Co-ordinated Sciences (0654)

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Comprehensive 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.

The preparation equations for the four routes

$metal$:\text{Zn(s)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{ZnSO}_4\text{(aq)} + \text{H}_2\text{(g)}$\cdot$ $base$:\text{MgO(s)} + \text{H}_2\text{SO}_4\text{(aq)} \rightarrow \text{MgSO}_4\text{(aq)} + \text{H}_2\text{O(l)}$\cdot$ $carbonate$:\text{CaCO}_3\text{(s)} + 2\text{HNO}_3\text{(aq)} \rightarrow \text{Ca(NO}_3)_2\text{(aq)} + \text{H}_2\text{O(l)} + \text{CO}_2\text{(g)} $\cdot$ $titration$:\text{KOH(aq)} + \text{HNO}_3\text{(aq)} \rightarrow \text{KNO}_3\text{(aq)} + \text{H}_2\text{O(l)}$

Used to write the equation for whichever route a preparation question names. Each is just the matching characteristic reaction of the acid, so the products follow the pattern and only the reactants change. The state symbols mark the route: the metal, base or carbonate is added as (s) and the alkali in the titration route is (aq), exactly why the first three can be filtered off in excess and the fourth cannot.

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.
- **A base does not have to be an alkali**: Magnesium oxide reacts with dilute hydrochloric acid to give a salt and water, yet it does not dissolve in water: it is a base but not an alkali. Reacting with an acid to give a salt and water is a property shared by *all* bases, soluble or not, so that reaction alone never proves a substance is an alkali. An alkali is specifically a base that dissolves in water; solubility is the extra condition, and it decides only whether the base is *also* an alkali, and whether it can affect an indicator.
- **Oxide character tracks position in the Periodic Table**: Because oxide character follows the character of the element, and metallic character falls across a period, oxide character tracks a metal-to-non-metal boundary: basic on the metal side, acidic on the non-metal side. Sodium oxide and magnesium oxide are basic; silicon dioxide and sulfur oxides are acidic. This is why the classification rule, metal oxides basic and non-metal oxides acidic, is not an arbitrary pairing: metals generally react with oxygen to form oxides that neutralise acids, and non-metals generally form oxides that react with bases.
- **Reading a neutralisation with universal indicator**: Universal indicator moves *up the scale in order and gradually* as an acid is neutralised, never in one jump: red, orange, yellow, green at pH 7, then blue and purple once the base is in excess. Reaching green shows the acid has been *exactly* neutralised by the alkali, neither in excess. The colour is the direct evidence for how much reaction has happened, so a question describing the colour is asking to be read against this order rather than guessed.
- **The finishing steps for salt preparation**: Once a pure salt solution has been obtained, whichever route made it, the finishing steps are fixed: *evaporate* to concentrate the solution to saturation, a

drop on a cold glass rod crystallises; *cool slowly* so crystals form; then *filter and dry* them. Do *not* evaporate to dryness. These two further steps, evaporate to saturation and cool, are what turn a filtered salt solution into solid crystals, and they are the same whichever of the four routes produced the solution.

- **Water of crystallisation**: *Water of crystallisation* is water chemically built into the structure of a crystal as it forms, and it is what makes a substance *hydrated*. Heating a hydrated salt drives that water off as steam and converts it to the *anhydrous* form: hydrated cobalt(II) chloride is pink and its anhydrous form is blue, hydrated copper(II) sulfate is blue and its anhydrous form is white. The change is reversible, which is why the colour change is used as a test for water.
- **Classification and indicator behaviour are separate questions**: A basic oxide reacts with an acid to give a salt and water regardless of whether it dissolves, so classification does not depend on solubility. Only a *soluble* basic oxide can affect an indicator, because an indicator responds only to what has actually dissolved: an insoluble oxide such as copper(II) oxide is basic, yet a suspension of it in water leaves litmus unchanged, since there are no dissolved hydroxide ions to detect. A *soluble* non-metal oxide such as CO_2 dissolves to give an acidic solution and does affect an indicator, because dissolving is exactly what makes its acidic character detectable.
- **One idea behind every acid reaction**: Every reaction of an acid makes a salt, and what comes out *alongside* the salt tells you what the acid met. Hydrogen means the acid met a metal. Water alone, with no gas, means it met a base. Water and carbon dioxide together mean it met a carbonate. Reading a question backwards from the products uses the same idea: salt and hydrogen only could only have come from a metal, because no other reactant releases a gas that pops with a lit splint.
- **Solubility and water of crystallisation are independent properties**: *Hydrated* and *anhydrous* describe whether water is chemically combined inside the crystal structure of a solid. *Soluble* and *insoluble* describe whether the solid dissolves when put into water, a separate property. A solid can hold water of crystallisation in its structure and still not dissolve, so an insoluble solid can perfectly well be described as hydrated or anhydrous; the two relationships to water do not have to agree with each other.

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 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.

TIP Fizzing stopping or a colour settling is not automatically the answer "neutral". If excess base is added to a fixed volume of acid, the indicator does not stop at green: once all the acid is used up, further base stays dissolved and pushes the colour on to blue, showing the mixture is now *alkaline*, not neutral. Green specifically means the acid and base have exactly cancelled; a question that says "excess" of either reactant is asking for the colour past green, not at it.

TIP Only two changes exist: blue litmus in acid turns red, and red litmus in alkali turns blue. Read which indicator, which starting colour, and which solution, in that order, before writing anything. The same discipline applies to methyl orange, where red (acid) and yellow (alkali) are the two ends and orange is only the neutral in-between; comparing two different solutions in two tubes means applying the same rule twice, not once.

TIP With two soluble reactants there is no leftover solid to filter and no visible change marking the exact moment the reaction is complete, so an excess of either reactant would stay dissolved and contaminate the salt. Titration finds the exact neutralising volume with an indicator present, and the reaction is then repeated with those same volumes and *no indicator at all*, so the dye does not colour the crystals. That neutral solution is evaporated to saturation, cooled and filtered as usual.

TIP Heating a hydrated salt to constant mass is what proves all the water of crystallisation has gone, whatever colour the anhydrous form happens to be. A sample heated until its mass stops falling has become chemically identical to a sample bought or made anhydrous by another route: same substance, same formula, same colour. Quoting "heated to constant mass" is the evidence the examiner wants, not simply describing the colour that was reached.

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.

Electron count in an atom and in an ion

$$\text{atom: electrons} = \text{proton number} \qquad \text{ion: electrons} = \text{proton number} \mp \text{charge}$$

Use to count electrons in any atom or ion. A neutral atom balances its electrons against its protons, so it carries no overall charge. Forming an ion changes only the electron count: an oxide ion, O^{2-}, forms when an oxygen atom (8 electrons) gains 2 more, giving 10 electrons and configuration $2, 8$.

Group and period from the electronic configuration

$$\text{period} = \text{number of occupied shells} \qquad \text{group} = \text{number of outer-shell electrons (Groups I to VII)}$$

Use to place any element with proton number 1 to 20 in the Periodic Table straight from its configuration. Chlorine ($2, 8, 7$) has three occupied shells and seven outer electrons, so it is in Period 3, Group VII. The two counts are independent: matching shells means the same period, matching outer electrons means the same group.

Reading an isotope or ion symbol

$${}^{A}_{Z}\text{X}: \ \text{protons} = Z, \quad \text{neutrons} = A - Z, \quad \text{electrons} = Z \text{ (atom) or } Z \mp \text{charge (ion)}$$

Use to read every particle count straight off a symbol such as ${}^{24}_{12}\text{Mg}$. For an ion, e.g. ${}^{35}_{17}\text{Cl}^{-}$, the proton and neutron counts read exactly the same as for the atom; only the electron count changes, by the charge.

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: $\mathrm{H_2}$, $\mathrm{Cl_2}$, $\mathrm{H_2O}$, $\mathrm{CH_4}$, $\mathrm{NH_3}$ 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 $\mathrm{Li^+}$ and $\mathrm{F^-}$ 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.
- **Graphite: layers held by weak forces**: *Graphite* is a giant covalent structure arranged in layers. Within a layer, each carbon atom is joined to three others by strong covalent bonds, extending across the whole layer. The separate layers are not joined by covalent bonds; they are held to each other only by weak forces, which is why the layers can slide over one another and graphite is soft.
- **Properties of ionic compounds**: An ionic compound such as LiF or NaCl has: *high melting and boiling points*; *good electrical conductivity when molten or aqueous, but poor when solid*; and it is *generally soluble in water*. The ions are held in a giant lattice.
- **Properties of simple molecular substances**: A simple molecular substance is made of small, separate molecules: strong covalent bonds *inside* each molecule, only weak forces *between* them. *Low melting and boiling points* follow, because melting overcomes only the weak forces between molecules. They *do not conduct electricity*, because there are no free ions and no free electrons to carry a current.
- **Telling a compound from a mixture**: Two questions settle every classification. First, *can the proportion vary?* If it can, the substance is a mixture, because a compound is locked to a fixed ratio by its bonding. Second, *did a new substance with different properties form?* If it did, a chemical bond has formed and the substance is a compound. Being made from more than one element is not, by itself, evidence of either: ammonia is a compound because its nitrogen and hydrogen atoms are chemically bonded in a fixed $1:3$ ratio.

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.

TIP Diamond and graphite are both giant covalent structures made only of carbon atoms, yet diamond is extremely hard and graphite is soft. The difference is bonding, not composition: diamond bonds every carbon to four neighbours in a rigid three-dimensional network, while graphite bonds each carbon to only three others in layers held by weak forces. Structure sets the property, not the element.

TIP A positive charge means electrons were *lost*; a negative charge means electrons were *gained*. Protons never move when an ion forms: $\mathrm{K^+}$ has exactly the same number of protons as the neutral potassium atom it came from, just one fewer electron.

TIP Isotopes must share the *proton* number, not the mass number. Two atoms can reach the same mass number through different combinations of protons and neutrons and still be different elements. Test every claim against the definition: same proton number and different neutron number is the only pairing that gives isotopes.

TIP Solid sodium chloride contains Na^+ and Cl^- ions, but it does not conduct electricity. The ions are fixed in position in the giant lattice and cannot move, and conduction needs charged particles free to carry charge through the structure. Melting or dissolving the compound frees the ions to move, and only then does it conduct.

TIP A recurring distractor argues that because a substance is made from two elements, it must be a mixture of them. Reject it: ammonia, NH_3, is made from nitrogen and hydrogen, but the atoms are chemically bonded in a fixed $1:3$ ratio and cannot be separated by a physical process, so it is a compound. Answer on the bonding and the ratio, never on the number of elements present.

TIP Solid sulfur, made of S_8 molecules, does not conduct electricity. Conduction needs charged particles, ions or electrons, free to move through the substance. Sulfur has no ions, and every electron is held within a covalent bond or as a lone pair on an atom, so there is nothing free to carry a current.

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).
- **A fat is a fixed assembly, not a polymer of many units**: A large carbohydrate is *many* identical glucose units joined in a chain. A fat, by contrast, is a small fixed assembly of *two different* kinds of unit, one glycerol and three fatty acids. Describing a fat's building blocks with the word "many", as if it were a polymer like starch, is incorrect.
- **Benedict's test is semi-quantitative**: As the concentration of reducing sugar rises, the colour on heating with Benedict's solution passes through a sequence: blue, green, yellow, orange, then brick-red. The final colour reached, and how quickly it is reached, indicate roughly *how much* reducing sugar is present, not merely whether any is present at all.
- **Designing a results table: foods as rows, tests as columns**: A food-test results table needs one row for each food sample and one column for each test, with every row and column headed, so that one cell holds exactly one final colour for one food-and-test pair. A layout that lists only the foods, or only the tests, loses the pairing between them.
- **Elements alone cannot separate a carbohydrate from a fat**: Both carbohydrates and fats are built from carbon, hydrogen and oxygen only, so an analysis finding these three elements and no nitrogen narrows a sample to one of those two families but does not decide between them. A confident answer is "not a protein, so a carbohydrate or a fat"; naming one of the two from elements alone is unsupported.
- **Starch, glycogen and cellulose: one building block, three roles**: All three named polysaccharides are built entirely from repeating glucose units, yet each plays a different role: *starch* stores energy in plants, *glycogen* stores energy in animals, *cellulose* forms plant cell walls. Identical building blocks can produce molecules with completely different functions.
- **Combustion evidence identifies elements one result at a time**: Burning a biological molecule and testing the products gives indirect evidence for its elements. Limewater turning milky shows carbon dioxide formed, so the molecule contained carbon. Anhydrous copper(II) sulfate turning from white to blue shows water formed, so the molecule contained hydrogen. A negative test on damp litmus paper gives no positive evidence of nitrogen; it shows only that this particular test found none, not that nitrogen is definitely absent.
- **The building-block map, in one place**: Every large biological molecule reduces to one question, which smaller unit builds it. Carbohydrates reduce to *glucose*; fats reduce to *one glycerol and three fatty acids*; proteins reduce to a chain of *amino acids*. Naming the correct family from an unfamiliar description is almost always a matter of matching it against this map.

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.

TIP An unchanged orange-brown with iodine, or an unchanged blue with Benedict's or biuret, is a completed negative test, not a test that failed to run. On a panel of several results, treat every unchanged colour as evidence of absence and state it explicitly rather than leaving the cell blank.

TIP When a mass of precipitate is used to compare how much reducing sugar two samples contain, Benedict's solution is added in excess so that the reducing sugar, not the reagent, is what runs out first. If the reagent were limited instead, the precipitate mass would measure the amount of reagent added rather than the amount of sugar present.

TIP Both biuret and Benedict's solutions start *blue*, the classic confusion in a mixed panel. Biuret needs no heating and turns *purple* for protein; Benedict's needs heating and turns *brick-red* for reducing sugar. Check the procedure as well as the final colour before naming the test.

TIP Comparing two samples by weighing a dried precipitate gives a number any two people using the same balance would read the same way. Judging the final colour of a Benedict's test by eye depends on the observer. When a question asks *how much* of a substance is present, repeat the measurement three times, take the mean, and prefer the measured mass over a colour judgement.

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.
- **Functions of each cell structure**: Each structure has one main function, tested in both directions. Cell membrane: controls entry and exit. Cytoplasm: where chemical reactions happen. Nucleus: holds DNA, controls the cell. Ribosomes: make protein. Mitochondria: release energy by aerobic respiration. Cell wall: supports and shapes the cell. Chloroplasts: absorb light for photosynthesis. Permanent vacuole: stores cell sap and keeps the cell firm.

- **Levels of organisation**: Cells build up in a fixed order: *cell* leads to *tissue* (a group of similar cells working together), which leads to *organ* (several tissues working together for a function), which leads to *organ system* (a group of organs working together), which leads to *organism* (the complete living individual). A ribosome is an organelle, smaller than a cell, so it does not belong on this ladder.
- **Specialised cells: feature to function**: *Ciliated cell* (lining the trachea and bronchi): hair-like cilia beat to sweep mucus, and trapped particles, along the airway. *Root hair cell*: a long, thin extension into the soil gives a large surface area for absorbing water and mineral ions. *Palisade mesophyll cell*: packed with chloroplasts to absorb the most light for photosynthesis. *Neurone*: long and thin, to conduct electrical impulses. *Red blood cell*: a biconcave disc gives a large surface area and short diffusion path, and no nucleus leaves more room for haemoglobin. *Sperm and egg cells (gametes)*: specialised for reproduction, the sperm has a tail to swim to the egg.
- **Differentiation follows mitosis**: Mitosis produces a new cell that is genetically identical to its parent but *unspecialised*. That cell later develops the features its job needs, a separate step called *differentiation*, for example growing the long extension of a root hair cell. Differentiation always follows division and changes the cell's structure, not its genes.
- **Structure count as a functional clue**: A cell that does a lot of one job tends to contain many copies of the structure that does that job. A muscle cell packed with mitochondria signals a high rate of aerobic respiration for contraction. A gland cell rich in ribosomes signals a high rate of protein synthesis. A palisade cell dense with chloroplasts signals a high rate of photosynthesis. State the structure *and* the consequence, not just the structure, to earn the mark.

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.

TIP The exam usually requires measuring the two lengths yourself. Line the 0 mm mark on one edge and read to the nearest whole millimetre. Measure the *same feature* on the image and the real specimen, not a different feature or a different specimen. When specimens vary, measure several and take a mean; measuring the same one twice does not help.

TIP Three clues identify an unlabelled structure: size, shape and position. *Ribosomes* are the smallest, many tiny dots in the cytoplasm. *Mitochondria* are oval with a folded inner membrane, usually several per cell. *Chloroplasts* are green ovals scattered in the cytoplasm of a plant cell. The *nucleus* is a single large, rounded structure. The *cell wall* is the thick outermost boundary; the *cell membrane* is the thin layer just inside it.

TIP M greater than 1 means the image is bigger than the real object, the usual case for a microscope drawing. M less than 1 means the image is smaller, as in a scaled-down photograph. Inverting the ratio, $\text{actual size} \div \text{image size}$, gives a magnified drawing an M below 1, the tell-tale sign the formula has been used the wrong way round.

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.
- **Excretion is not egestion**: Excretion removes the waste products of *metabolism*, made by the body's own chemical reactions, and substances in excess of requirements. Egestion removes *undigested food* as faeces from the gut. That material was never absorbed into the body's cells, so it was never part of metabolism and simply passed through — it is not excretion.
- **Growth is not reproduction**: Growth makes one existing organism bigger: a permanent increase in its own size and dry mass. Reproduction makes new, separate individuals, so it increases their *number* instead. The test is whether the process ends with a bigger organism (growth) or with more organisms (reproduction) — a plant's own leaves lengthening is growth, but a new plantlet growing on a runner and becoming a separate plant is reproduction.
- **Respiration is not breathing**: Respiration is *chemical* and happens inside every living cell, breaking down nutrient molecules to release energy. Breathing, properly called *ventilation*, is *physical*: the movement of air into and out of the lungs. Breathing only supplies the oxygen that respiration uses, so an organism with no lungs, such as a plant, still respires in every cell.
- **Sensitivity needs a stimulus and a response, not a nervous system**: Every example of sensitivity has two parts: a *stimulus*, the change that is detected, and a *response*, what the organism does in reply. The definition names no mechanism, so a nervous system is not required — a plant achieves sensitivity too, for example by closing its stomata as water loss rises.
- **A dormant organism is still living**: The seven characteristics describe what an organism is *capable* of over its lifetime, not activities it must visibly perform at every instant. A dry seed or a hibernating animal may show no detectable nutrition, growth or movement for months, yet each retains the capacity to resume every life process once conditions allow, so each remains a living organism.
- **Nutrition: two strategies, one definition**: Nutrition is the taking in of materials for energy, growth and development. Plants make their own food from carbon dioxide and water using light; animals take in ready-made organic food from other organisms. The two strategies work in opposite directions, yet both are the taking in of materials for energy, growth and development, so both count as nutrition. Nutrition also supplies the raw material for respiration: once an organism stops taking in nutrients, stored reserves run out and respiration cannot continue.
- **The four confusable boundaries in one place**: Growth against reproduction: a bigger existing organism, or a new and separate one. Excretion against egestion: metabolic waste the body made, or undigested food that was never absorbed. Respiration against breathing: a chemical release of energy inside cells, or the physical movement of air. Movement against sensitivity: a change of position on its own, or a detected stimulus that produces that change — one event, such as a plant folding when touched, can show both together.

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.

TIP Where a growth question mentions eating, drinking or a full gut, the added mass is food or water passing through and will later be egested or lost, so it is not growth. Apply the two decisive words, *permanent* and *dry mass*: only a lasting increase in the organism's own living material counts.

TIP For any question asking whether an event is sensitivity, state the change that is detected and the reply that follows, for example "the earthworm detects the bird's shadow and responds by retreating into its burrow." A vague answer such as "it reacts" usually scores nothing, whereas naming both parts secures the mark.

TIP Questions of the form "which of growth, movement and sensitivity does the organism show?" frequently reward *more than one* answer. Work through each definition in turn and accept every one the event genuinely satisfies, rather than stopping at the first characteristic recognised.

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.
- **Comparing reactions fairly**: The size of a temperature change only tells you which reaction transferred more thermal energy when the comparison uses the *same volume* of the *same solution* for every reaction tested. A smaller volume of solution warms up or cools down more for the same thermal energy transfer, so unequal volumes cannot be compared by temperature change alone.
- **Finding the temperature change**: To find a temperature change, subtract the smaller reading from the larger one and state whether it is a *rise* or a *fall*. For a rise, take the final temperature minus the starting temperature; for a fall, take the starting temperature minus the final temperature. The classification mark depends on stating the direction, not only the number.
- **Any energy calculation formula is supplied in the question**: Core questions never require an energy formula to be recalled from memory. Where a calculation appears, the question supplies both the formula, such as $E = m \times c \times \Delta T$, and every value needed to use it. The real skill is finding the temperature change, ΔT, first and substituting it correctly, not memorising the relationship.

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.

TIP Where several final temperatures are compared against a common starting temperature, "most endothermic" means the reaction that took in the *most* thermal energy: the *biggest fall*, which is the *lowest* final temperature. Do not pick the biggest final-temperature number by mistake; a high final reading belongs to an exothermic reaction, not the most endothermic one.

TIP A single temperature reading can be affected by a random error or an unusual, anomalous result. Repeating the reaction and taking the mean of the highest (or lowest) temperature reached each time reduces the effect of these random errors and gives a more reliable result.

TIP A lidded polystyrene cup inside a beaker reduces the thermal energy lost to (or gained from) the room, so the measured temperature change reflects the reaction itself rather than the surroundings. Read the thermometer to the precision stated in the question, usually the nearest 0.5 °C, for both the starting and the final temperature.

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.

Reduction of copper(II) oxide by hydrogen

$$\mathrm{CuO + H_2 \rightarrow Cu + H_2O}$$

Used to identify oxidation and reduction from an equation using only oxygen. The copper(II) oxide loses its oxygen to become copper, so it is the copper(II) oxide that is reduced; the hydrogen gains that oxygen to become water, so it is the hydrogen that is oxidised.

Rearranging the rate equation for time

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

Used when a question gives the rate and the total quantity of product and asks how long the reaction takes, rather than asking for the rate itself. Keep the units of quantity and rate consistent before dividing, since mixing $\mathrm{cm^3}$ with a rate given in $\mathrm{cm^3/min}$ gives a time in minutes, not seconds.

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 $\mathrm{H_2O(l)} \rightarrow \mathrm{H_2O(g)}$ 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.
- **Choosing the apparatus to measure a rate**: A rate is followed by measuring something that changes at fixed time intervals. If the reaction gives off a gas, a *gas syringe* both collects the gas and reads its volume directly off the barrel; alternatively, standing the flask on a *balance* records the falling mass as gas escapes. Where the mixture *clouds*, as with sodium thiosulfate and an acid, the *disappearing-cross method* times how long the cross beneath the flask takes to vanish. A thermometer measures temperature only, so it never answers which apparatus measures the rate.
- **The fixed-total-volume dilution experiment**: The standard Core rate experiment reacts a carbonate, or a metal such as magnesium, with dilute hydrochloric acid mixed with water so the *total volume is always the same*, commonly $25\ \mathrm{cm}^3$ or $50\ \mathrm{cm}^3$, while only the *proportion of acid to water* changes between runs. More acid in that fixed total means a higher concentration and a shorter reaction time; keeping the total volume constant means concentration is the only variable that changes, so the results isolate the effect of concentration alone.
- **Comparing catalysts by reaction time, not cost**: Two catalysts are compared *only on rate* by how much they cut the reaction time, not by price. A catalyst that reduces an 8-hour reaction to 2 hours has produced a *greater* increase in rate than one that reduces the same reaction to 6 hours, because the larger reduction in time corresponds to the larger increase in rate. The cost of the catalyst and whether it is recovered and reused are separate questions from its effect on rate.

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.

TIP A results graph needs both axes labelled with the *quantity and its unit*, an *even scale* on each axis chosen so the points spread over most of the grid, points plotted accurately, and one ruled *line of best fit* through them, not a line joining point to point. A value read from the graph should come from the *line*, not from the nearest plotted point, since the line averages out experimental scatter.

TIP When a carbonate reacts with acid in an *open* flask standing on a balance, the reading falls because the carbon dioxide gas produced *escapes into the air*, not because the acid has reacted and become lighter or because the balance has lost accuracy. The method only works where the gas is light enough, and the flask vented enough, for the mass loss to be measurable.

TIP Sublimation followed by condensation, as when solid ammonium chloride vaporises on heating and reappears as a solid on a cooler surface, looks dramatic but is still physical: the solid that reforms is chemically identical to the solid that vaporised. Judge by the new-substance test alone, not by whether a change looks reversible or passes through a state that seems to vanish and reappear.

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.

TIP Carbon dioxide fits neither of the other harm patterns. It is *not toxic*, unlike carbon monoxide, and it does not cause acid rain, unlike sulfur dioxide and the oxides of nitrogen. Its harm is *global warming*: as levels rise it drives climate change. "Carbon dioxide causes acid rain" is always a trap.

TIP Sedimentation, filtration and carbon do *not* kill microorganisms, and chlorination does *not* remove solids or fix taste. Where treatment stages are labelled with letters, match each stage to its job rather than its position; the microbe-killing stage is always the one where chlorine is added.

TIP Planting trees *removes* carbon dioxide already released, by photosynthesis. Reducing livestock farming, decreasing fossil-fuel use and increasing renewables *prevent* carbon dioxide or methane being released in the first place. Prevention acts on the source, so it is the more reliable long-term strategy.

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.
- **Coordinator versus effector**: The CNS is the *coordinator*: it receives impulses, processes them and sends impulses back out, but it never moves anything itself. The *effector*, a muscle or a gland, is what actually carries out the response, at the far end of the pathway. A sensory neurone alone cannot produce a coordinated response, because it can only deliver information inward; it cannot process it and cannot reach an effector.
- **Nervous system versus endocrine system**: The nervous system sends electrical impulses along neurones: fast, short-lived, and precisely targeted to one effector. The endocrine system sends chemical hormones in the blood: slower to arrive, longer-lasting, and able to act on several target organs at once.
- **An endocrine gland releases its hormone straight into the blood**: An endocrine gland has no duct; it secretes its hormone directly into the blood, which is why each of the four named glands can be pinpointed on a diagram purely from its position in the body, without needing to trace a tube leading anywhere.

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.

TIP Before matching shape or position, check direction: a neurone carrying an impulse towards the CNS is sensory, a neurone carrying an impulse away from the CNS to an effector is motor, and a neurone found only inside the CNS, connecting the other two, is relay.

TIP The two facts examined most often are that the adrenal glands sit on top of the kidneys, and that the pancreas is the gland that secretes insulin. Both are favourite distractor targets, so lock them in first.

TIP Where a summary offers several claims together, test each one against its own syllabus definition in turn, rather than judging the whole summary at once. State which claims hold and which fail, and name exactly where each failing claim breaks.

TIP "One on top of each kidney" identifies the adrenal glands; "in the abdomen, near the stomach and the small intestine" identifies the pancreas. Name the gland from its position first, and only then attach the hormone, rather than trying to do both at once.

10 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.
- **Classifying a route: what carried the pathogen decides it**: Apply the body-to-body test to each route on its own before deciding. Contaminated food, a droplet in the air, a shared surface or an animal bite all carry the pathogen, so each of those routes is indirect, even when an infected person was clearly the original source. Only a route with nothing carrying the pathogen between the two bodies is direct.
- **Each control measure breaks the transmission chain at a different point**: A transmissible disease spreads when a pathogen leaves an infected host, travels by some route, and reaches a new host. A clean water supply and sewage treatment both act on the water route, but at different ends: sewage treatment stops human waste contaminating the water in the first place, while a clean water supply removes pathogens before anyone drinks it. Hygienic food preparation acts on the food route, and good personal hygiene acts on the direct-contact and surface routes.
- **Isolating an infected person breaks the chain at its first link**: Keeping a symptomatic person away from others removes the shared air, shared surfaces and direct contact that would otherwise let a pathogen leave that host and reach a new one. Isolation does not change the pathogen itself and does not cure the infected person; it changes only where the infected person is, and that is enough to reduce the number of new infections.
- **Evaluating a claim: separate the fact from the conclusion**: Break a claim into what it actually asserts, then test each part against the biology. A claim that credits one protective measure with an effect several measures produced together usually fails on the same point: the body's natural defences, control measures and vaccination each act at a different point and none of them is complete on its own, so no single one explains the whole result.
- **Reading supplied test rules as present/absent patterns**: Where a question supplies a set of rules and a table of results, write each rule as a pattern of which substances must be present and which must be absent, then write the sample's own pattern the same way, including the substances that were *not* found. Match the sample pattern to exactly one rule; if two rules seem to fit, an absence has been missed.

- **Three layers of protection, each with a different limit**: Body defences act on or inside the body but can be overwhelmed by a large dose of pathogens. Control measures act in the environment between hosts, reducing the dose that reaches people, but do not remove every pathogen. Vaccination acts on the host before infection, but is available for some pathogens only. Because each layer has a different limit, no single layer covers the gaps the others leave.

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.

TIP A bigger wound breaks the skin barrier over a larger area and can let in a larger dose of pathogens at once. Both effects push the same way: more entry area and more pathogens entering together make it more likely the body's remaining defences are overwhelmed before they can respond.

TIP An antibiotic is a drug acting after infection to treat existing bacteria. An antibody is a body product, also acting after infection, made by white blood cells. A vaccine is given before infection as a control measure to a healthy person. A wrong option typically swaps one of these three for another, for example calling an antibody a drug or claiming a vaccine treats an existing illness.

TIP A vaccine protects against the specific pathogen its programme targets; it gives no protection against a different, unrelated pathogen, and it does not stop that pathogen being present in the environment. Hand washing, clean water and the other control measures still reduce the dose of every pathogen a vaccinated person meets, including the ones no vaccine covers.

TIP The commonest error when matching a sample to a rule is comparing only what is present. If two conditions both involve the same substance, only the substance that is absent from one and present in the other separates them, so a negative result cannot be skipped over.

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.
- **A drug is taken in from outside the body**: The phrase "taken into the body" excludes substances the body makes for itself. A hormone such as adrenaline also modifies chemical reactions, but the body makes adrenaline internally, so it fails this test and is not a drug. Caffeine, taken in from a drink, passes the test.
- **A drug modifies reactions rather than supplying energy**: A drug does not need to provide energy or building material, which is what separates it from a food. A glucose sports drink supplies energy, so it is a food rather than a drug, even though it is taken into the body.
- **Why an antibiotic does not harm the patient's own cells**: An antibiotic attacks structures a bacterium has but a human cell does not, such as the bacterial cell wall or its own ribosomes. Because human cells lack these exact targets, the antibiotic can damage the bacteria without poisoning the patient.
- **Comparing two samples shows relative resistance**: When two bacteria samples both start at 500 colonies and get the same antibiotic, comparing their drops shows how resistant each is. A sample that collapses to 5 colonies is still largely non-resistant; a sample that only falls to 480 has mostly survived, so most of its bacteria are resistant. The comparison, not either number alone, is what shows which sample is resistant.

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.

TIP A question may set the scene with detail such as "from a ward with heavy long-term antibiotic use." That is background information, not something you are being asked to explain. Focus on what the question actually asks, usually whether the data support a stated claim about the antibiotic's effect.

TIP A substance is only a drug if it is taken into the body from outside AND it modifies or affects a chemical reaction in the body. Failing either test, being made inside the body, or only supplying energy, means the substance is not a drug.

TIP When a claim uses a word like "any", "all", "never" or "only", check that word first. Antibiotics do not affect "any" infection, since they do nothing to viral ones, and repeated antibiotic use is not "only" beneficial, since it can encourage resistance. Absolute claims are almost always the ones with a flaw.

TIP In an "evaluate this claim" question, never give a verdict alone. State what part of the claim is correct, then state what part fails and why, since marks are usually awarded for each part separately.

12 Electricity and magnetism

KEY FORMULAS

Combined resistance in series

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

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.
- **Opening a switch in a series loop**: Opening a switch anywhere in a series loop stops the current *everywhere* in that loop, so any ammeter in the loop falls to zero, whatever else the circuit contains.
- **Testing for charge, conductors and insulators**: A charged object *attracts* light uncharged objects such as small pieces of paper. More decisive is *repulsion*: bring the object near a known charged object hanging on a thread, and repulsion confirms it is charged and carries the *same* type of charge. A *conductor* lets charge move through it freely (the metals, and graphite); an *insulator* does not (plastic, rubber, glass, dry wood).
- **Why the earth wire and the fuse work together**: A fault making the live wire touch a metal casing makes the casing live. The *earth wire* gives that fault a very low-resistance path to earth, so a very large current flows through the fuse, which then *melts and disconnects the supply*. Without the earth wire the fault current would stay too small to blow the fuse, and the casing would remain live and dangerous.

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.

TIP Ammeters are *analogue* (a needle over a scale) or *digital* (a display), and come in different ranges, for example 0 to 1 A for a torch circuit or 0 to 10 A for a mains appliance. Pick a range the expected current sits comfortably inside; on an analogue meter, work out the value of one small division before reading.

TIP The most frequently examined parallel fact is that every branch receives the *full supply voltage*, however many branches there are and whatever their resistances. Two unequal resistors in parallel across a 12 V supply both have 12 V across them; apply $I = V/R$ separately to each branch with that same voltage.

TIP Dividing by a number *smaller than one* makes the result *larger*, so check the shape of an answer before trusting it: a current below 1 A across a resistance above $1\ \Omega$ should give a small voltage, and vice versa. This catches the common slip of multiplying instead of dividing, or dividing the wrong way round.

TIP A *variable resistor* is the component to add when a lamp's brightness must be adjusted *smoothly*; a fixed resistor only dims it to one set level, and a switch gives nothing in between.

TIP For a bill, never convert to joules. Work directly in kilowatts and hours: energy in kWh $=$ power in kW $\times$ time in hours, then cost $=$ energy in kWh $\times$ price per kWh. A 2.2 kW appliance run for half an hour uses 1.1 kWh.

TIP Leaving the current on between readings heats the component, and a hot component's resistance drifts, so *open the switch* between settings of the variable resistor. Averaging several calculated resistances reduces the effect of *random errors* in reading the scales; a repeat far from the rest is *anomalous* and is discarded before averaging.

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.

The general pattern for a molten binary compound

$$\text{metal compound (molten)} \xrightarrow{\text{electrolysis}} \text{metal} + \text{non-metal}$$

Used to predict the products of any molten binary ionic compound (a metal joined to one non-metal) without being told the specific substance. Opposite charges attract, and the metal ion is the positive one, so the metal always forms at the cathode and the non-metal always forms at the anode.

Molten potassium iodide: overall equation

$$\text{potassium iodide} \xrightarrow{\text{electrolysis}} \text{potassium} + \text{iodine}$$

Applies the general binary-compound pattern to a second named compound. Potassium metal collects at the cathode; iodine, seen as a dark purple-grey vapour or solid, forms at the anode.

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.
- **Metals conduct but are never electrolysed**: A metal conducts electricity, but it is an element, not an ionic compound, so there is nothing for a current to decompose: metals are never electrolysed. The same two-part test applies to any sample: it must be an *ionic compound*, and its ions must be *free to move* (molten or dissolved), before it can both conduct and be electrolysed.
- **Why a fuel-cell vehicle releases no carbon dioxide**: A petrol engine burns a fuel that contains carbon, so its exhaust releases carbon dioxide. A hydrogen-oxygen fuel cell reacts only hydrogen and oxygen, and its only chemical product is water, so a fuel-cell vehicle releases no carbon dioxide as it runs. That single fact is what makes fuel-cell vehicles attractive in city centres with strict air-quality rules.
- **The two-condition test for conducting and electrolysing**: A sample both conducts electricity *and* is decomposed by that current only if it passes two conditions together: it must be an *ionic compound*, and its ions must be *free to move*. A solid ionic compound fails the second condition. A metal fails the first. Only a molten or aqueous ionic compound passes both.

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.

TIP Chlorine gas is acidic in water, so damp litmus paper may briefly redden, but the mark-worthy observation is that chlorine then *bleaches* the paper, turning it white. Answering only "turns red" describes an acidic gas in general and does not identify chlorine specifically.

TIP Products and observations are marked separately, so naming the substance alone often earns only half the available marks. State what forms *and* what is seen or tested, for example "bromine forms at the anode, seen as a red-brown vapour" rather than "bromine" alone, or "hydrogen forms at the cathode, tested with a lighted splint, giving a squeaky pop" rather than "hydrogen" alone.

TIP A vague answer such as "fuel cells are clean" or "fuel cells are good for the environment" scores nothing on its own. State the full syllabus fact: a hydrogen-oxygen fuel cell uses hydrogen and oxygen to produce electricity, with water as the only chemical product. Naming the two reactants and the one product is what earns the 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.
- **A small mass of enzyme processes a large mass of substrate**: Because an enzyme is not used up, a small, fixed mass of it can go on converting substrate until none is left; the reaction stops when the *substrate* runs out, never because the enzyme does. This is the property that makes a catalyst a catalyst: if the enzyme itself ran out, the reaction would stop early with most of the substrate untouched.
- **Catalase breaks down hydrogen peroxide into water and oxygen**: *Catalase* is an enzyme found in the cells of most living things; its substrate is *hydrogen peroxide*, which it breaks down into water and oxygen. Because a gas is released, the reaction is followed by the *foam* the oxygen produces: more catalase releases more oxygen in a fixed time, giving more foam and a greater measured height.
- **Matching an organism's enzymes to its habitat**: An organism's enzymes have optimum conditions that suit where it actually lives, or it could not survive there. A species from a hot, alkaline habitat needs a high optimum temperature and a high, alkaline optimum pH; testing an option against both requirements at once, rather than one at a time, is what separates a correct answer from a partial one.
- **Choosing apparatus to fit the measurement**: A *water bath* holds a fixed temperature and a *buffer solution* holds a fixed, known pH, so each can be controlled while the other variable is tested. A small syringe or measuring cylinder measures small volumes, such as 1 cm3, more accurately than a large beaker or a count of drops; a *gas syringe* measures the volume of gas released as a reaction proceeds.
- **The uneven foam surface limits how precisely height can be read**: The top of a foam column in the catalase practical is bubbly rather than flat, so different readers can reasonably choose different points to measure against a ruler, making the height reading less precise. A genuine practical difficulty names this specific problem rather than a generic "measurement error".

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".

TIP In the catalase practical, apple is *liquidised* to break open its cells and release the catalase trapped inside, since whole pieces keep most of the enzyme locked away. A yeast suspension is *stirred* immediately before sampling because the cells settle over time, and stirring spreads them evenly so every sample contains the same amount of catalase.

TIP Activity falls the further a value sits from the optimum, in either direction, so the lowest activity belongs to the option furthest away, not necessarily the most extreme value offered. Measure the distance of each option from the optimum before ranking; do not assume an extreme end of the scale is automatically the worst.

TIP Repeating each measurement, usually three times, allows the results to be compared: if two agree closely and one does not, the odd one is likely *anomalous* and should be excluded before a mean is calculated. A mean taken from consistent repeats is far more trustworthy than any single reading.

TIP If a temperature investigation also lets substrate concentration change between trials, any difference in rate could come from the temperature difference, the concentration difference, or both, so temperature alone can no longer be identified as the cause. This holds however carefully the rest of the method was followed.

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 $100\ \mathrm{g}$ of solvent but the experiment used a different mass of water. Scale the mass of water up (or down) to $100\ \mathrm{g}$ and scale the dissolved mass of solute by the *same* factor. E.g. $18\ \mathrm{g}$ dissolving in $50\ \mathrm{g}$ of water scales to $18 \times \frac{100}{50} = 36\ \mathrm{g}$ per $100\ \mathrm{g}$ 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 $0.05\ \mathrm{cm^3}$, reading the bottom of the meniscus at eye level.

Average of concordant titres

$$\text{average titre} = \frac{t_1 + t_2 + t_3}{3} \quad \text{(concordant values only)}$$

Used once an initial *rough* titration has located the end-point approximately and further, more careful, titrations have been repeated. Only *concordant* titres, those agreeing closely (typically within about $0.10\ \mathrm{cm^3}$), are averaged; a rough or anomalous titre is discarded first, since including it would distort the average.

Concentration ratio from a titre ratio

$$\frac{\text{concentration of P}}{\text{concentration of Q}} = \frac{\text{titre of Q}}{\text{titre of P}} \quad \text{(equal volumes of alkali)}$$

Used when two alkali solutions of the *same volume* are each titrated against the same acid; the one needing *more* acid to reach the end-point is the more concentrated. E.g. if P needs $30.0\ \mathrm{cm^3}$ of acid and Q needs $10.0\ \mathrm{cm^3}$, then P is $30.0 \div 10.0 = 3$ times as concentrated as Q, without ever calculating a mole quantity.

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* $\mathrm{CO_3^{2-}}$: add dilute acid, giving effervescence, and the gas turns limewater milky. *Chloride* $\mathrm{Cl^-}$, *bromide* $\mathrm{Br^-}$ and *iodide* $\mathrm{I^-}$: acidify with dilute nitric acid, then add aqueous silver nitrate, giving a *white*, *cream* and *yellow* precipitate respectively. *Sulfate* $\mathrm{SO_4^{2-}}$: 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.
- **A two-step recovery: filter, then crystallise**: To obtain a pure soluble solid from a mixture that also contains an insoluble solid, first *filter* to remove the insoluble solid as residue, leaving a filtrate that contains only the dissolved product. Then *crystallise* the filtrate: evaporate some water to reach saturation, then cool slowly so that pure crystals grow.
- **Distinguishing zinc from calcium with excess sodium hydroxide**: Both zinc and calcium give a *white* precipitate with a little aqueous sodium hydroxide, so the two are indistinguishable from the first observation alone. Adding *excess* sodium hydroxide tells them apart: the zinc precipitate *dissolves* to give a colourless solution, while the calcium precipitate stays insoluble. The behaviour in excess, not the initial colour, is the deciding test.
- **Identifying a substance by comparison**: An unknown is compared with several known reference substances spotted on the *same* baseline and developed in the *same* solvent, under identical conditions. If the unknown's spot lines up at exactly the same height as one reference's spot, and no other reference matches, the unknown is most likely that same substance.
- **Why the flask is swirled throughout**: Continuous swirling mixes the acid evenly into the alkali as it is added, so the reaction happens throughout the flask rather than only where the acid lands. Without swirling, a local colour change near the entry point could be mistaken for the end-point before the solutions have actually reacted completely, giving a titre that is too small.
- **Why the solution is acidified before an anion test**: Dilute nitric acid is added before silver nitrate (for a halide) or barium nitrate (for sulfate) to react away and remove any *carbonate* ions first. A carbonate would otherwise also give a precipitate with these reagents, producing a false positive. Acidifying first guarantees that any precipitate seen afterwards is genuinely the anion being tested for.
- **Designing a valid investigation**: A valid plan changes only the *independent* variable, keeps every other quantity (the *control* variables) fixed, and measures the *dependent* variable with a single consistent instrument. Using different instruments for different readings, or changing more than one

quantity at once, means any difference in the result cannot be pinned on the independent variable alone, so the test is no longer fair.

- **Locating agents reveal colourless substances**: A chromatogram only shows spots that can be *seen*, so colourless substances such as amino acids appear to have travelled nowhere at all. A *locating agent*, such as ninhydrin, is sprayed onto the *dried* chromatogram and reacts with the separated substances to form coloured spots, which can then be compared by height like any other chromatogram. The paper is dried first so the solvent front position is fixed before the spray is applied.
- **Why an impurity lowers and broadens a melting point**: In a pure solid, every particle is held in a regular, repeating arrangement by the same forces, so the whole structure breaks down at one single, sharp temperature. Impurity particles disrupt that regular arrangement, so the weakened regions break down at lower temperatures while the more ordered regions hold together longer. Melting therefore starts early and spreads over a *range*, instead of happening at a single fixed value.

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.

TIP Two different substances can occasionally travel the same distance in one solvent by coincidence, so a single spot matching a reference in *one* solvent is good evidence but not certain. Running the same unknown and reference again in a *second, different* solvent, and finding the spots still line up, gives much stronger evidence that the identification is correct.

TIP A measuring cylinder *can* measure a volume, but only approximately. When a question says "as precisely as possible", or quotes a reading to two decimal places, that is a signal to choose a *volumetric pipette* (one fixed volume) or a *burette* (a variable volume, read to $0.05\ \mathrm{cm}^3$) instead. Naming the right instrument is worth nothing without stating *why* it is more precise.

TIP Before filling, a burette is rinsed with a small amount of the *acid* it will hold, not only with water. Any water left inside would dilute the acid as it is run in, changing its concentration and giving an inaccurate titre. Rinsing with the acid itself removes that risk without affecting the concentration used.

TIP No single test identifies a salt completely; a cation test (sodium hydroxide, ammonia or a flame test) and an anion test (acidified silver nitrate, barium nitrate or dilute acid and limewater) must each be carried out and combined. E.g. a blue precipitate insoluble in excess sodium hydroxide identifies copper(II), and a white precipitate with acidified silver nitrate identifies chloride; together they identify the salt as copper(II) chloride.

TIP A measuring cylinder and a spatula load are both coarse. If a plan uses these to measure a liquid volume and a solid mass, the standard improvement is to swap them for finer apparatus: a *burette* reads volume to $0.05\ \mathrm{cm}^3$, and a *digital balance* gives an exact mass in grams instead of an unknown spatula load. Repeating a measurement improves *reliability*; changing to finer apparatus improves *accuracy*, and the two are not interchangeable answers.

TIP A crystallisation is stopped and left to cool as soon as crystals just begin to appear at the edge of the liquid, not boiled dry. Cooling *slowly* and undisturbed lets crystals grow gradually into large, well-formed, pure crystals; continuing to heat until the liquid is gone, or cooling rapidly, instead gives a mass of small crystals that are more likely to trap impurities.

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.

Total volume of air moved per minute

$$V = \text{breathing rate} \times \text{volume per breath}$$

Used to find the total volume of air breathed in one minute from a data table giving a rate and a volume per breath; multiply the two together, since both rise together during exercise.

Change expressed as a percentage of the original value

$$\text{Percentage change} = \frac{\text{change}}{\text{original value}} \times 100$$

Used when a question asks for a percentage rather than an absolute change; divide the change by the *original* (starting) value, then multiply by 100. Dividing by the new value instead is the common error.

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.

- **A fair test keeps everything but the air sample the same**: Comparing inhaled and exhaled air with limewater only works if the *only* difference between the two tubes is which air passed through them. The volume of limewater in each tube must be identical; a smaller volume clouds faster regardless of the air sample, so an unequal volume makes the comparison meaningless.
- **Both rate and depth increase during exercise**: During exercise, muscles respire faster, so they need more oxygen and produce more carbon dioxide. Breathing responds in *two* ways: the *rate* (breaths per minute) increases and the *depth* (volume of air per breath) increases. A data table showing both columns rising, even if the word "depth" never appears, is evidence for both changes.
- **Recovery after exercise is gradual, not instant**: When exercise stops, breathing rate and depth fall back toward the resting value, but *gradually*. Minutes after stopping, the breathing rate can still be above resting; a value moving back toward resting is not the same as a value that has returned to resting, and the two must be compared using the actual numbers given.
- **Reading a data table for gas-composition claims**: A claim about several gases at once must be checked against each gas separately, not assumed to apply to all of them. Given oxygen falling, carbon dioxide rising and water vapour rising between inspired and expired air, a claim that "all three increase" is wrong because oxygen actually decreases; only two of the three gases named do rise.

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*.

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

TIP A full answer to "how does breathing change during exercise" states that both the *rate* and the *depth* of breathing increase. Because the total air moved per minute depends on both, an answer naming only the rate misses the depth mark.

TIP When a question gives a gas that stays at essentially the same percentage on both sides of breathing (about 78%), it is testing whether nitrogen is recognised as unaffected by breathing, in contrast with oxygen and carbon dioxide, which do change measurably.

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.
- **A green field is not necessarily biodiverse**: Replacing natural habitat with a plantation or a single-crop field is still habitat destruction even though the land stays covered in plants. Biodiversity can collapse from dozens of species to one or two while the land remains green, since biodiversity counts different species, not how much of the ground is covered.
- **Hunting is not overharvesting**: *Hunting* is the deliberate killing of individuals, for example poaching rhinos for their horns. *Overharvesting* is removing individuals, often by fishing or collecting, faster than the population can replace them by breeding. The fingerprint of overharvesting is the phrase "faster than the population can replace by breeding"; hunting is identified by deliberate killing for a product, not by population arithmetic.

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.

TIP If an option describes planting trees, creating a reserve, recycling or treating waste before release, it is never one of the three reasons for habitat destruction. That single check removes several distractors at once in a "which reasons" question.

TIP Every deforestation distractor reverses one direction: biodiversity falls, soil is lost, flooding increases, carbon dioxide increases (fewer trees means less photosynthesis removing it). Read a claimed effect and check it moves the correct way before accepting it.

TIP A correct conservation answer names the method that suits the stated threat: monitoring and protecting a reserve against poaching or a predator, education against a demand-driven threat such as hunting, captive breeding to rebuild numbers of a rare animal, seed banks for a rare plant. A method that does not match the threat given is a wrong answer even if it sounds like conservation.

TIP A table of several rhino species' populations often lists the numbers out of size order, so the smallest figure might not sit in the first or last row. Read every row before deciding which species has the highest or lowest population; picking the first or last row without comparing is the most common wrong answer.

TIP Run two checks on a proposed conservation action. First, does the method match the *threat* actually described in the scenario? Second, is the method being used for what it can genuinely do, for example seed banks for plant seeds and captive breeding for raising animal numbers? Most wrong options in an evaluation question fail one of these two checks.

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.

Finding a nutrient's mass from its percentage

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

Used when a percentage by mass and a total portion mass are given and the actual mass of the nutrient is asked for; rearrange the percentage-by-mass formula for the nutrient's mass.

Finding the total mass from a nutrient's percentage

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

Used when a nutrient's mass and its percentage by mass are both given and the total portion mass is asked for; divide the nutrient's mass by the percentage expressed as a decimal.

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.
- **Absorption is not assimilation**: Absorption gets nutrients across the gut wall into the blood; assimilation is what happens next, when a body cell takes them in and uses them, for example to build new proteins. Absorption is a journey through the gut wall; assimilation is a use inside a cell.
- **Egestion is not excretion**: Egestion removes material that was never absorbed, so faeces are food that failed to get into the body. Excretion removes waste products of reactions that happened inside the body, such as urea in urine. Using "excretion" for faeces loses the mark even when the rest of the answer is right.
- **Energy needs are not fixed**: The energy a person needs from their diet depends on *age*, *sex* and *level of physical activity*, and on states such as pregnancy. A large, very active person needs more daily energy than a small, inactive one of the same age; the same balanced diet is simply scaled to fit the individual.
- **Ingestion, digestion, absorption, assimilation, egestion: where each happens**: *Ingestion* is the taking of food and drink into the body, at the mouth. *Digestion*, the breakdown of food, happens in the mouth, the stomach and the small intestine. *Absorption*, the movement of nutrients into the blood, happens mainly in the small intestine; the large intestine absorbs water. *Assimilation*, the uptake and use of nutrients by cells, happens in the body's cells, not in the gut at all. *Egestion*, the removal of undigested food as faeces, happens at the anus.
- **Nutrient source and importance: the load-bearing pairs**: Two pairings carry most of the reasoning questions in this section. *Vitamin D and calcium*: calcium is the material bones are built from, and vitamin D is what lets the gut absorb it, so a shortage of either weakens bones. *Iron and haemoglobin*: haemoglobin is the oxygen-carrying pigment in red blood cells, and iron is a required part of it, so an iron shortage limits how much oxygen the blood can carry.
- **The surface-area chain: chewing to faster chemical digestion**: Breaking food into smaller pieces increases its total surface area; enzymes can only act on a surface they can reach, so more surface means more enzyme molecules acting at once and faster chemical digestion. The full chain, smaller pieces, greater surface area, more contact with enzymes, faster chemical digestion, must all be stated; "it makes the food smaller so it digests faster" alone scores little.
- **Digestion undoes construction**: Starch, protein, and fats and oils are all built, in growth and storage, from smaller soluble units: glucose, amino acids, and fatty acids and glycerol. Chemical digestion runs that construction in reverse, breaking the same large molecules back down into the same small building blocks so they can be absorbed.
- **Why associated organs are not part of the alimentary canal**: The alimentary canal is the continuous tube food actually travels along; the liver, gall bladder and pancreas add secretions to that tube through ducts but food never passes through them. That structural distinction, not their importance to digestion, is why they are called *associated organs* rather than parts of the canal.

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.

TIP Diagram questions describe organs by shape and position and expect you to match. Name every labelled part first, from the description alone; examiners write distractors that get one label right, so checking only your most confident label can make a wrong row look correct.

TIP A bar-chart "best source" question asks you to read the chart, the tallest bar wins, not to recall which foods you happen to know are rich in that nutrient. If the chart names an unfamiliar food as tallest, that food is still the answer.

TIP A distractor for "which type of digestion is this" often says a molecule has become "smaller", which is also true of physical digestion. The word that actually decides the answer is *soluble*: only chemical digestion produces a different, soluble molecule; physical digestion only changes the size of the pieces.

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.

TIP There are two ratios a question can ask for, and they are often not the same. The *genotype ratio* counts the letter-pairs (how many of each genotype); the *phenotype ratio* counts what the offspring look like, merging any genotypes that share a look. Before writing a phenotype ratio, check whether the recessive genotype can even be produced: if one parent is homozygous dominant, no offspring can show the recessive phenotype, however varied the genotype ratio looks.

TIP State the parental genotypes and phenotypes; write each parent's gametes in circles, one allele per gamete; combine the gametes in a Punnett square, one parent's gametes across the top and the other's down the side; read off the offspring genotypes from the grid; convert to phenotypes using the dominant and recessive rule; state the ratio. Examiners reward this full method, not just the final ratio.

20 Metals

KEY FORMULAS

General equations for a metal with water and with steam

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

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

General reactions of a metal with oxygen and with dilute acid

$\text{metal} + \text{oxygen} \rightarrow \text{metal oxide}$ 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: $2\mathrm{Mg} + \mathrm{O_2} \rightarrow 2\mathrm{MgO}$. 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.

Predicting a displacement outcome as a word equation

$\text{metal A} + \text{salt of metal B} \rightarrow \text{salt of metal A} + \text{metal B}$ (only if A is more reactive than B)$

Use whenever a more reactive metal is added to a solution of a less reactive metal's salt; the more reactive metal takes metal B's place in the compound. For example, magnesium added to zinc sulfate solution: $\mathrm{Mg} + \mathrm{ZnSO_4} \rightarrow \mathrm{MgSO_4} + \mathrm{Zn}$.

Word equation for rusting

$\text{iron} + \text{oxygen} + \text{water} \rightarrow \text{hydrated iron(III) oxide}$

Use to state the conditions for rusting; both oxygen and water appear as reactants, which is exactly why removing either one prevents rusting. Rust is hydrated iron(III) oxide, not iron oxide alone.

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.
- **Reading a pure-metal versus alloy particle diagram**: A *pure metal* is drawn as circles of *one size* only, in a regular pattern. An *alloy* is drawn as circles of *two or more different sizes* mixed together. At Core, treat the diagram as an identification tool: it tells you which material is shown, which is what the question asks for.

EXAM TIPS

TIP The mark scheme for a barrier method wants the words *physical layer* and both blocked substances named: oxygen and water. Do not switch to a chemical explanation such as neutralising acid or forming an alloy; painting, greasing and plastic coating are physical barriers only.

TIP If every sample of a material has exactly the same percentage composition, its atoms are chemically joined and it is a *compound*. If the proportions vary from sample to sample, as they do in steel, it is a *mixture* and therefore an alloy.

TIP Where a use has two demands, argue each separately and then combine, because that is how the marks are allocated. Copper conducts better than aluminium, yet aluminium is chosen for overhead cables because the unsupported span makes low mass the limiting requirement, while copper is chosen inside a plug because the wire is short and fully supported, so conductivity alone decides.

TIP Calcium and sodium react readily with *cold water*; magnesium barely reacts with cold water but reacts rapidly when heated in *steam*. Where a metal reacts with steam but only very slowly with cold water, expect magnesium. Treat the two tests as separate points on the series and never merge them.

TIP The two ore names are easy to swap. *Hematite gives iron; bauxite gives aluminium.* Limestone is also added to the blast furnace, but it is not an ore; it is there to help remove impurities.

TIP A common error swaps the direction of charge. Losing negative electrons leaves the particle with unbalanced positive protons, so it becomes *more* positive, never more negative. Say it once: take away a minus, leave a plus.

TIP The Extended paper writes out the blast furnace as five balanced equations: coke burning to carbon dioxide, carbon dioxide reduced to carbon monoxide, carbon monoxide reducing the iron(III) oxide, limestone decomposing, and the slag-forming reaction. None of those equations is required at Core. State only that iron is extracted by *reduction of iron(III) oxide in the blast furnace*, and be able to read a labelled diagram.

TIP Conductivity and malleability are the properties examiners return to most often, because they separate a metal from a non-metal most sharply: a non-metal solid neither conducts nor bends without shattering.

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.
- **Floating and sinking from density**: Compare the density of the object with the density of the fluid it is in. If the object's density is *greater*, it sinks; if it is *less*, it floats. Water has a density of 1.0 g/cm^3, so a piece of wood of density 0.8 g/cm^3 floats while a piece of metal of density 7.9 g/cm^3 sinks. This is why most metals sink in water: almost all of them have a density well above 1.0 g/cm^3.
- **Friction and drag oppose motion**: *Friction* is the force between two touching surfaces that can impede relative motion and produce heating. The same effect acts on an object moving through a liquid or a gas, where it is called *drag*: air resistance is drag caused by movement through the air. Friction and drag always act to oppose the direction of motion.
- **Generating useful energy and electrical power**: Useful energy or electrical power can be obtained from fossil fuels, biofuels, water (including waves, tides and hydroelectric dams), geothermal resources, nuclear fission, sunlight (solar cells), infrared and other electromagnetic waves from the Sun (solar thermal collectors) and wind. Most of these methods follow the same chain: the resource heats water into steam or otherwise turns a *turbine*, the turbine turns a *generator*, and the generator produces the electricity.
- **Gradient and area on motion graphs**: On a *distance-time* graph the gradient of a straight-line section is the speed: a horizontal line means the object is stationary, and a steeper line means a greater speed. On a *speed-time* graph, a horizontal line means constant speed, a line sloping up means the object is accelerating and a line sloping down means it is decelerating. The area between the line and the time axis on a speed-time graph is the distance travelled.
- **How energy is transferred between stores**: Energy moves between stores by four pathways: mechanically, when a force does work; electrically, when a current does work; by heating; and by waves, including light and sound. Name the store and the pathway separately: a battery holds a *chemical* store, transferred *electrically* to a lamp, which then transfers energy to the surroundings by heating and as light.
- **Mass and weight are different quantities**: *Mass* is the quantity of matter in an object, measured in kilograms, and does not change with location. *Weight* is the gravitational force acting on that mass, measured in newtons, and changes if the gravitational field strength changes. A bag of mass 5 kg has the same mass wherever it is weighed, but its weight in newtons depends on the value of g at that place.
- **Meaning and position of centre of gravity**: The *centre of gravity* is the single point at which the entire weight of an object can be taken to act. For a uniform, symmetrical object such as a rectangular block, a sphere or a cylinder, it lies at the geometric centre. In a diagram the weight is drawn as one arrow acting vertically downwards from this point, however the object is oriented.
- **Moment as a turning effect**: The *moment* of a force is a measure of its turning effect about a pivot. Everyday examples include turning a spanner on a nut, pushing open a door and pressing down on

a see-saw. The same force produces a bigger moment the further it acts from the pivot, which is why a long spanner needs less force than a short one to loosen the same nut.

- **Reducing sources of error in a measurement**: A single reading can be wrong for reasons other than a slip: a *parallax error* comes from viewing a scale at an angle rather than straight on, and a *zero error* comes from an instrument that does not read zero when it should. Reduce the effect of small random errors by repeating a measurement and taking a mean. Read the meniscus at eye level and check an instrument reads zero before use to remove the other two.
- **Why a large contact area gives a small pressure**: In $p = F/A$ the force and the area are independent, so spreading the same force over a larger area lowers the pressure in proportion. A hiker's weight does not change when she swaps boots for snowshoes, but the much larger contact area of the snowshoes reduces the pressure on the snow, so she sinks in less.
- **Effect of centre of gravity on stability**: An object is more stable, harder to topple, when it has a *low* centre of gravity and a *wide* base. Both features make the object tilt through a larger angle before it becomes unstable. A racing car, built low and wide, is more stable than a tall, narrow vehicle of similar mass.
- **Finding the centre of gravity of a lamina by suspension**: Suspend a flat, irregularly shaped sheet freely from a pin through a hole near one edge, so it can swing. Hang a plumb line from the same pin and mark the vertical line it traces on the sheet. Repeat from a second hole. The centre of gravity is the point where the two lines cross, because a freely suspended object always hangs with its centre of gravity directly below the point of suspension.
- **Recognising motion from the shape of a graph**: On either a distance-time or a speed-time graph, a horizontal line means the object is at rest (distance-time) or moving at constant speed (speed-time). On a distance-time graph a straight sloping line means constant speed, while a curving line means the speed is changing. On a speed-time graph a straight line sloping upward means the object is accelerating and a straight line sloping downward means it is decelerating. Read which graph is shown before deciding what a horizontal or sloping section means.
- **The condition for equilibrium**: An object is in *equilibrium* when there is no resultant force and no resultant moment acting on it, so it neither accelerates nor turns. A door held open by hand and not moving is a simple example: the forces on it, and the moments of those forces about its hinge, balance.

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.

TIP A ruler marked in millimetres has a smallest division of 1 mm, so a single reading is uncertain by about ± 0.5 mm. This limit does not improve by reading more carefully, only by choosing a more precise instrument. Quote a length to the precision the ruler allows, not to more decimal places than the scale supports.

TIP An answer in pascals needs the area in m^2. Divide an area in cm^2 by 10 000, not by 100, because the conversion applies to both dimensions: 600 cm^2 $= 0.06$ m^2, giving $p = 840/0.06 = 14\,000$ Pa. Dividing by 100 gives an answer 100 times too small.

TIP The equation $W = mg$ requires the mass in *kilograms*, because g is in N/kg. A rock of mass 250 g weighs $0.25 \times 9.8 = 2.45$ N, not 24.5 N. Divide any mass given in grams by 1000 as the first line of working, before substituting.

TIP A question comparing energy resources is asking for a comparison across several factors, not just one. *Renewability* asks whether the resource runs out; *availability* and *reliability* ask whether it can be used at that place and whether it supplies power on demand, since wind and solar depend on the weather; *scale* asks how much power a single installation can supply; and *environmental impact* covers land use, waste and any polluting emissions. Structure an answer around these five factors rather than a single general statement.

TIP A question asking how electrical power is generated from a named resource wants the specific chain for that resource: for example, wind turning a wind turbine's blades, which turn a generator directly, without a boiler or steam. Answering with a general term such as "renewable energy" or "green power" in place of the named method and its turbine-generator chain does not answer the question asked.

TIP Energy that is not used for the intended purpose has not disappeared, only been transferred to another store, usually the internal (thermal) store of the surroundings. A description of an energy change should name the store the "missing" energy has gone to, rather than describing it as lost or used up.

TIP A resultant force found by adding or subtracting forces along a line has both a size and a direction, and a full answer states both. For two forces of 45 N and 18 N acting in opposite directions, "27 N" alone is an incomplete answer; the direction, the same as the larger of the two forces, must be given as well.

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.

Change in mass

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

The first step of the potato-cylinder practical calculation, always final minus initial so that the sign carries the meaning: a positive change means a gain of water, a negative change means a loss.

Rate of diffusion

$$\text{rate of diffusion} = \frac{1000}{\text{average time}}$$

Used in the agar-cube practical, defined so that a shorter time gives a bigger number. The average time is the mean of the repeated timings, in seconds, for a cube to turn completely red in acid.

Surface area of an agar cube

$$\text{surface area} = l \times l \times 6$$

Used in the agar-cube diffusion practical to find the surface area of a cube of side l; a cube has six square faces, so the 6 belongs to the area, never to the volume.

Volume of an agar cube

$$\text{volume} = l \times l \times l$$

Used alongside the surface-area formula to find the surface-area-to-volume ratio of a cube of side l; volume is three lengths multiplied, so it has no 6 in it.

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.
- **Diffusion continues until particles are evenly spread**: Diffusion continues until the particles are evenly spread (equilibrium), at which point net movement stops even though the random motion of individual particles never does. Once concentrations are equal, particles are equally likely to cross in either direction, so the two flows cancel.
- **Diffusion, osmosis and active transport side by side**: Diffusion moves any small particle down its gradient (high to low) and needs no energy. Osmosis is the same downhill movement but for water only. Active transport moves particles the cell needs against their gradient (low to high) and can only do this because it spends energy from respiration. Given a scenario, decide what moves, which way, and whether energy is being spent, and only one process fits.
- **Only water moves in osmosis**: Only water crosses the membrane in osmosis; the dissolved solute, such as sugar or salt, is held back by the partially permeable membrane and does not move with it. Writing that "the sugar moved into the cell" or "the salt moved out" throws the mark away.

EXAM TIPS

TIP Percentage change in mass is always found by dividing the change by the *initial* mass of that same cylinder, never by the final mass and never by another cylinder's mass. Keep the minus sign too, since a bare percentage with no sign loses the direction water moved.

TIP The rate formula divides 1000 by the time, never the other way round. Sense-check the answer: a faster experiment (a shorter time) must give a bigger rate, so an answer that looks tiny for a fast trial has probably divided the wrong way.

TIP A solute such as sugar or salt is never described as "moving by osmosis": osmosis moves only water, and the solute stays where the partially permeable membrane holds it back. Where a cell in a concentrated solution loses water, describe the water as leaving the cell, not the solute as entering it.

TIP Label both axes with the quantity and its unit, and use a linear scale that spreads the points over more than half the grid. Because the plotted points follow a curve, draw one single smooth curve of best fit rather than joining the points dot to dot or forcing a straight line through them. To read a value, draw a construction line up from the axis to the curve, then across to the other axis.

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.

Charge of a nucleus

$$\text{charge of nucleus} = (\text{number of protons}) \times (+1)$$

Use whenever a question gives the number of protons in a nucleus and asks for its overall charge. Only protons carry charge inside the nucleus; neutrons contribute 0. For 6 protons, the charge is $6 \times (+1) = +6$. Neutrons never change the answer, however many are present.

Corrected count rate

$$\text{corrected count rate} = \text{total count rate} - \text{background count rate}$$

Use before working with a reading taken near a source, because every measurement also picks up the background radiation that is always present. A total of 32 counts/s against a background of 8 counts/s gives a corrected count rate of $32 - 8 = 24$ counts/s due to the source alone.

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.
- **Ionising radiation damages living cells**: Ionising radiation can *kill* a living cell outright, or *damage its DNA* if the cell survives, which may cause a mutation and lead to cancer. The larger the dose received, the greater the risk, which is why exposure is always kept as low as practical rather than treated as safe up to some threshold.
- **Why the count never quite reaches zero**: Each half-life removes half of whatever remains, not a fixed amount, so later drops are smaller than earlier ones: $160 \to 80$ loses 80, but $20 \to 10$ loses only 10. The count keeps getting closer to zero without ever quite arriving, and this is also why the half-life itself does not change as a sample decays away.

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.

TIP Most half-life questions are settled by halving repeatedly. Write the chain from the starting value to the final value and count the arrows: $960 \to 480 \to 240 \to 120$ is 3 halvings. If that took 84 years, the half-life is $84 \div 3 = 28$ years. Where the data come from a detector, correct for background *before* counting the halvings.

TIP Between two charged plates, only a *charged* type of radiation is pushed off a straight path. *Gamma* carries no charge, so it passes straight through undeflected. *Alpha* is positive, so it curves toward the negative plate; *beta* is negative, so it curves toward the positive plate, in the *opposite* direction to alpha.

TIP A neutron's relative charge is 0, so it adds nothing to the charge of a nucleus no matter how many are present. The charge of a nucleus depends on the *proton number alone*: count the protons, and put a $+$ in front. This holds regardless of how many neutrons sit alongside them.

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.

Incomplete combustion of an alkane

$$\text{methane} + \text{oxygen (limited)} \rightarrow \text{carbon monoxide / carbon (soot)} + \text{water}$$

Used when the oxygen supply is limited: there is not enough oxygen to oxidise all the carbon fully, so carbon monoxide and soot (carbon) form as well as water, less energy is released, and the flame is yellow and smoky rather than clean.

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*, $\mathrm{CH_4}$.
- **Ethanol has two named uses: as a solvent and as a fuel**: As a *solvent*, ethanol dissolves many oily and greasy substances that water will not touch, which is why it appears in perfumes, inks, cosmetics and cleaning products. As a *fuel*, ethanol burns in air, releasing energy, which is why it powers spirit burners, camping stoves and blended motor fuels.
- **The aqueous bromine test result**: Shaking a hydrocarbon with orange (brown) aqueous bromine is the test to distinguish a saturated from an unsaturated hydrocarbon. An unsaturated hydrocarbon (alkene, has $\mathrm{C=C}$) turns the bromine from orange (brown) to colourless. A saturated hydrocarbon (alkane, single bonds only) leaves the bromine orange (brown), which is itself a real result.

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).

TIP Petroleum must first be separated into fractions; the fuel burned in a car engine is gasoline (petrol), one fraction obtained from petroleum. Naphtha is the fraction that is not burned at all, since it is the chemical industry's raw material.

TIP A colourless solution is still transparent, so "clear" describes clarity rather than colour, and "white" is the wrong colour word entirely. Write "colourless" for the positive bromine-test result.

TIP Whatever the stem means, the ending fixes the family: any name ending "-ane" is an alkane, any name ending "-ene" is an alkene, any name ending "-ol" is an alcohol. Hexane is an alkane and propene is an alkene, whether or not the stem is one you recognise.

TIP Addition polymerisation needs a carbon-to-carbon double bond to open up and link to neighbouring monomers. Ethane cannot be used to make poly(ethene) in place of ethene, because ethane is saturated and has no double bond to open.

TIP Every carbon atom needs exactly four lines (a double bond counts as two), every hydrogen needs one, every oxygen needs two. Use the rule to count atoms off a drawing, or to check a drawing you have made: if a carbon has three lines or five, the drawing is not finished.

TIP Every hydrocarbon that goes into the fractionating column comes out of it unchanged, just sorted into fractions by boiling point. Naming a chemical reaction, or claiming a fraction has been converted into a different substance, loses the mark.

TIP If asked for uses of ethanol other than in alcoholic drinks, the mark scheme wants the named pair, solvent and fuel. Facts such as "used in thermometers" or "used as an antiseptic" are true of ethanol but are not the syllabus answer and do not score.

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.
- **An introduced species harms natives in two ways at once**: When humans introduce a foreign species to a habitat, it can affect a native species along more than one feeding path simultaneously: by *eating it directly* (predation), and by *eating its food* (competition). Both routes push the native population in the same direction, so an exam answer usually needs both, not just one.
- **Fossil fuels form when decomposition is incomplete**: Most dead plant and animal material is broken down quickly by decomposers, releasing its carbon back to the atmosphere as carbon dioxide. Fossil fuels form instead where waterlogged, oxygen-poor conditions leave decomposers unable to fully break the material down, so its carbon stays locked in the compressed remains rather than being released.
- **Removing a species' food supply lowers its population**: Food chains and food webs can be used to predict the impact of humans removing part of a food supply. If a farmer's insecticide kills the insects that grass-eating insects fed small birds, the small birds' main food source disappears and their population is likely to *decrease*; the effect is read straight off the feeding arrows, not assumed from unrelated causes such as extra grass becoming available.
- **Decomposers are the last stop in the one-way energy journey**: When organisms die, decomposers such as earthworms and bacteria obtain their energy from the dead organic material. This is the final step of energy flow through an ecosystem: energy that started as sunlight, passed through producers and consumers by feeding, ends its journey being released as heat once decomposers, too, respire; none of it returns to restart the flow.
- **The carbon cycle's chemistry is the same photosynthesis and respiration taught elsewhere in Core**: The carbon cycle does not introduce new chemistry: it links photosynthesis (carbon dioxide and water forming glucose and oxygen, using light energy, from Plant nutrition) with respiration (glucose and oxygen releasing carbon dioxide, water and energy, from Respiration). Naming both processes with these word equations, rather than describing them only in words, is enough to explain both the removal and the return of carbon dioxide in the cycle.

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.

TIP Energy makes a single one-way journey from the Sun, into producers, then outward through consumers by feeding, before it is transferred to the environment for good. Unlike carbon, energy is never recycled back to the start, which is why the process is called energy *flow* rather than an energy cycle.

TIP Respiration is not limited to animals: plants, animals and decomposers all release carbon dioxide into the atmosphere by respiration. Only photosynthesis removes carbon dioxide from the air; every other named process in the cycle, respiration, decomposition and combustion, returns it.

TIP In a chain such as grass, wildebeest, hyena, lion, the wildebeest is a herbivore and the hyena and lion are both carnivores, based purely on what each one feeds on. Being larger than what you eat does not make an organism a carnivore, and being smaller than a predator does not make an organism a herbivore.

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.
- **Stoma is the hole, guard cells are the cells**: A *stoma* is the pore itself, the actual gap through the lower epidermis that gases pass through. The *guard cells* are the pair of curved cells on either side of it, which change shape to open and close the pore. Questions regularly label the pore as one letter and the surrounding cells as another; name each separately rather than as one blurred pair.
- **The three experiments at a glance**: Every leaf-starch experiment removes one factor and compares to a control. *Light*: cover part of a destarched leaf with black card; the uncovered part turns blue-black, the covered part stays orange-brown. *Chlorophyll*: use a variegated leaf, green in some areas and white in others; only the green areas turn blue-black. *Carbon dioxide*: seal a destarched plant under a bell jar with soda lime, which absorbs carbon dioxide; that leaf stays orange-brown while an uncovered control turns blue-black.
- **A variegated leaf tests for chlorophyll**: A variegated leaf is green in some areas and white in others because the white areas contain no chlorophyll. Destarched, exposed to bright light, then tested with iodine, only the *green* areas turn blue-black; the white areas, lacking chlorophyll, stay orange-brown even though they received the same light. This is the standard proof that chlorophyll, not just light, is needed for photosynthesis.
- **Gas movement through the leaf**: Carbon dioxide enters a leaf through a stoma, then moves across the leaf through the interconnected air spaces between the loosely packed spongy mesophyll cells

until it reaches a mesophyll cell; oxygen and water vapour take the same route outwards. Stomata and air spaces are the two features that together allow this movement; a thick waxy cuticle or tightly packed cells with no gaps would block it instead.

- **Naming the parts of a whole leaf**: Alongside the internal cross-section, know the parts visible from the outside: the *lamina* (the flat blade), the *midrib* (the thick central vein), the smaller *veins* branching from it, the *leaf stalk* or *petiole* joining the leaf to the stem, and the *margin* (edge), which may be smooth or serrated. A leaf may be a single blade or divided into *lobes*.

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.

TIP A biological drawing must be a plain, single continuous pencil line, filling at least half the space provided. No shading, no colouring and no pen, even where the specimen itself is brightly coloured. A feathery, broken or doubled line also loses marks; rub out an error rather than drawing over it.

TIP An experiment is only convincing if exactly one thing differs between the test and the control; everything else, light, temperature, water, the age of the plant, must be the same. If a second thing also differs, the result cannot say which one caused it. A rehearsed fix: "the two plants also differed in ___; to improve the investigation, keep ___ the same and change only ___."

TIP A very common wrong answer is that boiling the leaf in water removes the chlorophyll. It does not: the water step *kills* the leaf and stops any further reaction. It is the *ethanol* step, done in a hot water bath because ethanol is flammable, that removes the green chlorophyll so a colour change can be seen. Attach the reason to the wrong liquid and the mark is lost even with the right steps listed.

TIP When a question states two leaves are shown "at the same magnification", a size difference between them is genuine and worth stating as a comparison point. Without that phrase, comparing the apparent sizes of two separate images proves nothing, because they may simply be drawn or photographed at different scales.

TIP Both are pigments and both involve a gas, and both appear on the same paper, but they are not related. Chlorophyll is the green pigment in chloroplasts that absorbs light for photosynthesis. Haemoglobin is the red pigment in red blood cells that carries oxygen, and it belongs to animal biology, not plant nutrition.

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.
- **Controlling the spread of STIs**: The spread of STIs is controlled by using condoms as a barrier during sex, not sharing needles, reducing the number of sexual partners, and testing and treating infected people.
- **Insect-pollinated versus wind-pollinated flowers**: Insect-pollinated flowers have large, brightly coloured, scented petals, nectar, and anthers held inside the flower where a visiting insect brushes past them, because they must *attract and coat an insect*. Wind-pollinated flowers have small, dull petals, no nectar, and anthers hanging outside on long filaments, because they must *release pollen into the moving air*.
- **Investigating germination: the fair-test rule**: The syllabus tests experiment design for germination, not just the three conditions themselves. The rule is one line: *change only the condition being tested* and keep every other condition, including water and temperature, the same between groups.
- **Routes of HIV transmission**: HIV is transmitted by unprotected sexual contact; by contact with infected blood (for example, sharing needles); and from an infected mother to her child.
- **Sexual reproduction makes every offspring different, from each other and from both parents**: Because sexual reproduction combines genetic material from two parents by the fusion of gametes,

each offspring results from a different combination of genes. Offspring from the same two parents are genetically different from each other, and from both parents, not just different from one parent.

- **Sperm ducts, urethra and semen: tracing the route**: Sperm made in the testes travel up the *sperm ducts*. Near the base of the bladder, the *prostate gland* adds fluid where the sperm duct joins the *urethra*; sperm plus this fluid together make *semen*. The urethra then carries semen (and, separately, urine) through the penis out of the body.
- **Biological drawing technique: what earns full credit**: The syllabus asks students to *draw* flower structure, and this is marked on technique, not artistic skill. Full credit needs one clear continuous line per edge (no shading or colouring in), a drawing large enough to fill at least half the available space, and every structure included, not just the outline.
- **The stages of the menstrual cycle**: The lining of the uterus breaks down and is lost through the vagina (*menstruation*, lasting a few days). The lining then thickens and gains a rich blood supply. An ovary releases an egg roughly halfway through the cycle, around day 14 (*ovulation*). If the egg is not fertilised, the lining breaks down again and the cycle repeats.

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.

TIP When a question describes an unfamiliar organism, apply the definition as a two-part test: how many parents, and is there any fusion of gametes? One parent and no fusion means asexual, whatever the organism.

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.

Rate from time taken for a colour-change indicator

$$\text{rate} = \frac{1}{\text{time taken}}$$

Used when only a time is measured, such as how long DCPIP takes to turn from blue to colourless as yeast respires. A shorter time gives a larger value, so this converts the recorded times into a rate that can be plotted directly against temperature.

Rate of gas production

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

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

Increase in a quantity

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

Used to find how much a measurement, such as breathing rate or the volume of carbon dioxide produced, has risen between two readings. Subtract the original (starting) value from the new value; keep the same units throughout.

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.

- **Effect of temperature on the rate of respiration**: A higher temperature increases the rate of aerobic respiration, so an organism such as yeast produces carbon dioxide faster. A larger volume of carbon dioxide produced in the same time is evidence of a faster rate, which in turn means energy is being released more quickly for the organism's life processes.
- **What aerobic respiration does not produce**: Oxygen is a *reactant* of aerobic respiration, used up to break down glucose; it is never a *product*. A claim that aerobic respiration "produces oxygen, which is then used by the cell" reverses the equation's reactant and confuses respiration with photosynthesis, which does release oxygen.
- **A slower result shows a slower rate, not a wrong equation**: The word equation for aerobic respiration states which substances react and which are produced; it says nothing about *how fast* this happens. A flask of germinating seeds kept cold that produces carbon dioxide more slowly than an identical flask kept warm is not evidence against the word equation, only evidence that a lower temperature slows the rate of the reaction.
- **Slow respiration limits growth**: A hibernating mammal's cells respire only slowly through the winter, releasing barely enough energy to maintain essential functions such as a minimal body temperature. With so little energy available, none is left over for the growth-related uses of respiration, cell division and protein synthesis, which is why the animal does not grow or repair tissue while hibernating even though it is still respiring.

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.

TIP After exercise ends, breathing rate and depth stay raised for a while before falling back towards the resting values; they do not drop instantly, and they do not do the opposite of each other, one rising while the other falls. Both change in the same direction as the body's demand for energy falls back towards its resting level.

TIP The rate formula divides an amount (volume of gas, or 1) by time, so the units are always an amount *per unit time*, for example cm^3 per minute, never a time per amount such as minutes per cm^3. Dividing time by the amount instead is a common error.

TIP A control flask of dead or boiled organisms cannot respire, so its limewater should stay clear or its indicator unchanged over the same period. Comparing it with a flask of living, respiring organisms shows that any change seen with the living organisms is caused by their respiration, not by something already present in the apparatus.

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.

Benchmark distances to remember

$$d_{\text{Milky Way}} \approx 1.0 \times 10^5 \text{ ly}, \quad d_{\text{nearest galaxy}} \approx 2 \times 10^6 \text{ ly}$$

Two useful benchmarks for scale-of-the-Universe questions. Combine either with the light-year to kilometre conversion to answer a "how far in km" question.

Comparing masses by division

$$\text{ratio} = \frac{M_1}{M_2}$$

Used to find how many times more massive one body is than another, for example the Sun compared with a planet. Divide the leading numbers and subtract the exponents separately, then combine: $\frac{2 \times 10^{30}}{2 \times 10^{27}} = 1 \times 10^3 = 1000.$

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*.
- **Asteroids and the asteroid belt**: *Asteroids* are small rocky bodies that orbit the Sun directly. Most lie in the *asteroid belt*, a band between the orbits of Mars and Jupiter, that is, between the fourth and fifth planets.
- **Life cycle of a large or very large mass star**: A star of large or very large mass swells into a *red supergiant*, then explodes violently as a *supernova*. What is left behind depends on how heavy the star was: a large-mass star leaves a *neutron star*, and a very large mass star leaves a *black hole*.
- **Life cycle of a small-mass star**: A star of about the same mass as the Sun leaves the stable star stage and swells into a *red giant*, then sheds its outer layers as a planetary nebula, leaving behind a hot, dense *white dwarf*, which over an enormous time cools towards a *black dwarf*.
- **Moons orbit planets, not the Sun**: A *moon* is a natural object that orbits a planet rather than the Sun, so a moon orbits the Sun only indirectly, through the planet it circles. Earth has one Moon; Jupiter and Saturn have dozens each.
- **Orbit hierarchy**: The Sun is a star; planets and minor planets (dwarf planets, asteroids) orbit the Sun directly; moons orbit planets, and so orbit the Sun only indirectly. Keep this hierarchy in mind whenever a question asks what a given body orbits.
- **Pluto is not one of the eight planets**: Pluto is a *dwarf planet*, not one of the eight named planets, because it has not cleared other similarly sized objects from its orbital region. A student listing Mercury, Pluto, Earth and Saturn as "four planets" has made this exact mistake.
- **The Milky Way among billions of galaxies**: The Milky Way is one of many billions of galaxies making up the Universe, and is about 1.0×10^5 light-years across. A description naming one star and its planets is a *solar system*, not a galaxy, a single star system inside a galaxy of billions.
- **Why the Sun is the closest star**: A star's distance from Earth depends only on *where it is in space*, not on its size or what it is made of. The Sun is close because Earth orbits within the Sun's own Solar System; every other star lies outside it, light-years away.
- **Why the Sun's mass keeps the planets in orbit**: The Sun contains almost all the mass of the Solar System, about 99.8% of it. Gravitational attraction is stronger between larger masses, so the Sun's enormous mass gives it a strong gravitational pull on every planet, and that inward pull holds each planet on its orbit.

EXAM TIPS

TIP A question may combine two separate facts about the Sun, for example its size and the force that holds the planets in orbit. Check each half separately before choosing an answer; a statement is only correct if *both* halves are correct.

TIP The distinguishing feature is *what each orbits*, not size or shape. A moon orbits a planet; an asteroid orbits the Sun directly, most often within the asteroid belt. Both are held on their paths by gravity, but the central body differs.

TIP When two distances are already given in light-years, divide them directly rather than converting both to kilometres first. Matching the units before dividing is the whole trick; converting to kilometres first gives the same answer after far more arithmetic.

TIP The most common error is mixing the two branches, for example "red giant, then supernova" or "red supergiant, then white dwarf." Fix this by deciding the star's mass first, small versus large or very large, and only then reading off its branch in order.

TIP The asteroid belt lies between the orbits of Mars and Jupiter, so an object orbiting the Sun well beyond Saturn cannot belong to the belt, however small and rocky it is. Always compare the object's orbital distance with the belt's location before answering.

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.
- **Evaporation is not boiling**: Both change a liquid into a gas, but they happen differently. *Evaporation* occurs only at the *surface* of the liquid, and at *any* temperature below the boiling point, as long as some particles at the surface have enough energy to escape. *Boiling* occurs *throughout the whole liquid*, and only at the fixed boiling point. A question that describes a temperature below the boiling point is describing evaporation.
- **State symbols in a chemical equation**: A state symbol in brackets after a formula shows the physical state of that substance in the reaction: *(s)* solid, *(l)* liquid, *(g)* gas, *(aq)* aqueous, meaning dissolved in water. In $2\mathrm{Cu(s)} + \mathrm{O_2(g)} \rightarrow 2\mathrm{CuO(s)}$, the *(g)* after $\mathrm{O_2}$ shows that oxygen reacts as a gas, while the *(s)* symbols show that copper and copper(II) oxide are both solids.
- **Diffusion is not osmosis**: *Diffusion* is the net movement of *any* particles down a concentration gradient by random motion, and it occurs in gases, in liquids and in solution. *Osmosis* is the net movement of *water molecules only*, through a *partially permeable membrane*. An answer that names a membrane, or that restricts the movement to water, is describing osmosis and will not earn a diffusion mark.
- **The overall trend in particle separation and speed from solid to gas**: Going from solid, to liquid, to gas, the particles gain more and more energy at each stage. Their separation increases at each stage: solid particles touch, liquid particles are only slightly further apart, and gas particles are widely spaced with large gaps. Their speed of motion also increases at each stage, from vibrating in place, to sliding past one another, to moving quickly in all directions. Both properties increase together; neither one increases while the other falls.

- **Why a liquid is only slightly less dense than its solid**: On melting, particles move only *slightly* further apart and remain touching, so a given mass occupies only a little more volume and the density falls only a little. This is why the correct answer to a melting question is "slightly further apart, still touching" rather than the large separation of a gas.

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.

TIP *At constant pressure*, heating a gas increases its volume and cooling decreases it. *At constant temperature*, increasing the pressure on a gas decreases its volume and decreasing the pressure increases it. Read which quantity the question holds fixed before deciding which relationship applies.

TIP A definition that omits *net* describes ordinary particle motion rather than diffusion, and one that omits *random motion* invites the marker to assume an external force is at work. Quote the full wording: the *net* movement of particles from a region of higher *concentration* to a region of lower *concentration*, caused by their *random* motion.

TIP A smell spreading through a still room, with no fan and no draught, is diffusion, not convection. If a question states that the air or liquid was not stirred and nothing was pushed or carried, the particles are moving by their own *random motion* alone, from higher to lower concentration. Do not invent an external cause where none is described.

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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

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

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

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

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.

Rearranging Mr to find an unknown Ar

$$A_r(\text{unknown atom}) = M_r(\text{compound}) - \sum A_r(\text{every other atom shown})$$

Use when a formula and its overall M_r are given but one element's A_r is not. For sulfur trioxide, $\mathrm{SO_3}$, with $M_r = 80$ and $A_r(\mathrm{O}) = 16$, the three oxygens contribute $3 \times 16 = 48$, so $A_r(\mathrm{S}) = 80 - 48 = 32$. Work out the *total* contributed by every known atom before subtracting, not just one of them.

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 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 $\mathrm{Ca(s) + H_2SO_4(aq) \rightarrow CaSO_4(aq) + H_2(g)}$.
- **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 H_2, nitrogen N_2, oxygen O_2, fluorine F_2, chlorine Cl_2, bromine Br_2 and iodine I_2. A compound such as sodium chloride, $NaCl$, or ammonia, 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 C_2H_6 (ethane), the subscript after each symbol is the atom count for that element: 2 carbon atoms and 6 hydrogen atoms.
- **Deducing a molecular formula by counting atoms shown in a diagram**: Where a question gives a model or a diagrammatic representation of a molecule, the formula is deduced by *counting* how many atoms of each element are actually shown, not by reasoning about bonds or charges. Reading the atom count off a formula works the same way in reverse: in C_2H_6 (ethane) the subscript after H is 6, so the diagram would show exactly 6 hydrogen atoms alongside 2 carbon atoms.
- **Why relative atomic mass is not a whole number**: A single atom always has a whole-number mass, because it contains a whole number of protons and neutrons. An element, however, is a mixture of *isotopes*, and A_r is the *weighted average* of those isotope masses, weighted by how abundant each one is. A weighted average of whole numbers need not itself be a whole number, which is why boron's A_r is 10.8: it is not the mass of one isotope on its own, and it is not a simple unweighted average either.
- **Calculating Ar from isotopic abundance**: When a question gives the percentage abundance of each isotope, A_r is found by multiplying each isotope's mass number by the *fraction* of atoms present as that isotope, then adding the contributions together, never by taking a plain unweighted average of the mass numbers. For an element that is 70% X-35 and 30% X-37, the contributions are $0.70 \times 35 = 24.5$ and $0.30 \times 37 = 11.1$, giving $A_r = 24.5 + 11.1 = 35.6$. The plain average, $(35 + 37) \div 2 = 36.0$, is the standard error, since it silently treats the two isotopes as equally abundant.
- **The proportion method is not limited to a 1:1 substance ratio**: The reacting-mass-by-proportion method scales by *coefficient × formula mass*, not simply by formula mass alone, so it still works cleanly when a balanced equation is not $1:1$ between the two named substances. For $\mathrm{2Cu + O_2 \rightarrow 2CuO}$ the copper-to-oxygen atom ratio is $1:1$ even though the equation's own coefficients are $2:1$, because each CuO unit needs one Cu and one O; reading the ratio straight off the coefficients without checking how many atoms of each element that represents is the error this guards against.

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 $\mathrm{C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)}$: every number in front is a coefficient chosen to balance the atoms, and none of the subscripts inside C_3H_8, CO_2 or H_2O has been touched.

TIP When checking a balanced equation, remember that a coefficient in front of a formula multiplies *every* atom that formula contains, not just the first one. In $\mathrm{C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)}$, the 5 in front of O_2 supplies 10 oxygen atoms, and the 4 in front of H_2O supplies 8

hydrogen atoms and 4 oxygen atoms; checking each element separately, and leaving oxygen until last, is the reliable way to confirm a balance.

TIP The g/dm3 concentration formula needs the volume of solution in dm^3, and $1\ \mathrm{dm}^3 = 1000\ \mathrm{cm}^3$. A volume given in cm^3 must be divided by 1000 before it is used: $250\ \mathrm{cm}^3$ is $0.250\ \mathrm{dm}^3$, not 250. Using the cm^3 figure directly in the formula overstates the concentration by a factor of 1000.

TIP The commonest slip in an M_r sum is missing an atom once a formula has three or more elements. Magnesium sulfate, $\mathrm{MgSO_4}$, shows one magnesium, one sulfur and *four* oxygen atoms: $M_r = 24 + 32 + (4 \times 16) = 120$. Leaving out even one of the four oxygens, or adding only two, gives a wrong total that looks plausible.

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

$Na = 1,\ Mg = 2,\ Al = 3,\ Si = 4,\ P = 5,\ S = 6,\ Cl = 7,\ Ar = 8$ 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.

Manganese(IV) oxide catalyses hydrogen peroxide decomposition

$$2H_2O_2 \xrightarrow{MnO_2} 2H_2O + O_2$$

Used as the standard example of transition-element catalytic activity. Manganese(IV) oxide speeds up the decomposition of hydrogen peroxide without being used up itself, the same behaviour iron shows in industrial reactions.

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.
- **Noble gases are monatomic, halogens are diatomic**: A noble-gas atom already has a full outer shell, so it has no tendency to gain, lose or share electrons and exists as a single separate atom (*monatomic*). A halogen atom has seven outer electrons and shares a pair with a second atom to complete its shell, so it forms a *diatomic* molecule instead. Both are non-metals, but only one family bonds to itself.
- **Predicting an unfamiliar element's properties from its position**: Read the position, name the family, then recall that family's properties: far left (Group I) is a soft, low-density, reactive metal; the central block is a hard, dense, high-melting catalytic metal; Group VII (second from right) is a reactive, diatomic, coloured non-metal; the far-right column (Group VIII/0) is an unreactive, monatomic, colourless gas. No measured data or name is needed, only the position.
- **Transition metals contrasted with Group I metals**: The two metal families are opposites on almost every count. A transition metal is dense and high-melting, often acts as a catalyst, and forms coloured compounds; a Group I metal is low in density and low-melting, is not a catalyst, and forms white or colourless compounds. Both are metals, so both still conduct electricity and are malleable, which is why metallic properties alone cannot identify a transition element.
- **Why reactivity decreases down Group VII**: A halogen reacts by *gaining* one electron to complete its outer shell, the mirror image of Group I. Going down the group, the incoming electron would enter a shell further from the nucleus and behind more shielding, so it is attracted less strongly and gained less readily; reactivity therefore *decreases* down Group VII while it *increases* down Group I.
- **Why reactivity increases down Group I**: Every Group I atom has one outer-shell electron, and reactivity depends on how easily that electron is lost. Going down the group each atom has one more filled inner shell, so the outer electron lies further from the nucleus and is more *shielded* by the inner electrons; both effects weaken the nuclear hold on it, so it is lost more easily and reactivity rises.

EXAM TIPS

TIP Group I and Group VII are mirror images, and one sentence keeps them straight: Group I atoms *lose* an electron and Group VII atoms *gain* one. Anything that loosens the nucleus's grip going down a group *helps* Group I (easier to lose, more reactive downwards) and *hinders* Group VII (harder to gain, less reactive downwards). Same cause, opposite trends.

TIP Two observations together fix an unknown substance as a Group I metal: it *floats* on water, so its density is very low, and it reacts with *cold* water to release *hydrogen*, so it is highly reactive. No other family satisfies both, since a non-metal such as iodine does neither and denser metals react with cold water only slowly or not at all.

TIP A phrase such as "on the left-hand side of the table" is coded shorthand for a bundle of properties: metal, few outer-shell electrons, loses them easily, forms a positive ion, forms a *basic* oxide that reacts with acids. Unpack the whole bundle the moment you read the position. Do not confuse *most metallic* (far left, lowest group number) with the far right of the same period.

TIP In a letter-coded outline of the table, the letters are deliberately not chemical symbols. Write the family name next to each letter first, in the margin if you must, then attach that family's property list. The correct option is always the one whose every claim matches the right family; guessing from the letter shape alone gives nothing away.

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.
- **Heating never changes the size or number of particles**: Going solid to liquid to gas, the spacing grows, the arrangement becomes messier and the motion becomes freer, but the particles themselves stay the *same size* and the *same number* throughout. A common wrong answer says

particles "grow" or "multiply" when heated; correct answers only ever change spacing, arrangement or motion.

- **Why metals conduct better: vibration plus free electrons**: In any solid, heated particles vibrate more and pass on some of that vibrational energy to their neighbours by collisions; this mechanism exists in every solid, metal or not. Metals conduct thermal energy much faster because they additionally contain *free (delocalised) electrons*, not fixed to individual atoms, which gain kinetic energy at the hot end and move quickly through the metal, carrying energy far faster than vibration alone. Most non-metals have no free electrons and so are limited to the slower vibration-only mechanism, which is why they are poor conductors.

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.

TIP A metal spoon and a plastic spoon left in the same cup of hot tea are at the same temperature along their length, but the metal spoon feels much hotter to touch. Both spoons receive thermal energy from the tea at the same rate; the metal spoon *conducts* that energy along its length to your hand much faster than the plastic one does. The observation shows metals are better *conductors*, not that they reach a higher temperature.

TIP Blowing across a hot drink, or a breeze over wet washing, does not mainly cool by swapping in colder air. Moving air carries away the water vapour that has just evaporated from the surface, so more particles keep escaping instead of the air above the surface becoming saturated. That *extra evaporation* is what removes the additional thermal energy, so wind speed matters even when the incoming air is not obviously colder.

TIP In a smoke-cell experiment, replacing the air with a *denser* gas at the *same* temperature makes the smoke particles move with smaller, less erratic jerks, not larger ones. A denser gas packs more particles into the same volume, so the smoke particle is struck from many directions almost simultaneously; the unequal forces tend to *balance out* more, so the net random motion looks smaller and steadier, even though collisions are still happening constantly. Do not confuse "denser" with "hotter": the temperature, and so the average particle speed, has not changed here.

TIP A student claims convection can transfer thermal energy through a solid "as long as the material is hot enough." This is wrong at any temperature: convection relies on particles being free to circulate and carry energy with them as they move. A solid's particles are held in fixed positions and can only vibrate, however hot the solid becomes, so they can never circulate. A hot solid still transfers energy, but by *conduction*, never convection.

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.

Finding the count from a rate and a chosen interval

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

Rearranges the count-to-rate formula to predict how many beats should be counted in a chosen interval if the rate is already known, e.g. checking a stated rate against a shorter re-count.

Mean of repeated readings after discarding an anomaly

$$\text{mean} = \frac{\text{sum of the readings kept}}{\text{number of readings kept}}$$

Used once an anomalous reading has been identified and removed, so the mean reflects only the readings that fit the pattern, never the full set including the anomaly.

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.
- **Coronary heart disease and its risk factors**: *Coronary heart disease (CHD)* is the *blockage of the coronary arteries* by fatty deposits, which cuts the heart muscle's oxygen supply. The seven risk factors are diet (high saturated fat), lack of exercise, stress, smoking, genetic predisposition, age and sex; the first four can be changed by lifestyle, the last three cannot.
- **Diet and exercise reduce risk by different routes**: A diet low in saturated fat *reduces the fatty deposits* building up inside the coronary arteries, keeping them open. Regular exercise *keeps the heart muscle and blood vessels healthy*. Because the two act on the risk by different routes, doing both lowers risk more than either alone, though neither can remove a genetic risk.
- **Plasma: the liquid that transports everything else**: *Plasma* is the pale liquid part of blood. It transports the *blood cells and platelets* (suspended in it), plus dissolved *ions*, *nutrients*, *urea*, *hormones* and *carbon dioxide*. Urea is the one substance being carried *out*, from the liver to the kidneys for removal.
- **Platelets: fragments that clot**: *Platelets* are small *fragments of cells*, not whole cells. Their function is *clotting*; the syllabus states that details of how clotting works are not required, so "platelets help the blood to clot" is a complete Core answer.
- **Running a fair heart-rate investigation**: A fair investigation records a *resting (baseline)* rate first, changes only *one* variable (e.g. keeping the length of time spent on each activity the same), repeats each reading, and discards any *anomalous* result, one that clearly does not fit the pattern of the others, before averaging what remains.
- **Telling red and white cells apart**: The *nucleus* is the decider: red blood cells have none, so any cell with a visible nucleus in a photomicrograph is a white blood cell. Red blood cells are also far more numerous than white blood cells in a healthy sample.
- **The full vessel comparison**: Across all three features together: arteries have a thick muscular wall, a small lumen, high pressure and no valves; veins have a thin wall, a wide lumen, low pressure and valves; capillaries have a wall one cell thick and a very narrow lumen. Blood loses pressure as it squeezes through the narrow capillaries, which is why it arrives at a vein already at low pressure.
- **Three ways to monitor heart activity**: The syllabus names exactly three ways to monitor heart activity: the *pulse rate* (felt in an artery near the skin), listening to the *sounds of the valves closing* with a stethoscope, and an *ECG (electrocardiogram)*, which traces the heart's electrical activity. Only the ECG needs electrical equipment.

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.

TIP Keep the four clean: red cells transport *oxygen* using haemoglobin, white cells carry out *phagocytosis and antibody production*, platelets do *clotting*, plasma *transports* everything dissolved. Most wrong answers attach the right function to the wrong component.

TIP When a question specifies monitoring the heart *without electrical equipment*, the only correct answers are the *pulse* and a *stethoscope* listening to the valves closing. An *ECG* is always wrong for that phrasing, however detailed a record it gives, because it needs electrical equipment to trace the heart's electrical activity.

TIP Every white blood cell question offers a distractor combining phagocytosis or antibody production with oxygen transport. White blood cells only defend the body; transporting oxygen with haemoglobin is the red blood cells' job, never the white cells'.

TIP A *wall* running down the middle is the septum; a small *flap* between a chamber and the vessel or chamber beyond it is a valve; an enclosed *space* is a chamber (atrium or ventricle). Sort the label by which of those three kinds of thing the description matches before choosing a name.

TIP Blood in an artery has just been pumped from the heart, at high pressure. By the time it has been forced through the very narrow capillaries it has lost most of that pressure, so it arrives in a vein already slow and low-pressure, which is exactly why veins need valves and arteries do not.

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.
- **Four rules that turn readings into marks**: *Settle first*: do not take the first reading until the shoot has reached a steady rate. *Same edge*: read the same edge of the bubble every time, since the bubble has a length and switching edges adds a false extra distance. *Label properly*: both axes named with quantity *and* unit. *Even scale*: points spread across most of the grid, plotted through a single straight *line of best fit* with roughly as many points above as below.
- **Gradient of the graph: the rate of uptake in cm/min**: The gradient of bubble position (cm) against time (min) is taken from a *large* triangle drawn on the line of best fit, never from two plotted points: gradient = change in position ÷ change in time. Dividing cm by min always gives the unit *cm/min* — derive the unit from the division every time, never recall it from memory.
- **Higher temperature increases the rate of transpiration**: A higher temperature makes water *evaporate faster* from the mesophyll surfaces inside the leaf, so more vapour forms and diffuses out through the stomata, and the rate of transpiration *increases*.
- **Higher wind speed increases the rate of transpiration**: Moving air carries away the water vapour that has just diffused out of the stomata, keeping the air just outside the leaf drier, so more vapour follows and the rate of transpiration *increases*. In still air, vapour collects near the leaf surface and transpiration slows.
- **The water-uptake apparatus and what it measures**: A leafy shoot is sealed into a tube of water beside a horizontal capillary tube containing an *air bubble*. As the shoot draws up water to replace what it loses, the bubble is pulled along; the distance it travels in a fixed time measures the *rate of water uptake*. This one experiment supplies roughly a quarter of this chapter's exam marks, entirely on practical technique rather than biology.

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".

TIP In an investigation of temperature or wind speed on transpiration, change only that one variable; hold everything else that could affect transpiration constant, such as air temperature when testing wind, or wind and humidity when testing temperature. Never name the distance the bubble moves as a variable to control: that is the *result*, not something to keep the same.

TIP If a diagram shows wall thickness rather than location, you do not need position at all: the xylem is the tissue drawn with *thick walls and a hollow tube-like centre*; a phloem cell is thin-walled and living.

TIP In waterlogged soil, oxygen falls, so less energy is available from respiration for *active transport*, and mineral ion uptake falls sharply even though root-hair surface area is unchanged. Water uptake, driven by osmosis rather than active transport, is far less affected. The lesson: surface area sets how much *can* cross; energy sets whether the active step happens.

TIP Roughly a quarter of this chapter's exam questions come from the practical paper, and every one of them is about the water-uptake apparatus: reading the ruler, plotting the graph, drawing a best-fit line and taking a gradient. None of them tests the underlying biology, so revising the four rules in the Water Uptake section is worth as much here as revising xylem, phloem and transpiration combined.

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.
- **Bell curve or separate bars: the graph shapes**: Continuous variation, plotted for a large population, gives a smooth, symmetrical bell-shaped curve with a single central peak. Discontinuous variation gives a bar chart of separate columns, one per category, with gaps between them. The decision rule: can the characteristic be measured on a scale, or must it be sorted into named groups? Measured on a scale means continuous and a bell curve; sorted into groups means discontinuous and separate bars.
- **Mutation is the way new alleles are formed**: Mutation is the way in which new alleles are formed. A single base change does not always destroy a gene's function; most mutations have only a small effect or none at all, but occasionally a mutation produces a genuinely new allele of that gene.
- **Order matters: choose before you cross**: Selective breeding always starts with choosing the parents; the three stages run in a fixed order: select individuals with the desired feature, *then* cross them, *then* select the offspring that show the feature. A sequence that crosses plants before any selection has happened has not described selective breeding correctly.
- **Only genetic variation is inherited**: Environmentally caused differences, such as those produced by diet or exercise, are not written into the DNA and so are not passed on to offspring. Only variation encoded in the alleles, which ultimately arises from mutation, is inherited; this is why selection can only ever act on genetic variation.
- **The population changes, not the individual**: An individual organism does not adapt within its own lifetime. It is the *population* that changes across generations, as the proportion of individuals carrying an advantageous allele rises. "The population became better adapted over generations" is accurate; "each individual adapted to survive" is not, because no organism changes its own alleles during its own life.

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).

TIP To identify which process a scenario describes, ask who or what is choosing which individuals breed. If a human picks the parents for a desired feature, it is selective breeding (artificial selection); if survival in the environment decides, it is natural selection.

TIP A full answer to "why do individuals of a species differ" names both causes: *genetic* causes, the alleles inherited, and *environmental* causes, the conditions experienced, such as diet or sunlight. Only the genetic cause is passed on to offspring.

TIP A single base change in a gene's sequence does not always destroy the gene, and does not always improve it either: most mutations have only a small effect, or none at all. Avoid the overstated claim that a mutation "always" destroys or "always" improves a gene.

TIP Repeatedly breeding only from individuals with one desired characteristic reduces the range of alleles present in the population, because parents carrying other alleles are excluded generation after generation. A population with less genetic variation is more vulnerable: if a new disease appears, fewer individuals are likely to carry an allele that happens to resist it.

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.
- **Describing a wave**: *Crest* is the highest point of a wave above the rest position; *trough* the lowest point below it. *Amplitude* is the maximum distance a point moves *from the rest position*, measured up to a crest, never crest to trough (the crest-to-trough distance is *twice* the amplitude). *Wavelength* λ is the distance between two nearest points doing the same thing at the same time, for example crest to crest. *Frequency* f is the number of complete waves passing a point each second, in Hz.
- **Light through a rectangular glass block**: Entering a rectangular glass block, air into glass, the ray slows down and bends *towards* the normal. Leaving at the opposite, parallel face, glass into air, it speeds up and bends *away* by an equal amount, because the two normals are parallel. The two bends cancel in direction, so the emergent ray is *parallel to the original incident ray*, but shifted sideways from it.
- **Reflection and refraction of waves at a boundary**: A wave meeting a boundary can *reflect*, bouncing off at the same angle it arrived, or *refract* if its speed changes on crossing into the new medium. Frequency is set by the source and stays fixed at a boundary, so if the speed falls the wavelength must fall with it. Where the wave meets the boundary *at an angle*, one edge of the wave front slows before the other, swinging the whole front round into a new direction.

- **The audible range and ultrasound**: A healthy human ear hears frequencies from about 20 Hz to 20 kHz, that is 20 Hz to $20\,000$ Hz. *Ultrasound* is sound above 20 kHz, above the upper limit of human hearing; the boundary is the definition itself. Ultrasound is used for pre-natal scanning, cleaning delicate equipment and depth-sounding, because it reflects cleanly from boundaries.
- **The image in a plane mirror**: The image formed by a plane mirror is the *same size* as the object, the *same distance* behind the mirror as the object is in front, and *laterally inverted*, left and right swapped while the image stays the right way up. That is why text held up to a mirror reads backwards, and why a mirror image is never described as upside down.
- **Uses of the regions of the spectrum**: Radio waves: radio and television transmissions, radar. Microwaves: satellite television, mobile phones, microwave ovens. Infrared: television remote controllers, thermal imaging. Visible light: vision, photography. Ultraviolet: detecting fake bank notes. X-rays: medical scanning, security scanners. Gamma rays: detecting and treating cancer. The two pairs most often confused are microwaves against radio waves for satellite television, and infrared against microwaves for remote controllers.

EXAM TIPS

TIP Two measurement errors cost most marks in this topic. Amplitude is a *half-height*, so a crest-to-trough reading must be halved before it is amplitude. Wavelength is measured between *matching* points, crest to crest or trough to trough, never from a crest to the very next trough, which is only half a wavelength. Sketch the rest line first and mark exactly which two points a given distance connects.

TIP Decide first whether the given time is a round trip or a one-way trip. An echo time covers the distance to a surface and back, so it needs the factor of two; a starting-pistol timing, taken from seeing the smoke to hearing the bang, is a *one-way* sound journey with light arriving effectively instantly, so no factor of two applies. Stating which case a question describes, before substituting, avoids an answer exactly double or half the correct one.

TIP Before applying the bend rule, state in words which medium the ray is *entering* and whether light travels slower or faster there. A ray leaving water for air is entering a *faster*, less dense medium, so it bends *away* from the normal, the reverse of the more familiar air-to-glass case. Naming the medium first prevents the direction being guessed the wrong way round.

TIP The hardest part of the lens experiment is judging the sharpest image, since a small range of screen positions all look acceptably sharp; move the screen slowly back and forth and take the middle of that range. Repeat with a different object distance u: as u increases, v decreases, and every pair should give close to the same f, since focal length is a fixed property of the lens.

TIP A common Core trap quotes the angle between the ray and the mirror *surface* rather than the normal. Subtract that value from 90° to get the true angle of incidence before applying the law of reflection. Draw the dashed normal at 90° to the surface first, so there is no risk of substituting the wrong angle into $i = r$.

TIP When calculating $f = \dfrac{u \times v}{u + v}$, the numerator multiplies two lengths in cm together, giving a result in cm², while the denominator is a sum of lengths in cm. Keep the units separate through the calculation; only the final division by cm returns an answer in cm. Writing the unit at each step, rather than only on the final answer, catches this error before it costs a mark.

TIP X-rays come up more often than any other region. Fix three facts: they sit between *ultraviolet* and *gamma rays*, so they are the second highest in frequency; their hospital use is *medical scanning*, imaging bone and detecting fractures; their hazard is *mutation or damage to cells in the body*, because their high frequency carries enough energy to penetrate deeply. X-rays *image* the body; gamma rays *treat* cancer, do not swap the two uses.

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