

- **Dispersion and the order of the visible spectrum**: *Dispersion* is the spreading of white light into its separate colours by refraction, as at a glass prism, producing a *spectrum*. White light is a mixture of colours, and each is refracted by a different amount, so they leave the prism travelling in slightly different directions. In order: red, orange, yellow, green, blue, indigo, violet. Red is refracted *least*, violet *most*.
- **Image position, size and orientation by object distance**: For a thin converging lens the object distance alone decides the image, and every image on the Core paper is *inverted*. Object beyond $2F$: image between F and $2F$, *diminished*. Object exactly at $2F$: image exactly at $2F$, *same size*. Object

between F and $2F$: image beyond $2F$, *enlarged*. As the object moves towards the lens, the image moves away and grows.

- **Loudness and pitch**: Two properties of the source vibration control two independent properties of the sound. *Amplitude* controls *loudness*: a larger amplitude gives a louder sound. *Frequency* controls *pitch*: a higher frequency gives a higher-pitched note. They can change separately, turning a radio down drops the amplitude and the loudness while the frequency and pitch stay the same.
- **Principal axis, principal focus and focal length**: The *principal axis* is the straight line through the centre of a thin converging lens, at right angles to it. The *principal focus* F is the point on the principal axis where rays arriving *parallel to the axis* meet after passing through the lens. The *focal length* f is the distance from the lens to F; the point $2F$ is twice the focal length away. Rays from a *distant* object may be treated as parallel.
- **Refraction and the direction rule**: *Refraction* is the change in direction of a light ray as it crosses a boundary between two transparent media, caused by a change in the ray's *speed*. Entering a medium where light travels *slower*, such as air into water or air into glass, the ray bends *towards* the normal. Leaving that medium for one where light travels *faster*, the ray bends *away from* the normal by the same reasoning in reverse. A ray meeting the boundary along the normal changes speed but not direction.
- **Sound needs a medium**: Sound is produced by a *vibrating source* and the vibration is passed on from particle to particle, so sound needs a solid, liquid or gas to travel through and *cannot travel through a vacuum*. A bell rung inside a sealed jar grows quieter and quieter as a pump removes the air, even though the bell keeps vibrating exactly as before, because fewer particles remain to carry the vibration to the jar wall.
- **The focal-length experiment: u, v and p**: An illuminated object stands at the zero mark of a metre ruler; a converging lens is clamped a measured distance along it; a screen is moved until the image on it is as sharp as possible. Three distances lie on the same ruler: u, the *object distance* from object to lens; v, the *image distance* from lens to screen; and p, the *object-to-screen distance*, read directly off the ruler.
- **The normal, angle of incidence and angle of reflection**: The *normal* is the construction line drawn at 90° to the surface, at the exact point where a ray strikes it, and every angle in reflection or refraction is measured from it, never from the surface itself. The *angle of incidence* i lies between the incident ray and the normal; the *angle of reflection* r lies between the reflected ray and the normal.
- **The seven regions of the electromagnetic spectrum**: In order of *increasing frequency* and *decreasing wavelength*: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, gamma rays. All are transverse waves, all transfer energy, and all travel through a vacuum at the same very high speed, whatever their frequency. Reading the list backwards gives increasing wavelength.
- **The two construction rays**: Two standard rays from the top of the object locate the image. The first travels *parallel to the principal axis* and is refracted through the principal focus F on the far side of the lens. The second heads for the *centre of the lens* and carries straight on undeviated. Where the two refracted rays *actually cross* is the top of the image.
- **Waves transfer energy, not matter**: A *wave* is a disturbance, produced by a *vibrating source*, that transfers *energy* from one place to another *without transferring matter*. Drop a stone into a pond and ripples spread outward, yet a cork floating on the surface only bobs up and down in place, it is never carried to the shore. The pattern travels; the water itself does not.