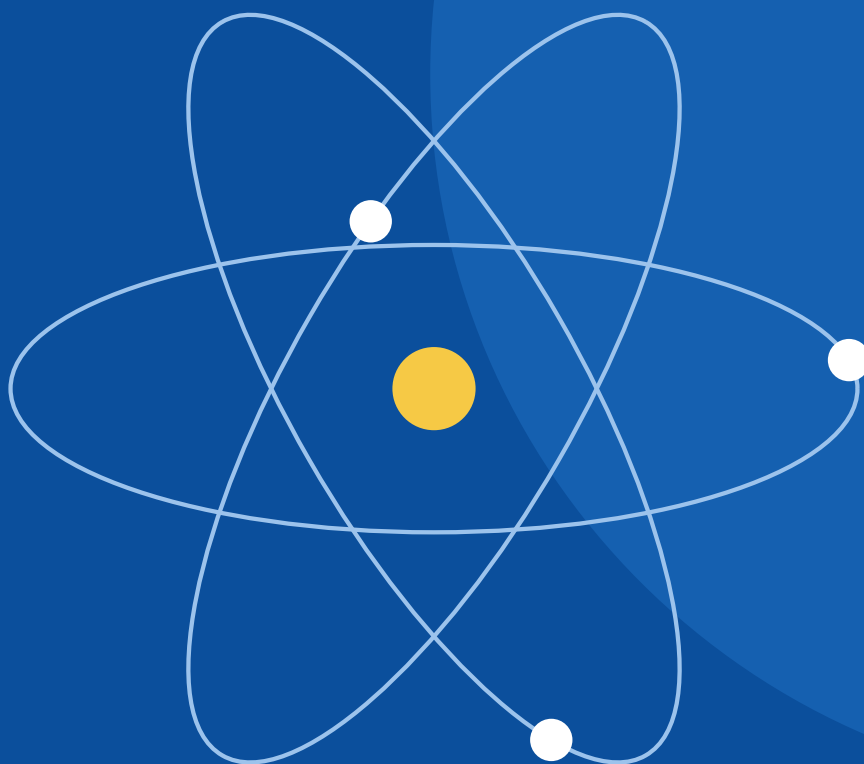




EXAMINATIONS COUNCIL OF ESWATINI · SYLLABUS 6888 · 2024 – 2026

EGCSE

Physical Science

Complete Study Guide

Chemistry C1–C14 · Physics P1–P15

Notes · Diagrams · Exercises · Exam-style questions · Answer keys

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Practise online at www.sigungusekuyala.com

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About this guide

This guide turns the **EGCSE Physical Science (6888)** syllabus for examinations in 2024 to 2026 into a complete revision course. Every topic in the Chemistry section (**C1 to C14**) and the Physics section (**P1 to P15**) has its own chapter, written to match the syllabus objectives.

Each chapter contains the same parts, so you always know where you are:

Part of the chapter	What it gives you
By the end of this chapter	The syllabus objectives for the topic, in plain language, so you can tick them off.
Notes with illustrations	Short, exam-focused notes. Bold type marks the core concepts, definitions and key words that earn marks.
Core concept, Worked example and Exam tip boxes	Definitions to learn, calculations set out step by step, and advice on how marks are won and lost.
Exercise	Short questions to check your understanding straight after reading the notes.
Exam-style question	A structured question with marks, written in the style of Papers 1 and 2.
Answer Key	Answers to every exercise and exam-style question, at the back of the guide.

How to study a chapter. (1) Read the objectives. (2) Read the notes and redraw each diagram from memory. (3) Learn the bold terms. (4) Do the exercise without looking at the answers. (5) Attempt the exam-style question under timed conditions. (6) Mark your own work and rewrite anything you got wrong.

PRACTISE ONLINE

Test yourself with exam-style practice questions, notes and past papers at www.sigungusekuyala.com (Sigungusekuyala). Use this guide to learn a topic, then use the website to check that it has stuck.

Units in this guide. Following the syllabus, volumes are given in **dm³** and **cm³** (never litres), $g = 10 \text{ m/s}^2$ for free fall, and chemical formulae are written with subscripts, for example H_2O and CO_2 .

Source of syllabus content: Examinations Council of Eswatini (ECESWA), Physical Science (6888) syllabus. Past papers and specimen papers are available at www.examsCouncil.org.sz.

The syllabus at a glance

Physical Science (6888) is a **two-year course** examined in Form 5. It is for learners with a wide range of abilities and is based on **practical work**. Candidates must study **both** the Chemistry (C1 to C14) and Physics (P1 to P15) sections. Grades **A* to G** are available. The recommended teaching time is at least **six periods of 40 minutes** each week over **60 weeks**.

Assessment objectives

Objective	Learners should be able to	Typical command words
A Knowledge with understanding	Recall and use scientific phenomena, facts, laws, definitions, concepts and theories; vocabulary, symbols, quantities and units; instruments and apparatus, including safety; scientific and technological applications and their social, economic and environmental implications.	define, state, identify, describe, explain, outline
B Handling information and solving problems	Locate, select, organise and present information; translate between words, symbols, graphs and numbers; manipulate numerical data; identify patterns and trends; make predictions; solve problems, including quantitative ones.	discuss, predict, suggest, calculate, explain, determine
C Experimental skills and investigations	Use techniques, apparatus and materials safely; make and record observations and measurements; interpret and evaluate experimental data; plan and carry out investigations; evaluate methods and suggest improvements.	perform, investigate, plan, record, evaluate

Scheme of assessment

Paper	Duration	Marks	Description	Weighting
Paper 1	1 hour	40	Compulsory short-answer paper. Tests mainly objectives A and B.	27%
Paper 2	1 hour 15 min	80	Compulsory structured theory paper on all the material. Tests mainly objectives A and B.	53%
Paper 3 or Paper 4	1 hour 15 min or 1 hour	40	Practical Test (Paper 3), or Alternative to Practical (Paper 4), a written paper on laboratory procedures. Tests objective C.	20%

The **Data Sheet (Periodic Table)** is given in Papers 1 and 2. Chemistry Practical Notes are given in Paper 3. Skills (handling information, solving problems, practical and investigative work) and knowledge with understanding each carry **50%** of the marks, and no more than 25% of the marks may be pure recall.

Weighting of the assessment objectives

Assessment objective	Paper 1 (marks)	Paper 2 (marks)	Papers 3 and 4 (marks)	Overall weighting
A Knowledge with understanding	25 to 30	48 to 53	0	50% (not more than 25% recall)
B Handling information and solving problems	10 to 15	27 to 32	0	30%
C Experimental skills and investigations	0	0	40	20%
Weighting of paper	27%	53%	20%	

Measuring instruments you must be able to use

Quantity	Apparatus
Volume	measuring cylinder, burette, pipette
Mass	digital balance, triple beam balance, lever arm balance
Temperature	laboratory thermometer
Time	stopwatch (analogue and digital)
Potential difference	voltmeter
Current	ammeter
Length	metre rule, micrometer screw gauge, vernier callipers

Experimental techniques that may be examined: paper chromatography; purification (solvent, filtration, evaporation, crystallisation, simple and fractional distillation, sublimation); melting-point and boiling-point tests for purity; graph construction; preparing salts; preparing and collecting gases; determining density; determining the resistance of wires; building simple circuits; detecting charges.

Exam technique

Marks are won by answering the **question that is asked**. The first word of a question, its **command word**, tells you how much to write. The full list of command words from the syllabus is in the **Glossary** at the back of this guide. These are the ones used most often:

Command word	What to do	Example
State	Give a short answer with no explanation.	State the unit of power.
Define	Give the exact meaning, using a formal statement.	Define the term <i>isotope</i> .
Describe	Say what happens or what you would see. Use a diagram if it helps.	Describe how sodium reacts with water.
Explain	Give reasons. Use the words <i>because</i> or <i>so</i> , and link to theory.	Explain why a metal conducts electricity.
Calculate	Work out a number. Show the formula, the substitution and the unit.	Calculate the speed of the car.
Suggest	Apply your knowledge to a situation you have not seen before.	Suggest why the reaction slowed down.
Predict	Use the pattern you know to give a likely answer.	Predict the melting point of rubidium.

Ten habits of high scorers

1. **Use the mark allocation.** A 3-mark question needs three separate points.
2. **Show your working** in every calculation. Method marks are given even if the final answer is wrong.
3. **Write the unit** after every numerical answer, and use the units from the syllabus (m/s, J, W, N, dm³, mol).
4. **Write the formula first**, then substitute, then calculate.
5. **Give the answer to a sensible number of significant figures**, usually 2 or 3.
6. **Use correct scientific words**, such as *particles*, *ions*, *electrons* and *molecules*, not vague words like *stuff* or *things*.
7. **Draw diagrams with a ruler and pencil.** Label every part and add arrows to show direction.
8. **Read graphs carefully.** Check the axis labels, the units and the scale before you read a value.
9. **Balance every equation** and check that the state symbols are correct when they are asked for.
10. **Check your answer makes sense.** A car cannot travel at 3 000 m/s, and a pH cannot be 17.

PAPERS 3 AND 4: THE PRACTICAL PAPERS

Experimental skills carry **20%** of the marks. When you carry out or describe an experiment, state the **apparatus**, the **method**, the **measurements to take**, what you keep the **same** (control variables), what you change (**independent variable**) and what you measure (**dependent variable**). Then say how you would make the results **more reliable**, for example by repeating readings and calculating an average.

PART A

Chemistry

Topics C1 to C14

C1 Introduction to Chemistry

Syllabus reference: **C1.1**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Name the apparatus used to measure the volume of a liquid and say which one to choose.
- Describe how to use a **measuring cylinder**, a **burette** and a **pipette** correctly.
- Read a meniscus accurately and avoid **parallax error**.
- Convert between **cm³** and **dm³** and calculate a **titre**.

Chemistry is the study of the **composition** of substances and how they **react** with one another. Nearly every experiment involves measuring the **volume** of a liquid or solution, so choosing and using the right piece of apparatus is the first practical skill.

CORE CONCEPT

Units of volume: **1 dm³ = 1000 cm³**. The syllabus uses **dm³** instead of the symbol for litre. Divide by 1000 to change cm³ to dm³ and multiply by 1000 to change dm³ to cm³.

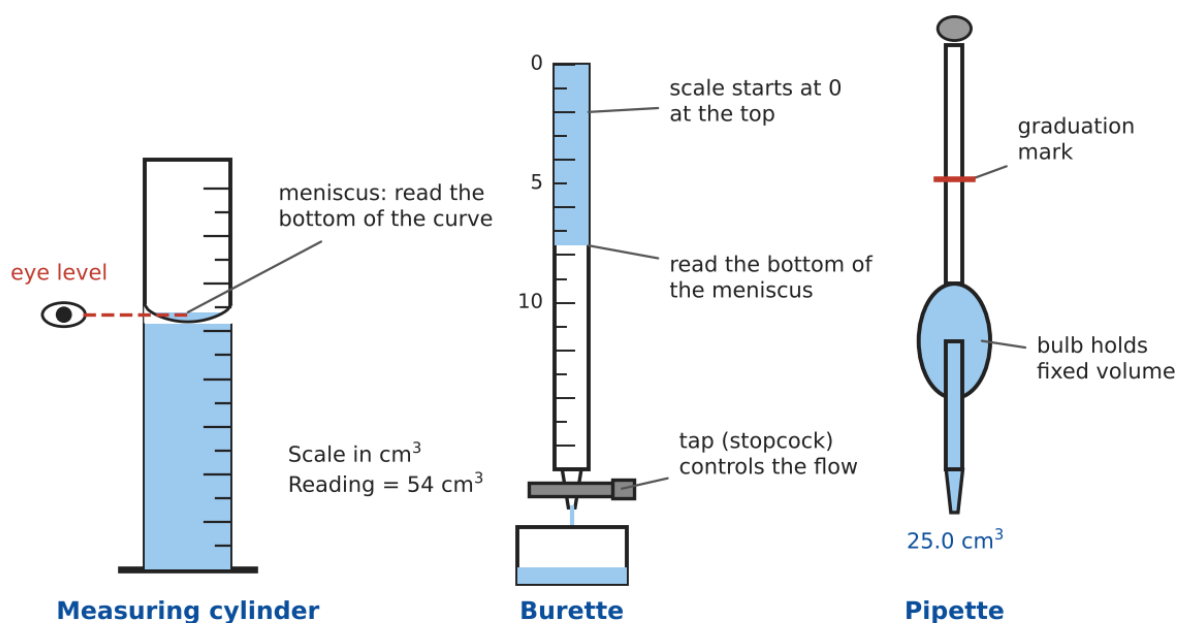


Figure C1.1 A measuring cylinder, a burette and a pipette. Always read the bottom of the meniscus with your eye level with the liquid surface.

Choosing the right apparatus

Apparatus	What it measures	Accuracy	Typical use
Measuring cylinder	Any volume up to its maximum (10 to 1000 cm ³)	Approximate (about ± 1 cm ³ for a 100 cm ³ cylinder)	Adding roughly measured volumes of acid or water to an experiment
Burette	A variable volume delivered through a tap (0 to 50 cm ³)	Accurate to ± 0.05 cm ³	Titration: adding acid or alkali drop by drop
Pipette	One fixed volume only, e.g. 25.0 cm ³	Very accurate	Delivering an exact volume of solution into a conical flask

Using the apparatus correctly

- **Measuring cylinder:** stand it on a flat surface. Pour in the liquid until it is close to the mark, then add the last drops with a dropper. Put your **eye level with the liquid surface** and read the **bottom of the meniscus**.
- **Burette:** rinse with the solution it will hold, clamp it upright, fill above the zero mark using a funnel, then **remove the funnel** and run liquid out of the tap until the **bottom of the meniscus is on the scale**, with **no air bubble in the tip**. Record the **start** reading, add the solution slowly, then record the **final** reading.
- **Pipette:** rinse with the solution, draw liquid up with a **pipette filler** (never by mouth) until the bottom of the meniscus sits on the **graduation mark**, then let it drain into the flask. Touch the tip against the flask wall. Do **not** blow out the last drop.

A **meniscus** is the curved surface of a liquid in a narrow tube. Water forms a **concave** meniscus (the centre is lower than the edges). If your eye is above or below the surface you make a **parallax error** and the reading will be too high or too low.

WORKED EXAMPLE: calculating a titre

A burette reads 0.60 cm^3 at the start and 24.40 cm^3 at the end.

Titre = final reading – start reading = $24.40 - 0.60 = 23.80 \text{ cm}^3$

The burette is read to the nearest 0.05 cm^3 , so the answer is written to 2 decimal places. For two or more **concordant** results (within 0.10 cm^3 of each other), the **mean** is used.

EXAM TIP

Say *what* you are reading and *where* you are reading it: "the bottom of the meniscus, at eye level". This one phrase earns the mark in many practical questions.

Exercise C1: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C1.1** Name the piece of apparatus that is best for (a) delivering exactly 25.0 cm^3 of solution, (b) adding acid drop by drop in a titration, (c) measuring about 80 cm^3 of water quickly.
- C1.2** Convert (a) 2.5 dm^3 to cm^3 and (b) 350 cm^3 to dm^3 .
- C1.3** State where you should look when reading a measuring cylinder, and what part of the meniscus you read.
- C1.4** What is a **parallax error**? Describe how to avoid it.
- C1.5** A burette reads 2.10 cm^3 at the start and 26.35 cm^3 at the end of a titration. Calculate the titre.
- C1.6** Three titres are 23.80 , 23.85 and 23.75 cm^3 . Are they concordant? Calculate the mean titre.
- C1.7** Explain why a **pipette** rather than a measuring cylinder is used to measure 25.0 cm^3 of alkali in a titration.
- C1.8** Give two precautions needed when filling a burette.

EXAM-STYLE QUESTION · C1 · [6 marks]

A student carries out a titration. She uses a pipette to measure 25.0 cm^3 of sodium hydroxide solution into a conical flask and adds a few drops of indicator. She fills a burette with hydrochloric acid and adds the acid until the indicator changes colour. Her burette readings are: start 1.20 cm^3 , finish 25.40 cm^3 .

- (a) Name **one** other piece of apparatus, apart from the pipette, that the student could use to measure 25 cm^3 of liquid, and say why the pipette is a better choice. [2]
- (b) Calculate the volume of hydrochloric acid added (the titre). [2]
- (c) State where the student should look when taking the burette reading. [1]
- (d) Suggest **one** way the student can make her final result more reliable. [1]

C2 Particulate Nature of Matter

Syllabus reference: **C2.1 to C2.2**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the **arrangement and movement** of particles in solids, liquids and gases.
- Explain **melting, freezing, boiling, evaporation, condensing and sublimation** using the kinetic particle theory.
- Describe and explain **diffusion** and **Brownian motion** as evidence that particles move.

The **kinetic particle theory** says that all matter is made of **tiny particles** (atoms, molecules or ions) that are **always moving**. The state of a substance depends on how close the particles are and how strongly they attract each other.

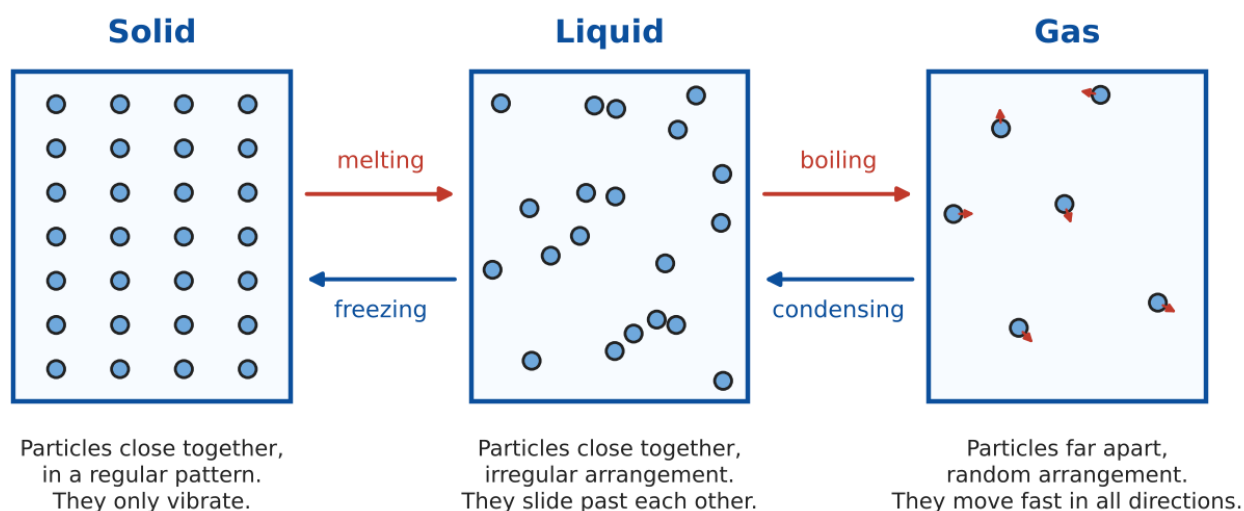


Figure C2.1 Particle arrangement in the three states of matter, and the changes of state between them.

Property	Solid	Liquid	Gas
Arrangement	Regular pattern, touching	Irregular, touching	Random, far apart
Movement	Vibrate about fixed positions	Slide past each other	Fast, random, in all directions
Shape	Fixed	Takes the shape of the container	Fills the container
Volume	Fixed	Fixed	Not fixed
Compressible?	No	Hardly	Yes (large gaps)
Forces between particles	Strong	Weaker	Almost none

Changes of state

- **Melting** (solid to liquid) and **boiling** (liquid to gas) need **heat energy**. The particles gain kinetic energy, then overcome the forces holding them together.
- **Freezing** (liquid to solid) and **condensing** (gas to liquid) **release** energy as the particles slow down and attract each other.
- **Evaporation** happens at the surface of a liquid at **any temperature**. **Boiling** happens **throughout** the liquid at the boiling point.
- **Sublimation** is a solid changing directly to a gas without becoming a liquid (iodine, dry ice).

CORE CONCEPT

During melting and boiling the **temperature stays constant** even though heat is added. The energy is used to **overcome the forces between particles**, not to make them move faster.

Evidence that particles move

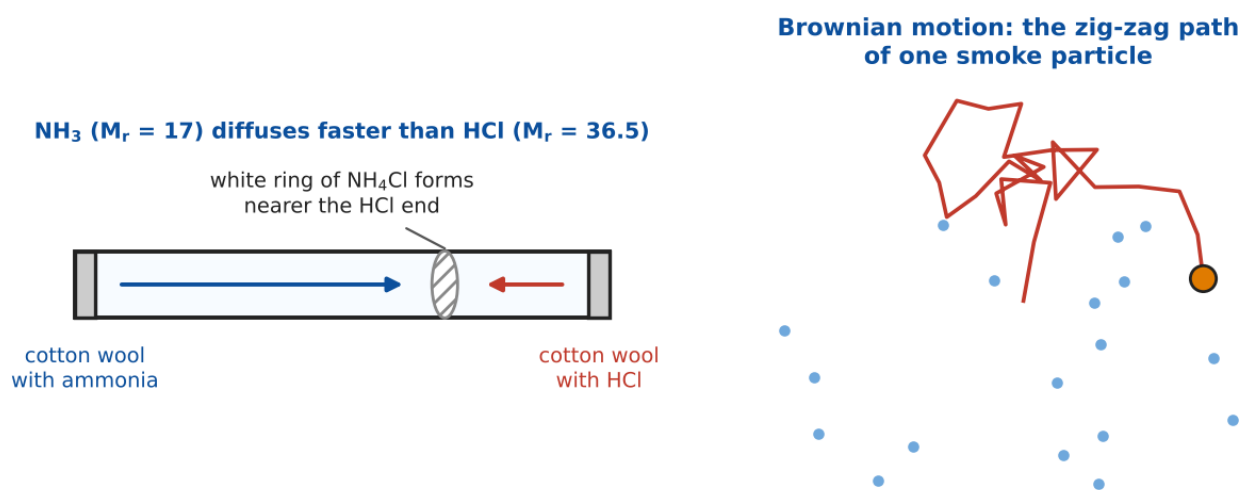


Figure C2.2 Left: diffusion of ammonia and hydrogen chloride along a tube. Right: Brownian motion of a smoke particle.

Diffusion is the **net movement of particles from a region of higher concentration to a region of lower concentration**, caused by their random motion. It is fastest in **gases**, slower in **liquids** and almost absent in solids. It is faster at a **higher temperature** (particles move faster) and for particles of **lower relative mass**. In the tube shown, the ring forms nearer the hydrochloric acid because the heavier HCl molecules diffuse more slowly than NH_3 .

Brownian motion is the **random, zig-zag movement of visible particles** (smoke or pollen grains) in a gas or liquid. It is caused by **collisions with fast-moving, invisible molecules** of the gas or liquid, so it is evidence that the molecules exist and are moving.

EXAM TIP

Never say that particles "expand" or "get hot" when a substance is heated. Say that they **move faster / vibrate more** and **move further apart**.

Exercise C2: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C2.1** State two differences between the arrangement of particles in a solid and in a gas.
- C2.2** Name the change of state in which (a) a solid becomes a liquid, (b) a gas becomes a liquid, (c) a solid becomes a gas.
- C2.3** Explain why a gas can be compressed but a liquid cannot easily be compressed.
- C2.4** Ice is heated at its melting point. Explain why the temperature does not rise until all the ice has melted.
- C2.5** Define diffusion.
- C2.6** A drop of purple potassium manganate(VII) is placed in water and slowly spreads. Explain this using the particle theory.
- C2.7** In the NH_3/HCl experiment, why does the white ring form closer to the hydrochloric acid end?
- C2.8** What is Brownian motion, and what does it show about the particles of a gas?

EXAM-STYLE QUESTION · C2 · [7 marks]

Bromine is a red-brown liquid that evaporates easily. A few drops are placed in a sealed gas jar of air. After some minutes the whole jar is filled with red-brown vapour.

- (a) Name the process by which the bromine vapour spreads through the jar. [1]
- (b) Describe the movement of bromine molecules in the jar. [2]
- (c) The experiment is repeated in a warm room. Predict the effect on the time taken to fill the jar, and explain your answer. [2]
- (d) Describe how the arrangement of the particles differs between liquid bromine and bromine vapour. [2]

C3 Elements, Compounds and Mixtures

Syllabus reference: **C3.1 to C3.3**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Define **atom, element, compound, mixture and molecule**.
- Describe the **differences** between elements, compounds and mixtures.
- Identify** elements, compounds and mixtures from formulae, names and particle diagrams.

Term	Definition	Examples
Atom	The smallest particle of an element that can take part in a chemical reaction.	H, O, Fe
Element	A substance made of only one type of atom . It cannot be broken down into simpler substances by chemical means.	oxygen, iron, copper, carbon, sodium
Molecule	Two or more atoms joined together by covalent bonds. The atoms can be the same or different.	O ₂ , H ₂ , H ₂ O, CO ₂
Compound	A substance made of two or more different elements chemically combined in a fixed ratio .	water, sodium chloride, carbon dioxide, copper(II) oxide
Mixture	Two or more substances not chemically combined , in any proportion .	air, sea water, soil, brass

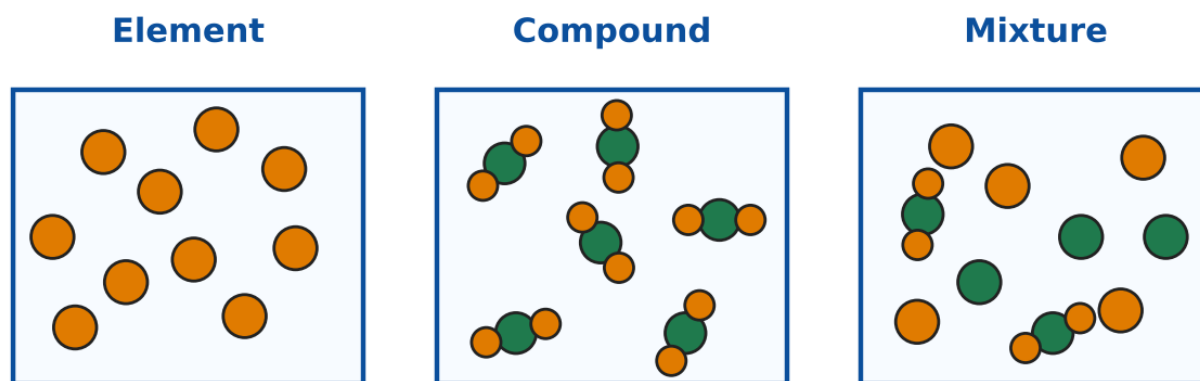


Figure C3.1 Particle diagrams. Orange and green circles are atoms of different elements.

Comparing compounds and mixtures

	Compound	Mixture
Composition	Fixed ratio of elements, shown by a formula (e.g. H ₂ O)	Variable proportions
Bonding	Elements are chemically combined	Substances are not joined
Properties	Different from the elements it contains	Each substance keeps its own properties
Separation	Only by a chemical reaction	By physical methods (filtering, distilling, magnet)
Energy change on forming	Usually heat or light given out or taken in	Little or none

WORKED EXAMPLE: iron and sulfur

A **mixture** of iron filings and sulfur powder is yellow-grey. The iron can be pulled out with a **magnet**, and each element keeps its own properties. When the mixture is **heated**, it glows and forms **iron(II) sulfide**, a black solid that is **not magnetic**. Iron(II) sulfide is a **compound**: the iron and sulfur are chemically combined and can only be separated by a chemical reaction.

CORE CONCEPT

To **identify** a substance: if the **formula** has one kind of symbol (Cl_2 , Fe) it is an **element**; if it has two or more different symbols joined (NaCl , CO_2) it is a **compound**. If the description says "air", "sea water" or "alloy", it is a **mixture**.

EXAM TIP

A **molecule** is not always a compound. O_2 and Cl_2 are molecules of **elements**. Only molecules with **different** atoms are compounds.

Exercise C3: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C3.1** Define (a) an element and (b) a compound.
- C3.2** Classify each as an element, compound or mixture: sea water, carbon dioxide, sulfur, brass, sodium chloride, nitrogen.
- C3.3** State two differences between a mixture and a compound.
- C3.4** Why is carbon dioxide a compound but oxygen (O_2) is not?
- C3.5** How could you show that a mixture of iron and sulfur is not a compound?
- C3.6** Give one example each of a molecule that is (a) an element and (b) a compound.
- C3.7** Name the type of mixture and one method of separating it: salt dissolved in water.
- C3.8** The formula of a substance is Na_2CO_3 . State the elements present and whether it is an element or a compound.

EXAM-STYLE QUESTION · C3 · [8 marks]

Figure C3.1 shows the particles in three different substances, A, B and C. Orange and green circles represent atoms of two different elements.

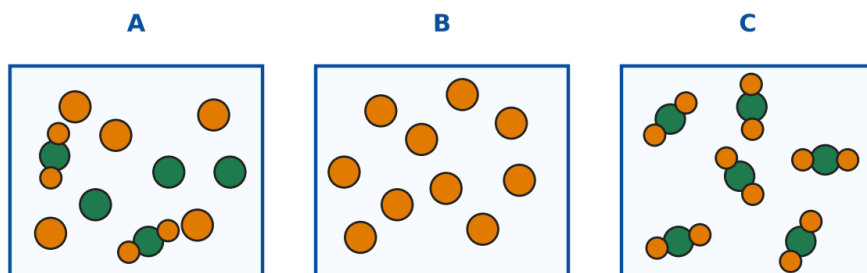


Figure C3.1 Particles in substances A, B and C.

- (a) Define the term *mixture*. [1]
- (b) State which box, A, B or C, shows an **element**. Give a reason. [2]
- (c) State which box shows a **compound**, and explain your choice. [2]
- (d) Box A shows a mixture. Suggest **one** way in which the particles in A show that it is a mixture. [1]
- (e) Air is a mixture of nitrogen, oxygen and argon. Explain why air is not classed as a compound. [2]

C4 Experimental Techniques

Syllabus reference: **C4.1 to C4.2**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe how to purify and separate substances by **filtration, evaporation, crystallisation, distillation (simple and fractional), separating funnel and sublimation**.
- Describe **paper chromatography** and interpret chromatograms.
- Use **melting point and boiling point** to test purity and interpret **heating and cooling curves**.

A **pure substance** contains **only one substance**. Most substances found in nature are **mixtures**, so chemists use physical methods of **separation**. The method chosen depends on the **properties** of the substances in the mixture.

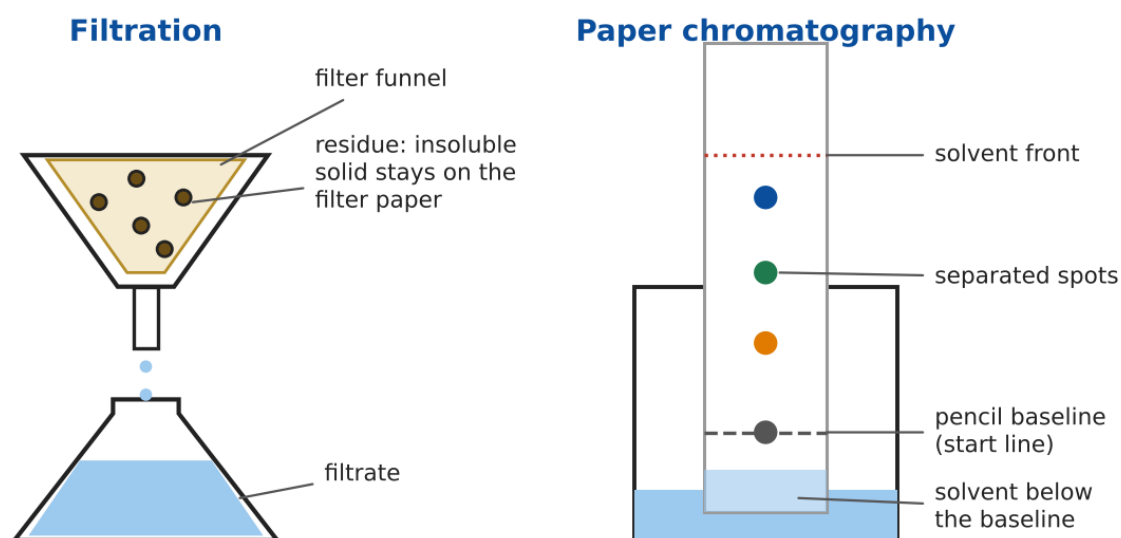


Figure C4.1 Filtration and paper chromatography.

Method	Used to separate	Principle / example
Filtration	An insoluble solid from a liquid	Sand from water. The solid stays on the filter paper as the residue ; the liquid passes through as the filtrate .
Evaporation	A dissolved solid from its solution	Salt from salt solution. Heat until the water has gone.
Crystallisation	A dissolved solid as pure crystals	Heat to evaporate some water until saturated, leave to cool, filter and dry the crystals (e.g. copper(II) sulfate).
Simple distillation	A solvent from a solution	Pure water from salt water. Water boils, vapour condenses in the condenser and is collected as the distillate .
Fractional distillation	Liquids with different boiling points	Ethanol (78 °C) from water (100 °C); the fractions of crude oil; gases from liquid air. A fractionating column is added.
Separating funnel	Two immiscible liquids	Oil and water. The denser liquid is run off through the tap.
Sublimation	A solid that sublimes from one that does not	Ammonium chloride or iodine from sand: heat, and the vapour re-solidifies on a cold surface.
Magnet	A magnetic substance from a non-magnetic one	Iron filings from sulfur.

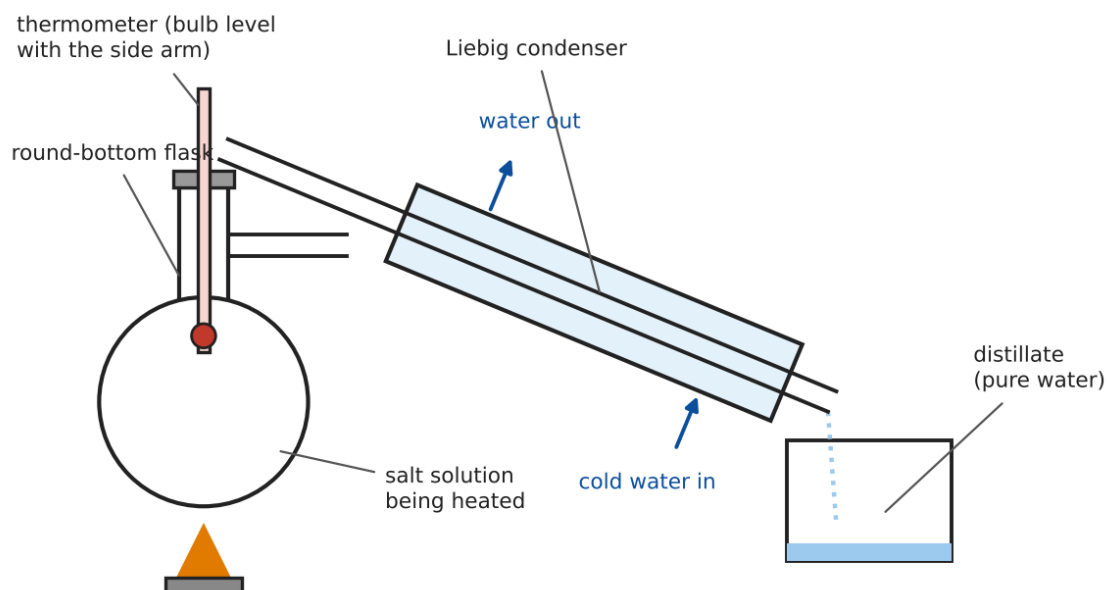


Figure C4.2 Simple distillation. The salt solution boils, the water vapour condenses in the condenser and pure water is collected.

Paper chromatography

Chromatography separates **soluble coloured substances** (e.g. inks and dyes). A **pencil baseline** is drawn and a spot of each sample is placed on it. The paper is stood in a **solvent** (water or ethanol) whose level is **below the baseline**. The solvent rises, carrying the substances with it at **different rates**, so they separate into spots.

- A **pure** substance gives **one spot**; a **mixture** gives **two or more**.
- Two substances are the **same** if their spots travel the **same distance** under the same conditions.
- **Pencil** is used for the baseline because it does **not dissolve** in the solvent (ink would run).
- **Colourless** substances (e.g. amino acids) are made visible by spraying with a **locating agent** (e.g. ninhydrin) or by viewing under **ultraviolet light**.
- The **R_f value** = distance moved by the spot $\div$ distance moved by the solvent front. It is always less than 1.

Testing purity: melting point and boiling point

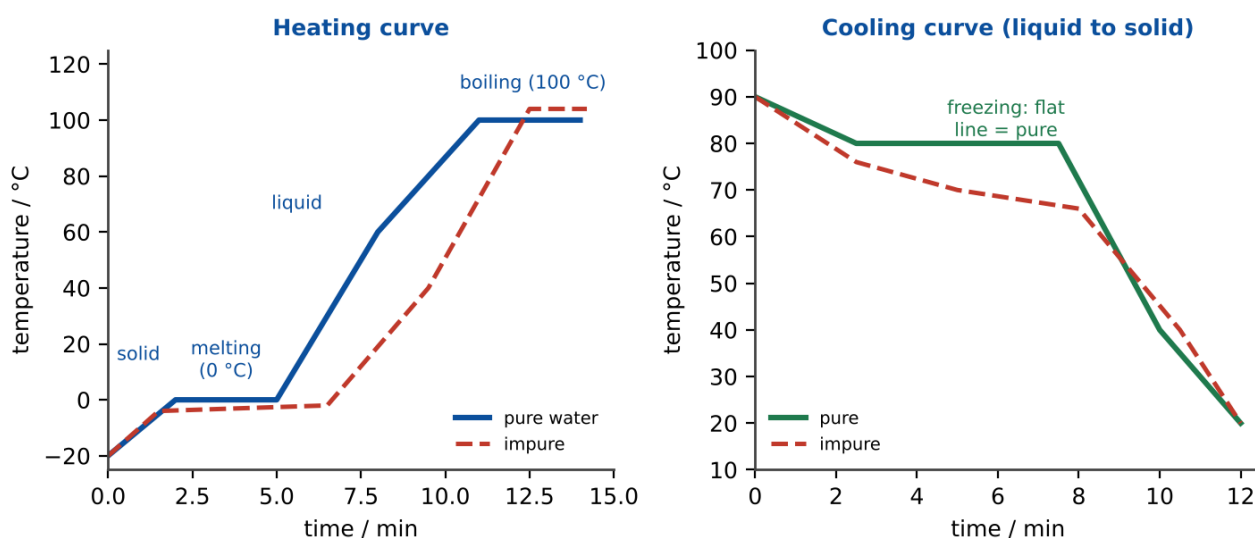


Figure C4.3 Heating and cooling curves for a pure substance (solid lines) and an impure one (dashed).

- A **pure** substance melts and boils at **sharp, fixed temperatures** (water: 0 °C and 100 °C at normal pressure). The temperature is **constant** during the change of state, giving a **flat line** on a curve.
- **Impurities lower** the melting point and **raise** the boiling point, and the substance melts or boils over a **range** of temperatures.
- On a **heating curve** the flat sections show melting and boiling. On a **cooling curve** the flat section shows freezing.

EXAM TIP

To get the marks for a **purity test**, always state the **expected result**: "it will melt at exactly 0 °C if it is pure", not just "measure the melting point".

Exercise C4: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C4.1** Name the method that you would use to separate (a) sand from water, (b) salt from salt solution, (c) pure water from sea water, (d) ethanol from a mixture of ethanol and water.
- C4.2** Define the terms **residue** and **filtrate**.
- C4.3** Why is the baseline in chromatography drawn in pencil and not in ink?
- C4.4** A chromatogram has a sample that gives three spots. What does this show?
- C4.5** A spot moves 3.0 cm while the solvent front moves 6.0 cm. Calculate the R_f value.
- C4.6** A student finds that a liquid boils over the range 100 to 104 °C. What does this suggest about the liquid?
- C4.7** Explain why fractional distillation can separate ethanol and water, but simple distillation cannot do so well.
- C4.8** Describe how to obtain pure, dry crystals of copper(II) sulfate from its solution.

EXAM-STYLE QUESTION · C4 · [8 marks]

A student wants to find out whether a green food colouring contains more than one dye. She uses paper chromatography with water as the solvent.

- (a) Describe how she should set up the experiment. [3]
- (b) The result shows two spots at different heights. State what this tells her. [1]
- (c) She wants to know whether the lower spot is the dye *tartrazine*. Suggest what she should do. [2]
- (d) A sample of the solvent is a liquid that boils at 100 °C. Explain how this value could be used to show that the liquid is pure water. [2]

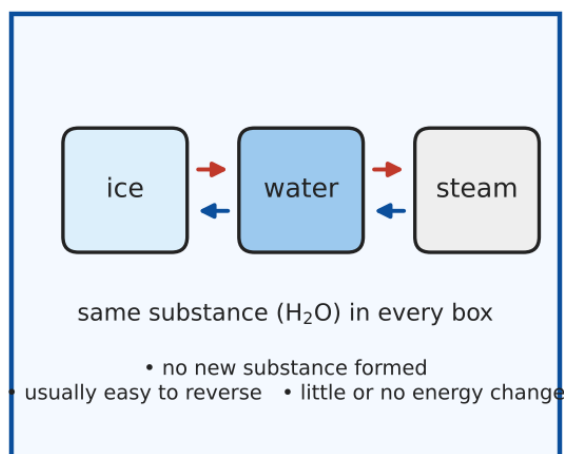
C5 Physical and Chemical Change

Syllabus reference: **C5.1 to C5.2**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- List the **properties** of a physical change and of a chemical change.
- Identify and describe** physical and chemical changes in everyday examples.
- Give **evidence** that a chemical reaction has taken place.

Physical change



Chemical change

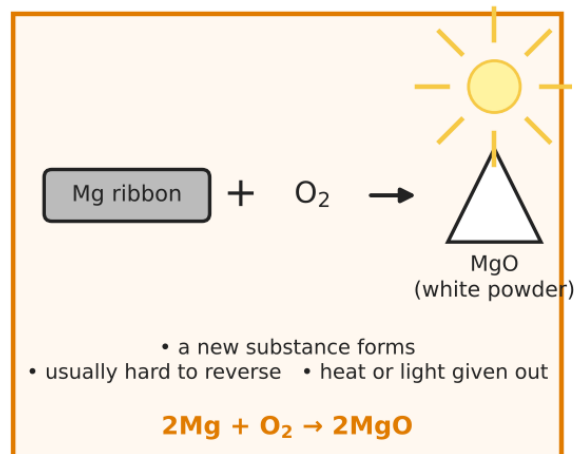


Figure C5.1 Left: melting, boiling and freezing of water are physical changes. Right: burning magnesium is a chemical change.

	Physical change	Chemical change
New substance formed?	No. The substance is the same; only its form or state changes.	Yes. One or more new substances are formed.
Reversible?	Usually easy to reverse (freeze the water again).	Usually difficult or impossible to reverse.
Energy change	Small or none.	Heat, light or other energy is given out or taken in.
Mass	Mass stays the same.	Total mass is conserved (mass of reactants = mass of products).
Examples	Melting, freezing, boiling, evaporating, condensing, dissolving, crushing, filtering	Burning, rusting, cooking, respiration, photosynthesis, fermentation, acid + carbonate

Evidence that a chemical change has happened

- A **colour change** (copper(II) oxide black, copper(II) sulfate solution blue).
- A **gas** is given off (bubbles when an acid is added to a carbonate).
- A **precipitate** (insoluble solid) forms when two solutions are mixed.
- A **temperature change** or a flame, **light or sound** (burning, explosions).
- The product has **different properties** from the reactants.

Change	Type	Reason
Ice melting	Physical	Still H ₂ O; reversible

Change	Type	Reason
Sugar dissolving in water	Physical	No new substance; sugar can be recovered by evaporation
Burning magnesium	Chemical	White MgO forms with bright light and heat
Iron rusting	Chemical	Iron + oxygen + water form hydrated iron(III) oxide
Frying an egg	Chemical	Proteins change permanently; cannot be reversed
Marble chips + acid	Chemical	Fizzing: carbon dioxide gas is produced
Crushing chalk	Physical	Smaller pieces of the same substance

CORE CONCEPT

A **word equation** summarises a chemical change: **reactants** → **products**. For example, *magnesium + oxygen* → *magnesium oxide*. The arrow means "reacts to form".

EXAM TIP

Say **why**: "it is a chemical change because **a new substance is formed**". Do not say it is chemical "because it cannot be reversed" on its own. Some chemical changes can be reversed (e.g. blue copper(II) sulfate crystals lose water when heated, and turn blue again when water is added).

Exercise C5: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C5.1** List three properties of a chemical change.
- C5.2** State whether each is a physical or chemical change: (a) boiling water, (b) burning wood, (c) dissolving salt, (d) rusting of a nail, (e) freezing of water.
- C5.3** A student heats magnesium ribbon in air and a bright white flame forms with a white powder. Give two observations that show a chemical change.
- C5.4** Explain why dissolving sugar in water is a physical change.
- C5.5** Write a word equation for the burning of magnesium in oxygen.
- C5.6** Marble chips fizz when dilute hydrochloric acid is added. State the evidence for a chemical change.
- C5.7** Give an example of a physical change that is reversible and a chemical change that is hard to reverse.
- C5.8** 5.0 g of iron wool is burned in air and the product has a mass of 6.2 g. Explain why the mass has increased.

EXAM-STYLE QUESTION · C5 · [7 marks]

Iron nails left outside in damp air slowly turn brown. A student weighs a clean iron nail, leaves it in a damp place for two weeks, and finds that the brown nail has a larger mass.

- (a) Name the chemical change that has happened to the nail. [1]
- (b) State **two** observations or properties that show the change is chemical and not physical. [2]
- (c) Explain why the mass of the nail increased. [2]
- (d) Name one physical change that the student could carry out on the iron nail, and say how you know it is physical. [2]

C6 The Periodic Table

Syllabus reference: C6.1 to C6.4

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Explain how the **Periodic Table** is arranged and use it to predict properties.
- Relate **group number** to outer electrons and **period number** to the number of shells.
- Describe the properties and trends of **Group I (alkali metals)** and **Group VII (halogens)**.
- Describe **transition elements** and the **noble gases**.

The **Periodic Table** arranges the elements in order of increasing **proton (atomic) number**. It classifies the elements so that their properties can be **predicted**. A copy is given in Papers 1 and 2.

Period	I	II											III	IV	V	VI	VII	0
1	¹ H 1																	² He 4
2	³ Li 7	⁴ Be 9											⁵ B 11	⁶ C 12	⁷ N 14	⁸ O 16	⁹ F 19	¹⁰ Ne 20
3	¹¹ Na 23	¹² Mg 24											¹³ Al 27	¹⁴ Si 28	¹⁵ P 31	¹⁶ S 32	¹⁷ Cl 35.5	¹⁸ Ar 40
4	¹⁹ K 39	²⁰ Ca 40	Transition elements (Sc to Zn)										Ga to Kr (not needed)					
Alkali metals Alkaline earth metals Transition elements Other metals Metalloids Non-metals Halogens Noble gases																		

Each box shows: atomic number (top left), symbol, relative atomic mass (bottom).

Figure C6.1 The first 20 elements of the Periodic Table, coloured by type.

- **Groups** are the **vertical columns**. Elements in a group have **similar chemical properties** because they have the **same number of outer-shell electrons**. The **group number** = number of outer electrons (Groups I to VII).
- **Periods** are the **horizontal rows**. The **period number** = the **number of electron shells** the atoms have.
- Across a period, the elements change from **metallic** (left) to **non-metallic** (right). Metals are on the left and centre; non-metals are on the right.
- The elements named by group: **alkali metals** (Group I), **alkaline earth metals** (Group II), **halogens** (Group VII) and **noble gases** (Group 0 or VIII).

Group I: the alkali metals (Li, Na, K)

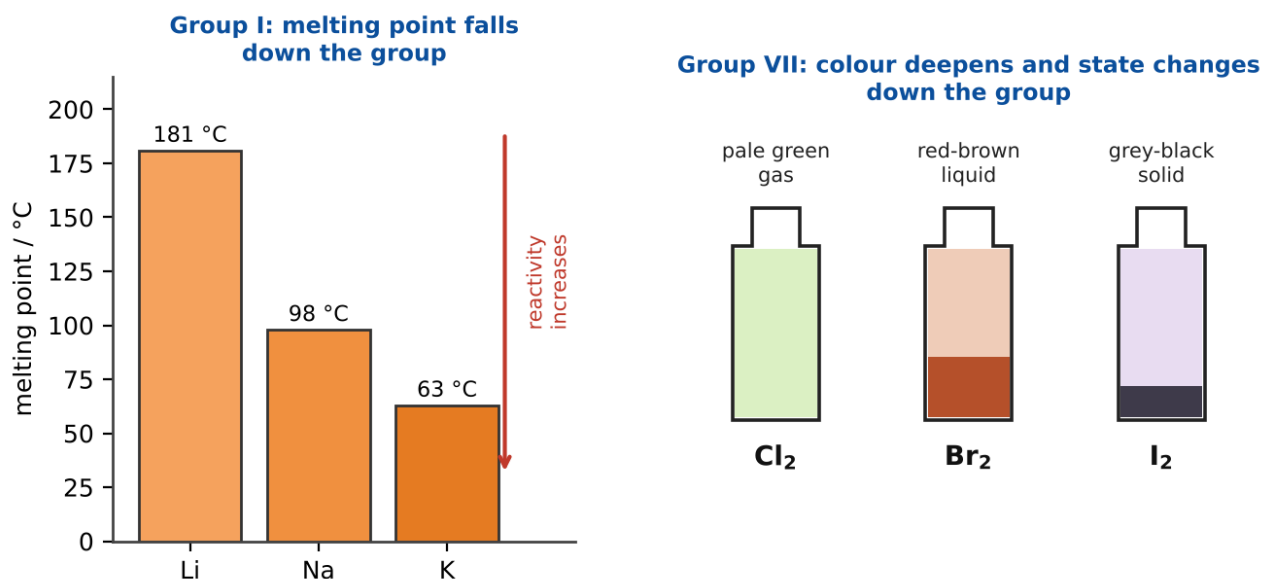


Figure C6.2 Left: melting points of Group I metals. Right: the appearance of the Group VII elements.

- **Physical properties:** soft (cut with a knife), shiny when freshly cut, **low melting points** and **low densities** (Li, Na and K float on water). The **melting point decreases** down the group, and density generally increases (K is an exception).
- **Chemical properties:** they are stored in oil, tarnish quickly in air, and react with water to form **hydrogen** and a **metal hydroxide** (an alkaline solution): $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$.
- **Trend in reactivity:** it **increases down the group**. Lithium fizzes steadily; sodium melts into a ball and fizzes rapidly; **potassium** bursts into a lilac flame. Each atom has **one outer electron**, which is lost more easily as the atom gets bigger.
- **Predictions:** rubidium and caesium are **softer, with lower melting points** and **react more violently** than potassium.

Group VII: the halogens (Cl, Br, I)

Halogen	Colour and state at room temperature	Melting/boiling points	Reactivity
Chlorine Cl ₂	Pale yellow-green gas	Lowest	Most reactive of the three
Bromine Br ₂	Red-brown liquid (orange vapour)	Higher	Intermediate
Iodine I ₂	Grey-black solid (purple vapour)	Highest	Least reactive of the three

- Halogens are **diatomic** (two atoms per molecule): Cl₂, Br₂, I₂, with **seven outer electrons**. They are poisonous non-metals.
- **Colour deepens** and the state changes from gas to liquid to solid **down the group**. **Reactivity decreases** down the group.
- **Displacement:** a **more reactive halogen displaces a less reactive halide ion** from solution. Cl₂ + 2KBr → 2KCl + Br₂ (orange solution forms); Br₂ + 2KI → 2KBr + I₂ (brown solution). Iodine does **not** displace chloride or bromide. Fluorine is a pale yellow gas, more reactive than chlorine; astatine is a black solid, less reactive than iodine.

Transition elements and noble gases

- **Transition elements** (the block between Groups II and III, e.g. iron, copper) are **hard, strong metals** with **high densities and high melting points** (except mercury), and **good conductors**. Their compounds are **coloured** (copper(II) compounds are blue; iron(II) compounds green; iron(III) compounds red-brown). They show **variable oxidation states** (Fe^{2+} and Fe^{3+} ; Cu^+ and Cu^{2+}). Many are used as **catalysts**: iron in the Haber process for ammonia, nickel in the hydrogenation of oils to make margarine.
- **Noble gases** (He, Ne, Ar, Kr, Xe, Rn) are **unreactive** monatomic gases because their outer shells are **full** (2 electrons for helium, 8 for the others). **Uses**: **helium** in weather balloons and airships (low density, non-flammable); **argon** in filament lamps and welding (an **inert atmosphere** stops the hot filament or metal reacting with oxygen); **neon** in advertising signs.

EXAM TIP

For "predict" questions, write the **trend first** ("melting point decreases down Group I"), then use it: "rubidium is below potassium, so it melts at a **lower** temperature than 63 °C".

Exercise C6: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C6.1** State what the (a) group number and (b) period number tell you about an atom.
- C6.2** Chlorine is in Group VII and Period 3. State the number of outer electrons and the number of shells in a chlorine atom.
- C6.3** Describe the trend in reactivity of Li, Na and K with water, and explain it.
- C6.4** Write a word equation and a balanced symbol equation for the reaction of sodium with water.
- C6.5** Predict the melting point trend and reactivity of caesium compared with potassium.
- C6.6** Chlorine water is added to potassium iodide solution. State what you see and write a word equation.
- C6.7** Why is argon used in light bulbs?
- C6.8** State **two** properties of transition elements that are different from the Group I metals.

EXAM-STYLE QUESTION · C6 · [9 marks]

Lithium, sodium and potassium are Group I elements. Their melting points are: lithium 181 °C, sodium 98 °C and potassium 63 °C.

- (a) Describe the trend in melting point down the group. [1]
- (b) Predict the melting point of rubidium, which is below potassium in the group. [1]
- (c) Describe what you would see when a small piece of potassium is dropped onto water. [3]
- (d) Name the two products and write a balanced equation for the reaction of sodium with water. [3]
- (e) Explain why Group I elements are stored in oil. [1]

C7 Atomic Structure and Bonding

Syllabus reference: **C7.1 to C7.2**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the structure of an atom: **protons, neutrons and electrons**, their charges and masses.
- Define **proton number, nucleon number and isotopes**, and use **nuclide notation**.
- Describe the **build-up of electrons in shells** for elements 1 to 20.
- Describe and draw **ionic and covalent bonding**, and explain the properties of **ionic, covalent, giant covalent and metallic** substances.

Structure of the atom

Particle	Relative charge	Relative mass	Where found
Proton	+1	1	In the nucleus
Neutron	0	1	In the nucleus
Electron	-1	about 1/1840 (negligible)	In shells around the nucleus

- The **nucleus** is tiny, dense and **positively charged**. Almost all of the mass of the atom is in the nucleus.
- An atom is **neutral**: the number of electrons = the number of protons.
- **Proton (atomic) number, Z** = the number of **protons** in the nucleus. It identifies the element.
- **Nucleon (mass) number, A** = the number of **protons + neutrons** in the nucleus.
- **Nuclide notation**: the nucleon number is written at the top left of the symbol and the proton number at the bottom left. For sodium: nucleon number 23, proton number 11, so sodium has **11 protons, 11 electrons and 23 – 11 = 12 neutrons**.

CORE CONCEPT

Isotopes are **atoms of the same element** (same proton number) with **different numbers of neutrons** (different nucleon numbers). Isotopes have the **same chemical properties** because they have the same number of electrons. Example: chlorine-35 and chlorine-37 (that is why the relative atomic mass of chlorine is 35.5).

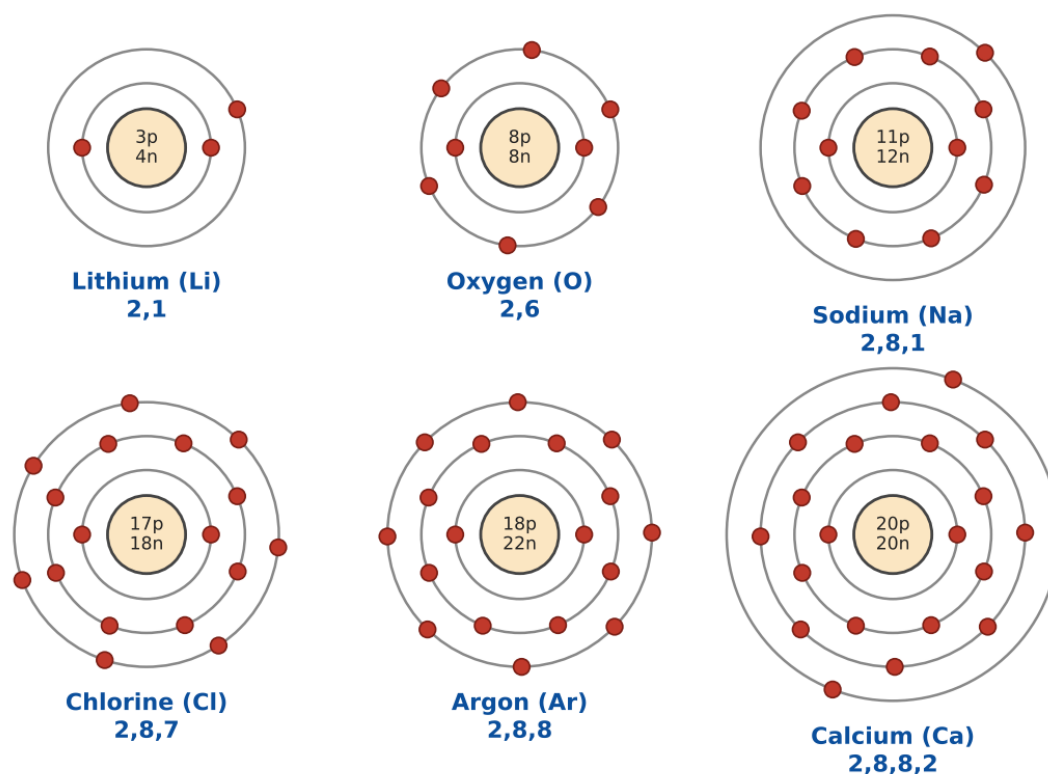


Figure C7.1 Electron arrangements of six atoms. The first shell holds 2 electrons, the second and third hold up to 8.

Electrons are arranged in shells. The first shell holds a maximum of **2** electrons, the second **8**, and the third **8** (for the first 20 elements). Fill the shells from the inside outwards. Sodium (11 electrons) is **2,8,1**; chlorine (17) is **2,8,7**; calcium (20) is **2,8,8,2**.

- The **outermost shell** controls chemical properties. The number of outer electrons = the **group number**.
- **Noble gases** (He 2; Ne 2,8; Ar 2,8,8) have **full outer shells**. This is a **stable** arrangement, so they are unreactive. Other atoms react to gain a full outer shell by **losing, gaining or sharing** electrons.

Ionic bonding (metal + non-metal)

A metal atom **loses** electrons to form a **positive ion** (cation); a non-metal atom **gains** electrons to form a **negative ion** (anion). The oppositely charged ions attract each other strongly: this **electrostatic attraction** is the **ionic bond**. Ions form a **giant lattice**.

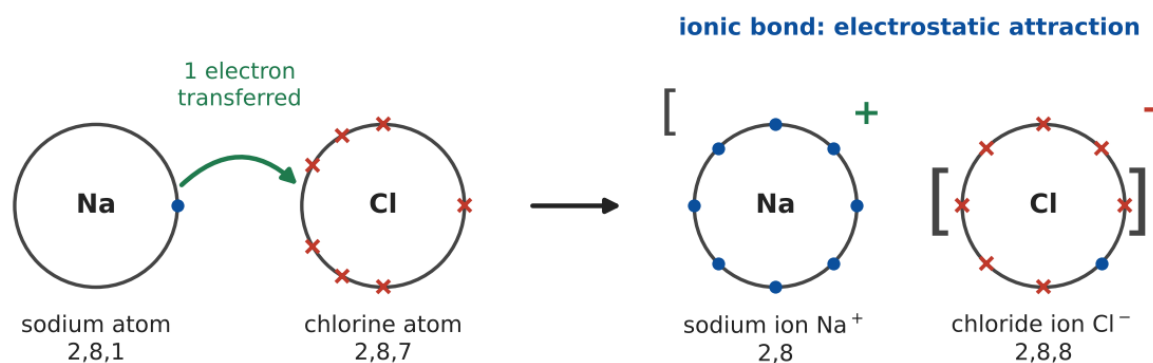


Figure C7.2 Formation of sodium chloride by transfer of one electron from sodium to chlorine. Dots show electrons from sodium, crosses show electrons from chlorine.

Group	I	II	III	VI	VII
Ion charge	+1	+2	+3	-2	-1
Examples	Na^+ , Li^+ , K^+	Mg^{2+} , Ca^{2+}	Al^{3+}	O^{2-} , S^{2-}	Cl^- , F^-

In magnesium oxide, Mg loses **two** electrons (to form Mg^{2+}) and O gains **two** (O^{2-}). In calcium chloride, Ca loses two electrons and **two** chlorine atoms gain one each, so the formula is **CaCl_2** .

Covalent bonding (non-metal + non-metal)

In a **covalent bond**, atoms **share a pair of electrons**, so that each atom has a **full outer shell**. The atoms are held together in **molecules**. A single bond is one shared pair, a **double bond** two pairs, and a **triple bond** three pairs.

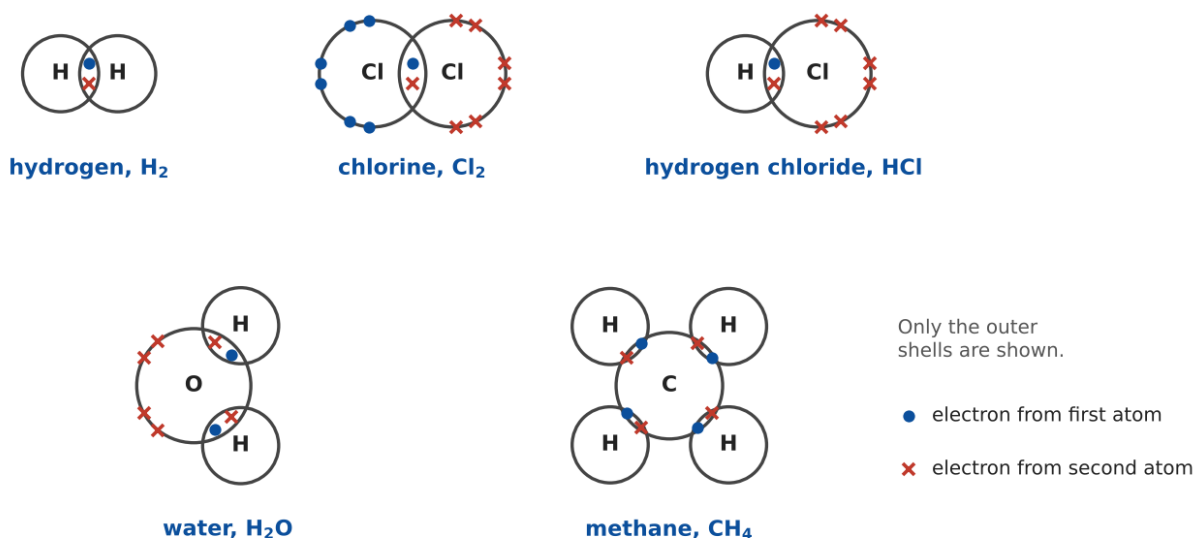


Figure C7.3 Dot-and-cross diagrams for hydrogen, chlorine, hydrogen chloride, water and methane (single covalent bonds).

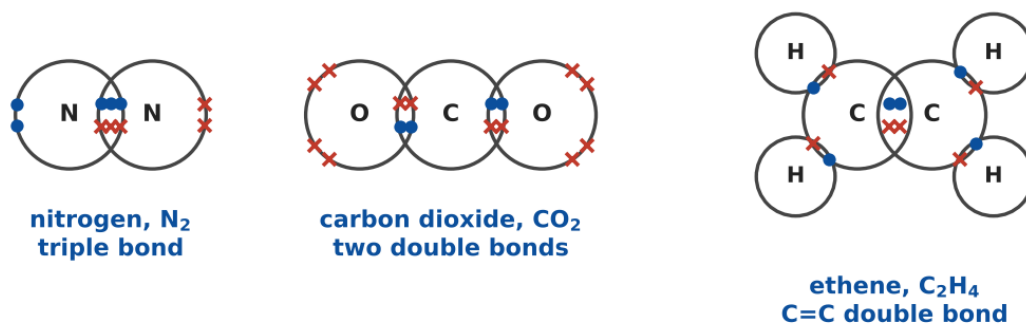


Figure C7.4 More complex molecules: nitrogen (triple bond), carbon dioxide (two double bonds) and ethene (one $C=C$ double bond). Methanol, CH_3OH , has a $C-O$ single bond and an $O-H$ single bond.

Property	Ionic compounds	Simple covalent molecules
Melting and boiling points	High (strong attraction between many ions)	Low (weak forces between molecules; the covalent bonds are not broken)
Electrical conductivity	Conduct when molten or dissolved (ions free to move); not when solid	Do not conduct (no ions or free electrons)
Solubility in water	Many are soluble	Usually insoluble in water (soluble in organic solvents)
Volatility	Not volatile	Often volatile

Giant molecules (macromolecules): carbon

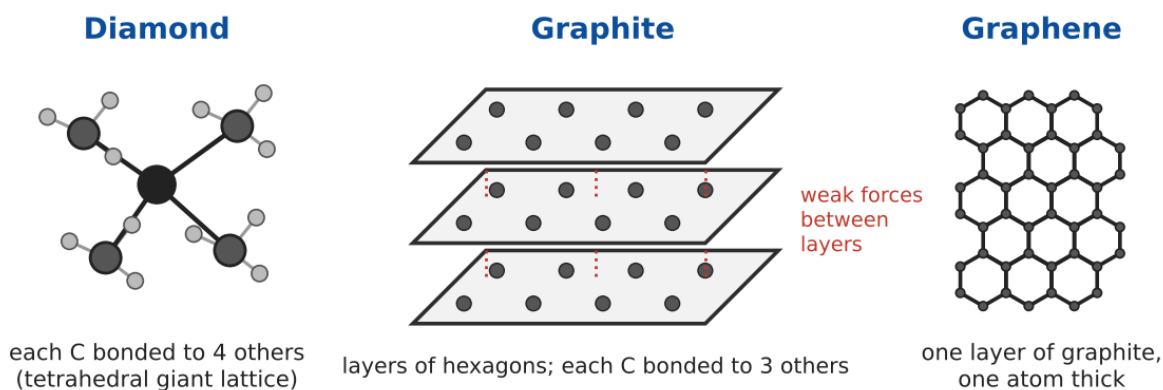


Figure C7.5 Diamond, graphite and graphene: three different structures of carbon atoms.

	Diamond	Graphite	Graphene
Structure	Each C bonded to 4 others; rigid 3-D giant lattice	Layers of hexagons; each C bonded to 3 others; weak forces between layers	A single layer of graphite
Hardness	Very hard	Soft, layers slide over each other	Extremely strong, flexible
Conducts electricity?	No (no free electrons)	Yes : one outer electron per atom is delocalised	Yes , excellent conductor
Melting point	Very high	Very high	Very high
Uses	Cutting and drilling tools, jewellery	Pencil leads, lubricants, electrodes	Electronics, strong light composites

Metallic bonding

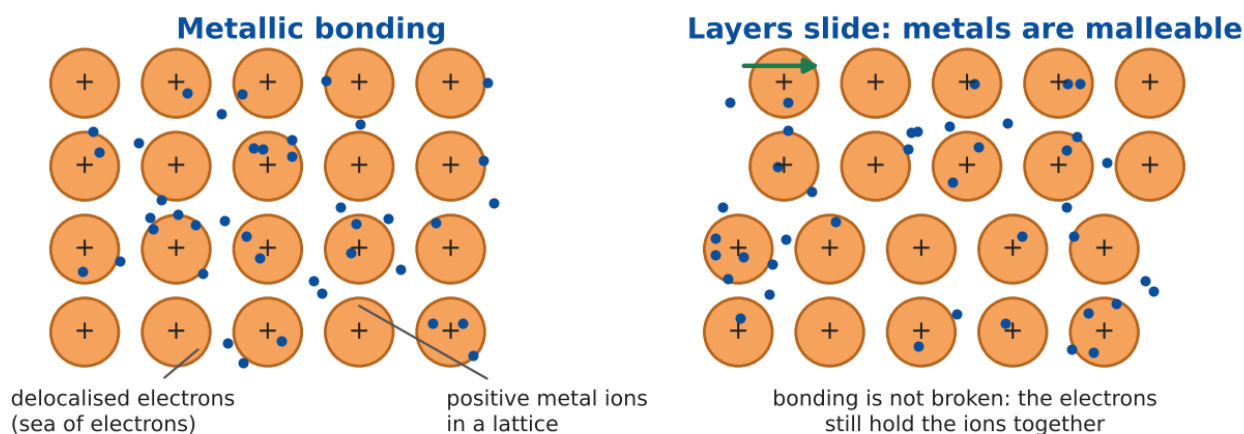


Figure C7.6 A metal is a lattice of positive ions in a sea of delocalised electrons.

Metallic bonding is the **attraction between positive metal ions and the delocalised electrons**. Metals **conduct electricity** because the delocalised electrons are **free to move** and carry charge. They are **malleable** (can be hammered) and **ductile** (can be drawn into wires) because **layers of ions can slide over each other** without breaking the bonding.

EXAM TIP

When explaining conductivity always name the **particles that carry the charge**: **ions** (molten or dissolved ionic compounds) or **electrons** (metals and graphite). Never say "the electricity moves".

Exercise C7: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C7.1** Complete the table: particle, relative charge, relative mass for a proton, neutron and electron.
- C7.2** An atom of potassium has proton number 19 and nucleon number 39. Give the number of protons, neutrons and electrons.
- C7.3** Write the electron arrangement of (a) oxygen ($Z = 8$), (b) magnesium ($Z = 12$), (c) argon ($Z = 18$).
- C7.4** Define isotopes and say why isotopes of an element have the same chemical properties.
- C7.5** Describe, in terms of electrons, how a magnesium atom becomes a magnesium ion with charge $2+$.
- C7.6** Draw a dot-and-cross diagram (outer shells only) for hydrogen chloride and for methane.
- C7.7** Explain why diamond is hard but graphite is soft.
- C7.8** Explain why sodium chloride conducts electricity when molten but not when solid.
- C7.9** Why do metals conduct electricity and why are they malleable?

EXAM-STYLE QUESTION · C7 · [11 marks]

Sodium chloride (NaCl) and water (H₂O) are both compounds. Sodium has proton number 11 and chlorine has proton number 17.

- (a) State the electron arrangement of a sodium atom and of a chlorine atom. [2]
- (b) Describe, in terms of electron transfer, how sodium chloride is formed. [3]
- (c) Explain why sodium chloride has a high melting point. [2]
- (d) Water has a low melting point. Explain why. [2]
- (e) Draw a dot-and-cross diagram for a water molecule showing outer electrons only. [2]

C8 Stoichiometry

Syllabus reference: **C8.1 to C8.14**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Write **formulae** of compounds and **balanced equations**, with state symbols.
- Define and calculate A_r , M_r and **relative formula mass**, and **percentage composition**.
- Use the **mole**, **Avogadro's constant**, **molar volume (24 dm³)** and **concentration** in calculations.
- Calculate **reacting masses and gas volumes**, **empirical and molecular formulae**, and identify the **limiting reactant**.

Formulae and equations

A **formula** shows the **atoms present in a substance**. The formula of an ionic compound is found by **balancing the charges** of its ions so that the total charge is **zero**.

Positive ions	Charge	Negative ions	Charge
Hydrogen H^+ , sodium Na^+ , potassium K^+ , silver Ag^+ , ammonium NH_4^+	1+	Chloride Cl^- , bromide Br^- , iodide I^- , hydroxide OH^- , nitrate NO_3^-	1-
Magnesium Mg^{2+} , calcium Ca^{2+} , zinc Zn^{2+} , copper(II) Cu^{2+} , iron(II) Fe^{2+}	2+	Oxide O^{2-} , sulfide S^{2-} , carbonate CO_3^{2-} , sulfate SO_4^{2-}	2-
Aluminium Al^{3+} , iron(III) Fe^{3+}	3+		

WORKED EXAMPLE: writing a formula

Aluminium oxide: Al^{3+} and O^{2-} . The smallest equal total charges are 6+ and 6-, so **2 Al^{3+}** and **3 O^{2-}** : Al_2O_3 .

Calcium hydroxide: Ca^{2+} and OH^- . One Ca^{2+} needs two OH^- : **$Ca(OH)_2$** . Use brackets round a group of atoms when you need more than one.

A **balanced equation** has the **same number of each kind of atom on both sides** because atoms are not created or destroyed. Balance by changing the **big numbers in front** of formulae (never the small subscripts). State symbols: **(s)** solid, **(l)** liquid, **(g)** gas, **(aq)** aqueous (dissolved in water).

- $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$
- $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$
- $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Relative masses

- **Relative atomic mass, A_r** = the **average mass of the atoms of an element compared with 1/12 of the mass of an atom of carbon-12**.
- **Relative molecular mass, M_r** = the **sum of the relative atomic masses of all the atoms in the molecule**. For compounds that are not molecules (ionic), it is called the **relative formula mass (RFM)**.
- Use A_r : H = 1, C = 12, N = 14, O = 16, Na = 23, Mg = 24, Al = 27, S = 32, Cl = 35.5, K = 39, Ca = 40, Fe = 56, Cu = 64, Zn = 65.

WORKED EXAMPLE: M_r and percentage composition

M_r of $\text{CaCO}_3 = 40 + 12 + (3 \times 16) = 100$.

M_r of $(\text{NH}_4)_2\text{SO}_4 = 2 \times (14 + 4) + 32 + (4 \times 16) = 132$.

% of nitrogen in $(\text{NH}_4)_2\text{SO}_4 = (2 \times 14) \div 132 \times 100 = 21.2\%$.

percentage of an element = $(A_r \times \text{number of atoms} \div M_r) \times 100$

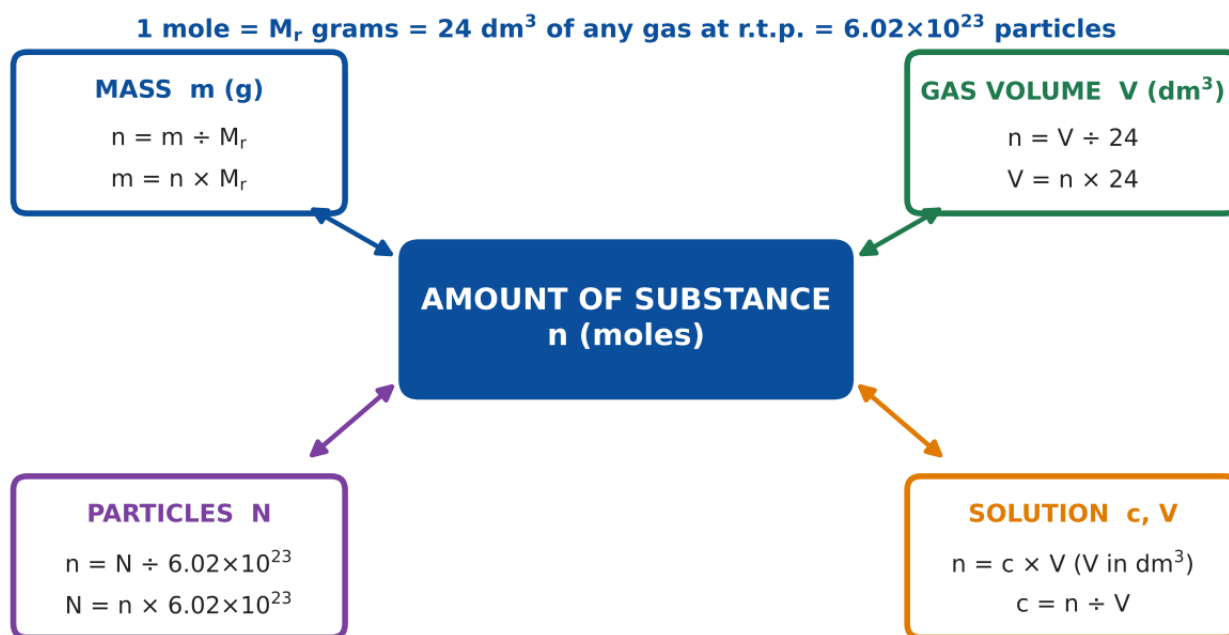
The mole

Figure C8.1 The mole links mass, gas volume, number of particles and solution concentration.

CORE CONCEPT

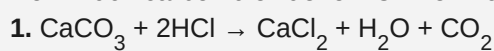
The **mole** is the **amount of substance** that contains 6.02×10^{23} particles (the **Avogadro constant**). **One mole of a substance has a mass of M_r grams.** One mole of **any gas** occupies **24 dm³ at room temperature and pressure (r.t.p.)**.

$$\text{moles} = \text{mass} \div M_r \quad \text{gas volume (dm}^3\text{)} = \text{moles} \times 24 \quad \text{moles} = \text{concentration} \times \text{volume (dm}^3\text{)}$$

Concentration	Meaning	Conversion
mol/dm ³	moles of solute in 1 dm ³ of solution	mol/dm ³ = moles ÷ volume in dm ³
g/dm ³	mass of solute in 1 dm ³ of solution	g/dm ³ = mol/dm ³ × M_r

WORKED EXAMPLE: reacting masses and gas volume

How much carbon dioxide forms when **10 g of calcium carbonate** reacts with excess acid?



2. Moles $\text{CaCO}_3 = 10 \div 100 = 0.10 \text{ mol}$

3. Ratio $\text{CaCO}_3 : \text{CO}_2 = 1 : 1$, so moles $\text{CO}_2 = 0.10 \text{ mol}$

4. Volume $\text{CO}_2 = 0.10 \times 24 = 2.4 \text{ dm}^3$ (or mass = $0.10 \times 44 = 4.4 \text{ g}$)

Empirical and molecular formulae; limiting reactants

- **Empirical formula** = the **simplest whole-number ratio** of atoms in a compound. **Molecular formula** = the **actual number** of atoms in a molecule = (empirical formula) $\times n$, where $n = M_r \div \text{mass of the empirical formula}$.
- **Limiting reactant** = the reactant that is **completely used up** first; it **limits** the amount of product made. The other reactant is in **excess**.

WORKED EXAMPLE: empirical and molecular formula

A hydrocarbon contains **2.4 g of carbon** and **0.6 g of hydrogen**. Its M_r is 30.

Moles: C = $2.4 \div 12 = 0.20$; H = $0.6 \div 1 = 0.60$. **Ratio** C : H = $0.20 : 0.60 = 1 : 3$. **Empirical formula** = **CH₃** (mass 15).

$n = 30 \div 15 = 2$, so the **molecular formula** is **C₂H₆**.

EXAM TIP

Always set out calculations in steps: **(1) write the balanced equation, (2) convert the given quantity to moles, (3) use the ratio from the equation, (4) convert moles to the quantity asked for.** Marks are given for each step.

Exercise C8: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C8.1** Write the formula of (a) sodium oxide, (b) magnesium chloride, (c) aluminium oxide, (d) calcium hydroxide, (e) ammonium sulfate.
- C8.2** Balance: (a) $\text{Mg} + \text{O}_2 \rightarrow \text{MgO}$; (b) $\text{H}_2 + \text{Cl}_2 \rightarrow \text{HCl}$; (c) $\text{Fe} + \text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$; (d) $\text{CH}_4 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}$.
- C8.3** Calculate M_r of (a) H_2SO_4 , (b) $\text{Mg}(\text{OH})_2$.
- C8.4** Calculate the percentage by mass of iron in Fe_2O_3 .
- C8.5** How many moles are in 11 g of carbon dioxide ($M_r = 44$), and what volume do they occupy at r.t.p.?
- C8.6** 4.0 g of sodium hydroxide ($M_r = 40$) is dissolved to make 250 cm^3 of solution. Calculate the concentration in (a) mol/dm^3 and (b) g/dm^3 .
- C8.7** Calculate the mass of magnesium oxide formed when 12 g of magnesium burns completely. ($2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$)
- C8.8** 2.4 g of magnesium is added to 100 cm^3 of 1.0 mol/dm^3 hydrochloric acid. $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$. Which reactant is limiting, and what volume of hydrogen forms at r.t.p.?

EXAM-STYLE QUESTION · C8 · [8 marks]

Calcium carbonate decomposes when heated strongly in a lime kiln: $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$. (A_r : C = 12, O = 16, Ca = 40.)

- | | |
|--|-----|
| (a) Calculate the relative formula mass of calcium carbonate. | [1] |
| (b) Calculate the number of moles in 25 g of calcium carbonate. | [1] |
| (c) Calculate the mass of calcium oxide made from 25 g of calcium carbonate. | [3] |
| (d) Calculate the volume of carbon dioxide formed at r.t.p. | [2] |
| (e) State the meaning of the term <i>mole</i> . | [1] |

C9 Chemical Reactions

Syllabus reference: C9.1 to C9.4

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the **production of energy** from hydrogen, uranium-235 and **simple cells**.
- Distinguish **exothermic** and **endothermic** reactions, and explain them in terms of **bond breaking and forming**.
- Define **speed of reaction** and **catalyst**, and explain how **concentration, particle size, temperature and catalysts** affect speed using **collision theory**.
- Describe **oxidation and reduction** and identify **redox** reactions.

C9.1 Production of energy

- Hydrogen as a fuel:** hydrogen burns in oxygen to give **only water**: $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$. It is used in **rockets** (liquid hydrogen with liquid oxygen). It is a clean fuel (no carbon dioxide), but it is **flammable and explosive**, difficult to store, and is usually made from fossil fuels or by electrolysis, which needs energy.
- Uranium-235** is used in **nuclear power stations**. The **nuclear fission** of U-235 releases a very large amount of energy as heat, which makes **steam** to turn **turbines** and generate electricity. It does not release carbon dioxide but produces **radioactive waste** (see P14).
- Simple cells** convert **chemical energy into electrical energy**.

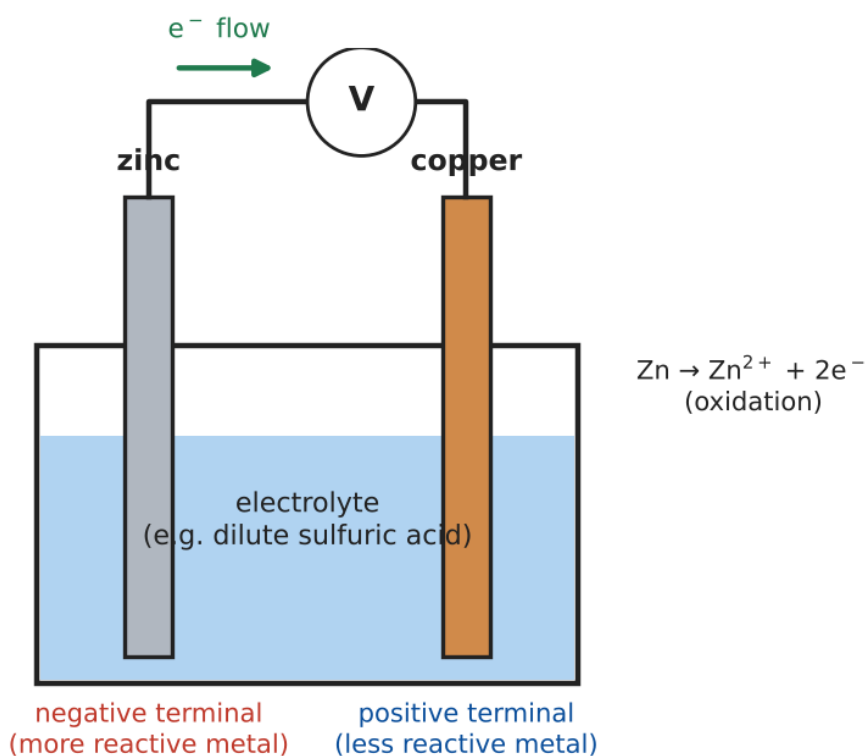


Figure C9.1 A simple cell: two different metals in an electrolyte. Electrons flow from the more reactive metal (zinc) to the less reactive metal (copper).

A simple cell consists of **two different metals (electrodes) in an electrolyte**. The **more reactive metal** forms the **negative electrode** and loses electrons (it is **oxidised**). The **greater the difference in reactivity**, the **higher the voltage**: a magnesium/copper cell gives a larger voltage than a zinc/copper cell. Two electrodes of the **same metal** give **no voltage**.

C9.2 Energetics of a reaction

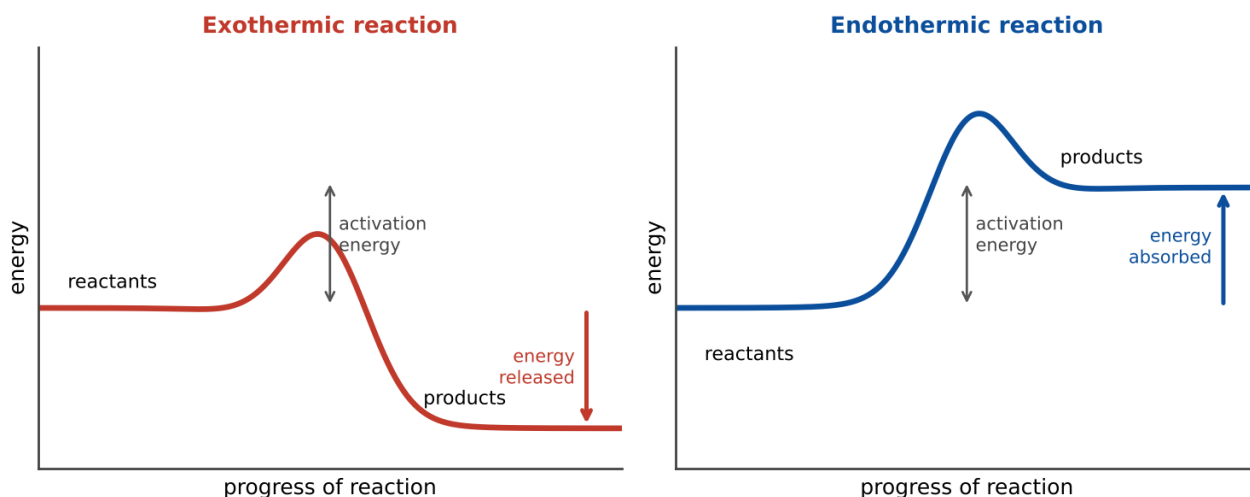


Figure C9.2 Energy level diagrams for exothermic and endothermic reactions.

	Exothermic	Endothermic
Energy change	Energy is given out to the surroundings	Energy is taken in from the surroundings
Temperature of surroundings	Rises	Falls
Products compared with reactants	Products have less energy	Products have more energy
Examples	Combustion, neutralisation, respiration, rusting	Thermal decomposition, photosynthesis, dissolving ammonium nitrate

CORE CONCEPT

Bond breaking is endothermic (energy is absorbed to pull atoms apart). **Bond making is exothermic** (energy is released). If **more energy is released making new bonds than is absorbed breaking old bonds**, the reaction is **exothermic overall**; if less, it is **endothermic**.

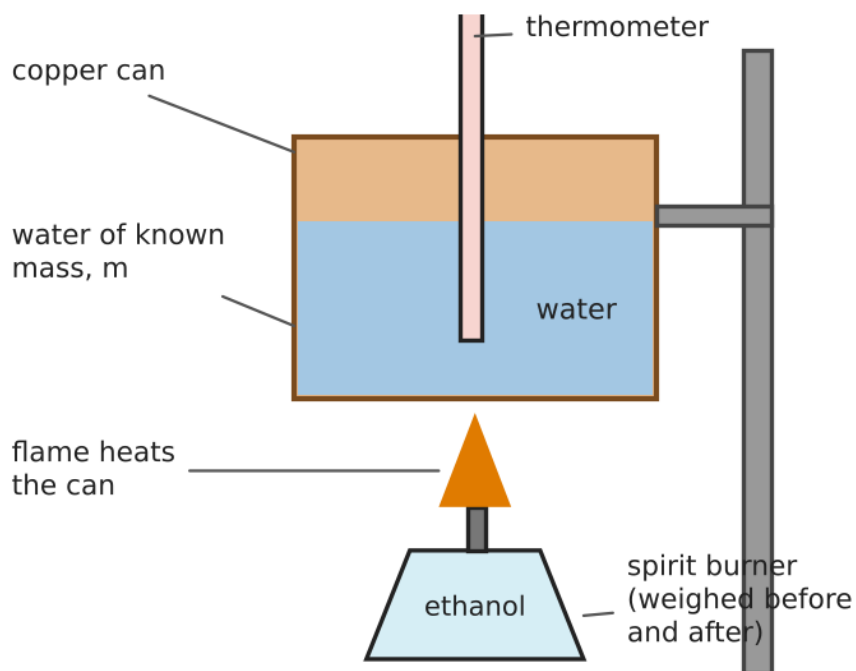


Figure C9.3 Measuring the energy released when a fuel burns.

Measuring energy from fuels and foods. Burn a known mass of fuel (ethanol) or food (a peanut) under a can of water of known mass and record the temperature rise. The energy transferred is $Q = m \times c \times \Delta T$, where m is the mass of water (g), c is the specific heat capacity of water ($4.2 \text{ J/g}^\circ\text{C}$) and ΔT is the temperature rise ($^\circ\text{C}$). Divide Q by the mass of fuel burned to find the energy released **per gram**.

WORKED EXAMPLE: energy from ethanol

Burning 0.50 g of ethanol raises the temperature of 100 g of water from 20°C to 45°C .

$$Q = m \times c \times \Delta T = 100 \times 4.2 \times 25 = 10\,500 \text{ J} = 10.5 \text{ kJ}$$

Energy per gram = $10\,500 \div 0.50 = 21\,000 \text{ J/g} = 21 \text{ kJ/g}$. (Some energy is lost to the air, so the true value is higher.)

C9.3 Speed of a reaction

Speed (rate) of a reaction is how fast **reactants are used up or products are formed**. It can be measured by the **volume of gas** given off, the **loss of mass**, or the **time** taken for a colour change or a precipitate to appear. A **catalyst** is a substance that **speeds up a reaction and is not used up** (it is unchanged chemically at the end). **Inorganic catalysts** include manganese(IV) oxide, iron and platinum. **Enzymes** are **organic (biological) catalysts**, e.g. in yeast during fermentation; they work best at about 37°C and are **destroyed (denatured)** by high temperatures.

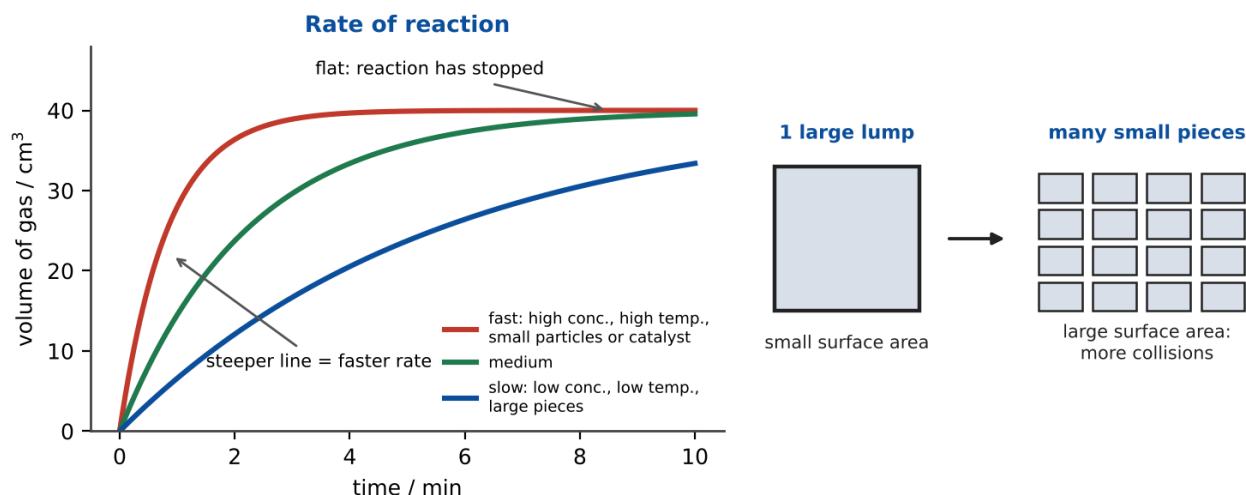


Figure C9.4 Left: how the reaction rate shows on a graph. Right: breaking a solid into smaller pieces increases its surface area.

Factor	Effect on speed	Explanation (collision theory)
Concentration ↑	Faster	More particles in the same volume, so more frequent collisions
Particle size ↓ (powder)	Faster	Larger surface area, so more particles exposed and more collisions per second
Temperature ↑	Faster	Particles move faster and collide more often , and more collisions have enough energy (activation energy)
Catalyst	Faster	Provides an alternative pathway with lower activation energy

Collision theory: a reaction happens only when particles **collide with enough energy**. The minimum energy needed is the **activation energy**. **Explosions:** very fine powders (flour, coal dust) or gases (methane in mines) have a huge surface area, so they burn almost instantly and can **explode** if a spark is present. Flour mills and coal mines use ventilation, dust control and a ban on naked flames.

EXAM TIP

To investigate the effect of **one** variable, change **only that variable** and keep the others the same (**fair test**). For example, to test temperature, use the **same mass of marble chips, same acid concentration and volume**; change only the temperature.

C9.4 Redox

	Oxidation	Reduction
Oxygen	Gain of oxygen	Loss of oxygen
Hydrogen	Loss of hydrogen	Gain of hydrogen
Electrons	Loss of electrons	Gain of electrons

Remember OIL RIG: Oxidation Is Loss, Reduction Is Gain (of electrons). A **redox reaction** is one in which **oxidation and reduction happen together**. In $\text{CuO} + \text{H}_2 \rightarrow \text{Cu} + \text{H}_2\text{O}$, copper oxide loses oxygen (**reduced**) and hydrogen gains oxygen (**oxidised**). In $\text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu}$, zinc loses two electrons (oxidised) and Cu^{2+} gains two (reduced).

Light and chemical change: in **photography**, light turns **silver ions to silver** ($\text{Ag}^+ + \text{e}^- \rightarrow \text{Ag}$; **reduction**), which makes the film darken. In **photosynthesis**, **chlorophyll** absorbs sunlight and the energy is used to turn **carbon dioxide and water into glucose** (and oxygen): $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$.

Exercise C9: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C9.1** Explain why hydrogen is described as a "clean" fuel.
- C9.2** A simple cell is made from magnesium and copper, and another from zinc and copper. Which gives the larger voltage? Explain.
- C9.3** Which metal is the negative electrode in a zinc/copper cell, and what does it do to its electrons?
- C9.4** Define (a) exothermic reaction and (b) endothermic reaction, with one example of each.
- C9.5** Explain, in terms of bonds, why a reaction is exothermic.
- C9.6** 1.0 g of peanut heats 200 g of water from 22 °C to 52 °C. Calculate the energy released in joules and per gram. ($c = 4.2 \text{ J/g}^\circ\text{C}$)
- C9.7** Use collision theory to explain why powdered zinc reacts faster with acid than zinc lumps.
- C9.8** Explain why a rise in temperature increases the speed of reaction.
- C9.9** State what happens to the iron in: $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$. Is it oxidised or reduced?
- C9.10** Why do flour mills have strict rules about naked flames?

EXAM-STYLE QUESTION · C9 · [9 marks]

A student reacts 2.0 g of marble chips (calcium carbonate) with excess dilute hydrochloric acid and measures the volume of carbon dioxide produced every 30 seconds. She repeats the experiment using 2.0 g of powdered marble.

- (a) Name the piece of apparatus that could be used to measure the volume of gas. [1]
- (b) Sketch the graph of volume of gas against time for both experiments on the same axes and label them. [3]
- (c) Explain, using collision theory, why powdered marble reacts faster. [3]
- (d) State **one** other way of increasing the rate of this reaction. [1]
- (e) The reaction between calcium carbonate and hydrochloric acid is exothermic. State what a thermometer in the acid would show. [1]

C10 Acids, Bases and Salts

Syllabus reference: **C10.1 to C10.5**

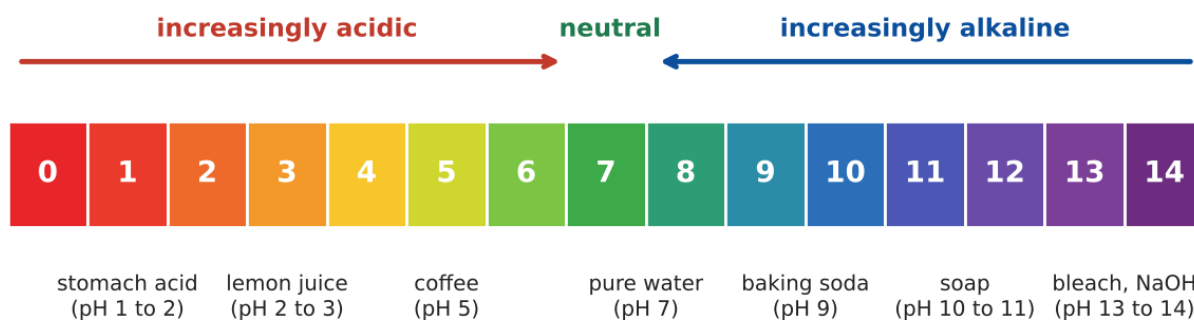
BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Define **acids, bases and alkalis** and describe the **properties of acids**.
- Use the **pH scale** and **Universal Indicator**, and describe **neutralisation** and its uses.
- Classify **oxides** as acidic, basic, neutral or amphoteric.
- Prepare soluble and insoluble salts**, and carry out **tests for ions and gases**.

CORE CONCEPT

An **acid** is a **proton (H^+) donor**. A **base** is a **proton (H^+) acceptor**. An **alkali** is a **soluble base** (it forms OH^- ions in water). All alkalis are bases, but not all bases are alkalis (copper(II) oxide is a base that does not dissolve).

Acids	Bases and alkalis
Hydrochloric acid HCl , sulfuric acid H_2SO_4 , nitric acid HNO_3 , ethanoic acid CH_3COOH	Metal oxides and hydroxides, e.g. copper(II) oxide CuO , magnesium oxide MgO ; alkalis : sodium hydroxide $NaOH$, potassium hydroxide KOH , calcium hydroxide $Ca(OH)_2$, aqueous ammonia $NH_3(aq)$
pH below 7 ; turn blue litmus red ; sour; conduct electricity	pH above 7 ; turn red litmus blue ; feel soapy; conduct electricity (alkalis)



Universal Indicator colours: red (pH 0 to 2), orange (3 to 4), yellow (5), green (6 to 7), blue (8 to 10), purple (11 to 14).

Figure C10.1 The pH scale with Universal Indicator colours. Only whole-number pH values are used.

Reactions of acids

Acid reacts with...	Products	Example
A metal (above hydrogen in the reactivity series)	salt + hydrogen	$Mg + 2HCl \rightarrow MgCl_2 + H_2$
A base / alkali	salt + water (neutralisation)	$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$
A carbonate	salt + water + carbon dioxide	$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

Neutralisation is the reaction of an **acid with a base** to form a **salt and water**. In terms of ions: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. **Uses:** adding **lime** (calcium oxide or hydroxide) to **acidic soil** or lakes; **antacid** tablets for indigestion (neutralising excess stomach acid); treating **acidic industrial waste**; toothpaste neutralises mouth

acids; preparing **salts** in the laboratory.

Oxides

Type	Formed by	Behaviour	Examples
Basic	Metals	React with acids to form a salt and water	CuO, MgO, CaO, Na ₂ O
Acidic	Non-metals	React with alkalis; dissolve in water to give acid solutions	CO ₂ , SO ₂ , SO ₃ , NO ₂
Neutral	Some non-metals	React with neither acids nor alkalis	H ₂ O, CO, NO
Amphoteric	Some metals	React with both acids and alkalis	Al ₂ O ₃ , ZnO

Preparing salts

Preparing copper(II) sulfate crystals

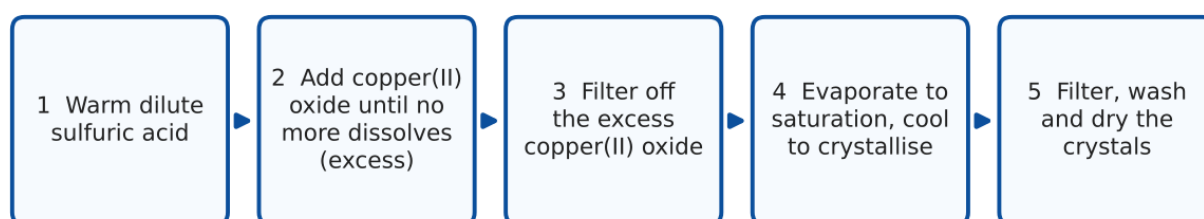


Figure C10.2 Preparing a soluble salt (copper(II) sulfate) from an insoluble base and an acid.

- **Soluble salt from an insoluble base, carbonate or metal:** add the solid in **excess** to warm acid, **filter** off the excess, evaporate the filtrate to the **saturation point**, **cool** to crystallise, then filter and dry.
- **Soluble salt from an alkali (e.g. NaOH or ammonia):** do a **titration** with an indicator to find the exact volumes, repeat **without indicator**, then evaporate to crystallise. Ammonium salts such as **ammonium sulfate** and **nitrate** are used as **fertilisers**.
- **Insoluble salts** are made by **precipitation**: mix two solutions that contain the ions, **filter** off the precipitate, **wash** it with distilled water and **dry** it. Example: $\text{Pb(NO}_3)_2\text{(aq)} + 2\text{KI(aq)} \rightarrow \text{PbI}_2\text{(s)} + 2\text{KNO}_3\text{(aq)}$ (yellow precipitate).

Salt type	Soluble	Insoluble
Nitrates	All	None
Chlorides	Most	Silver chloride, lead(II) chloride
Sulfates	Most	Barium sulfate, lead(II) sulfate (calcium sulfate slightly)
Carbonates	Sodium, potassium, ammonium	All others
Sodium, potassium and ammonium salts	All	None

Tests for ions

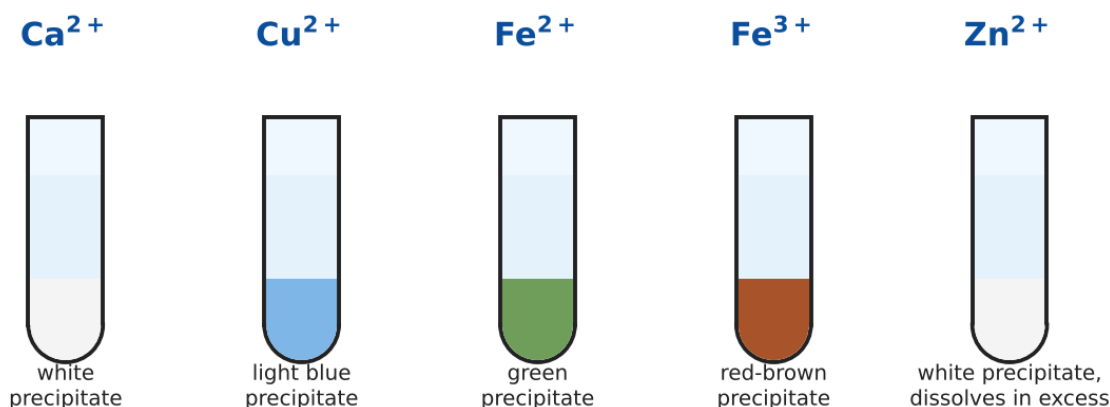


Figure C10.3 Precipitates formed when sodium hydroxide solution is added to solutions of metal ions.

Ion	Test	Positive result
Ammonium NH_4^+	Add NaOH solution and warm	Ammonia gas (pungent) turns damp red litmus blue
Calcium Ca^{2+} , zinc Zn^{2+}	Add NaOH solution, then excess	White precipitate. Zn²⁺ : precipitate dissolves in excess; Ca²⁺ : does not
Copper(II) Cu^{2+}	Add NaOH solution	Light blue precipitate (insoluble in excess)
Iron(II) Fe^{2+} and iron(III) Fe^{3+}	Add NaOH solution	Fe^{2+} : green precipitate; Fe^{3+} : red-brown precipitate
Carbonate CO_3^{2-}	Add dilute acid	Fizzing ; gas turns limewater milky
Chloride Cl^- , iodide I^-	Add dilute nitric acid then silver nitrate	Cl^- : white precipitate; I^- : yellow precipitate
Sulfate SO_4^{2-}	Add dilute hydrochloric (or nitric) acid then barium chloride (nitrate)	White precipitate
Nitrate NO_3^-	Add NaOH and aluminium foil , warm	Ammonia gas turns damp red litmus blue

Tests for gases

Gas	Test	Result
Carbon dioxide	Bubble through limewater	Turns milky (cloudy)
Hydrogen	Hold a lighted splint at the mouth of the tube	Squeaky pop
Oxygen	Insert a glowing splint	Relights
Ammonia	Hold damp red litmus paper	Turns blue
Chlorine	Hold damp litmus paper	Bleached white

Exercise C10: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C10.1** Define (a) an acid, (b) a base and (c) an alkali.
- C10.2** State the colour of Universal Indicator in (a) hydrochloric acid, pH 1, (b) pure water, (c) sodium hydroxide, pH 13.
- C10.3** Write a balanced equation for the reaction between magnesium and hydrochloric acid, and name the salt.
- C10.4** Write the ionic equation for neutralisation.
- C10.5** Explain why farmers add lime to acidic soil.
- C10.6** Classify as acidic, basic, neutral or amphoteric: CO_2 , CaO , CO , ZnO .
- C10.7** Describe how to make pure dry crystals of zinc sulfate from zinc oxide and sulfuric acid.
- C10.8** A white precipitate forms when sodium hydroxide is added to a solution and dissolves in excess. Name the ion.
- C10.9** Describe the tests that identify (a) sulfate ions, (b) chloride ions, (c) carbon dioxide gas.
- C10.10** Name the gas that gives a squeaky pop with a lighted splint and say what the test shows.

EXAM-STYLE QUESTION · C10 · [9 marks]

Copper(II) sulfate crystals are prepared by adding copper(II) oxide to warm dilute sulfuric acid.

- | | |
|---|-----|
| (a) State why the copper(II) oxide is added in excess. | [1] |
| (b) Describe how the excess copper(II) oxide is removed from the mixture. | [1] |
| (c) Describe how crystals of copper(II) sulfate are obtained from the filtrate. | [3] |
| (d) Write a balanced equation for the reaction. | [2] |
| (e) Describe a test that shows the solution contains copper(II) ions. | [2] |

C11 Metals

Syllabus reference: **C11.1 to C11.4**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Compare the **physical and chemical properties** of metals and non-metals.
- Place metals in the **reactivity series** and use displacement and other reactions to deduce an order.
- Describe how metals are **extracted** (including the **blast furnace** and **aluminium electrolysis**) and the importance of **conservation**.
- Define **alloys**, explain why they differ from pure metals, and state the **uses** of metals and alloys.

Property	Metals	Non-metals
Conduction of heat and electricity	Good conductors	Poor conductors (except graphite)
Appearance	Shiny (lustrous)	Dull
Strength / shape	Strong; malleable and ductile	Brittle when solid
Melting and boiling points	Usually high	Usually low
Density	Usually high	Usually low
Oxides	Basic oxides	Acidic (or neutral) oxides
Ions formed	Positive ions (lose electrons)	Negative ions (gain) or share electrons

The reactivity series

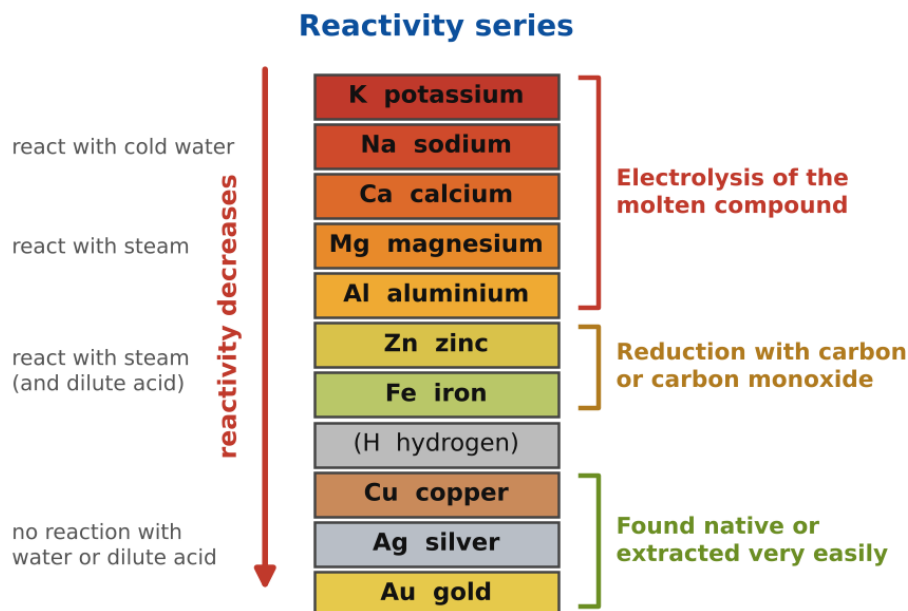


Figure C11.1 The reactivity series, with reactions and the methods used to extract each metal.

A **more reactive metal displaces a less reactive metal** from a solution of its salt: $\text{Zn(s)} + \text{CuSO}_4\text{(aq)} \rightarrow \text{ZnSO}_4\text{(aq)} + \text{Cu(s)}$ (blue solution fades; brown copper forms). The more reactive the metal, the **more vigorously** it reacts with water, steam, acid and oxygen. **Magnesium** burns in air with a bright white flame; **copper** does not react with dilute acid.

Why does aluminium appear unreactive? Aluminium is high in the series, but it is covered by a **thin, tough layer of aluminium oxide (Al_2O_3)** that sticks to the metal and **prevents further reaction**.

WORKED EXAMPLE: deducing an order of reactivity

Metals W, X, Y and Z were added to dilute hydrochloric acid. W fizzes rapidly, X fizzes slowly, Y has no reaction and Z fizzes very slowly after heating. **Order of reactivity (most to least): $W > X > Z > Y$** . To **design an experiment**, use the same size piece of each metal and the same volume and concentration of acid, and compare the **rate of bubbling or temperature rise**.

Extraction of metals

- The **ease of extraction** depends on a metal's position in the reactivity series. **Unreactive** metals are easy to obtain; reactive metals need **electrolysis**.
- Native** metals (found uncombined in the ground): **gold** and **copper** (also silver).
- Main ores: aluminium:** bauxite (Al_2O_3); **iron:** haematite (Fe_2O_3); **copper:** copper pyrites (CuFeS_2) and malachite ($\text{CuCO}_3 \cdot \text{Cu(OH)}_2$).

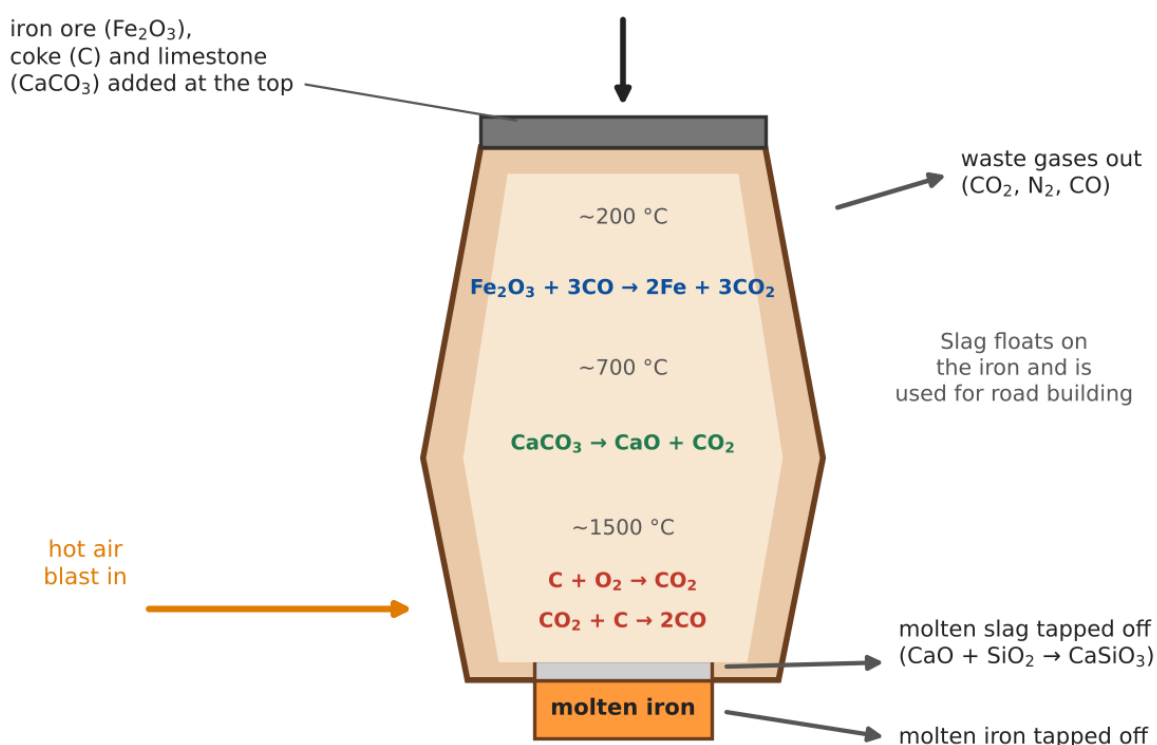


Figure C11.2 The blast furnace used to extract iron from haematite.

Blast furnace reactions. (1) **Coke burns** in the hot air blast: $\text{C} + \text{O}_2 \rightarrow \text{CO}_2$ (exothermic: heats the furnace). (2) The carbon dioxide is **reduced** to carbon monoxide: $\text{CO}_2 + \text{C} \rightarrow 2\text{CO}$. (3) **Carbon monoxide reduces the iron(III) oxide** to iron: $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$. (4) **Limestone** decomposes: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$, and the calcium oxide combines with **silica (sand) impurities** to form **slag**: $\text{CaO} + \text{SiO}_2 \rightarrow \text{CaSiO}_3$. Molten iron and slag run out at the bottom; the slag floats on top of the iron.

Aluminium is made by the **electrolysis of pure aluminium oxide dissolved in molten cryolite**. Cryolite **lowers the melting point** (from over 2000 °C to about 900 °C), which saves energy. **Carbon (graphite) electrodes** are used. At the **cathode (-)**: $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$. At the **anode (+)**: $2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$. The oxygen reacts with the hot carbon anodes to form carbon dioxide, so the anodes **burn away** and must be replaced.

Conservation and the environment

- Metal ores are **finite resources**, so **recycling** and reusing metals **conserves ores** and saves energy.
- **Mining and extraction** can destroy **vegetation** and habitats, produce **dust and noise** that harm **human health**, pollute rivers and soil (poisoning **animals**), leave waste heaps, and release **carbon dioxide and sulfur dioxide**.

Alloys

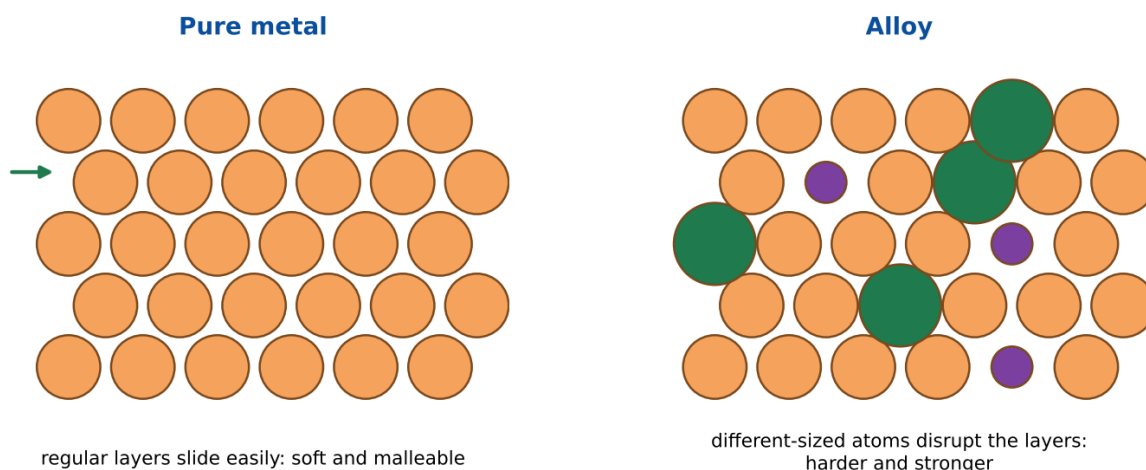


Figure C11.3 In a pure metal the layers of identical atoms slide easily. In an alloy, atoms of different sizes stop the layers sliding.

CORE CONCEPT

An **alloy** is a **mixture of a metal with one or more other elements** (usually other metals). Alloys are **harder and stronger** than pure metals because the **different-sized atoms disrupt the regular layers**, so the layers cannot slide over each other easily.

Alloy	Composition	Important uses
Brass	Copper and zinc	Musical instruments, door handles, electrical fittings
Bronze	Copper and tin	Statues, bells, medals, ship propellers
Mild steel	Iron with a small amount of carbon (about 0.25%)	Car bodies, buildings, bridges, machinery
Stainless steel	Iron, chromium and nickel (with carbon)	Cutlery, kitchen sinks, surgical instruments, chemical plant

- **Aluminium:** electrical cables (low density, good conductor), **aircraft bodies** (low density, strong as an alloy), **food containers** (non-toxic, resists corrosion).
- **Copper:** **electrical wiring** (very good conductor, ductile), **cooking utensils** (good conductor of heat, unreactive).
- **Zinc:** **galvanising** iron to stop rusting, and making **brass**.

Exercise C11: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C11.1** State three physical properties that are typical of metals.
- C11.2** Put these metals in order of reactivity (most reactive first): copper, magnesium, sodium, iron, zinc.
- C11.3** Write a word equation and describe what you see when a piece of zinc is placed in copper(II) sulfate solution.
- C11.4** Explain why aluminium does not react with water or air as expected from its position in the reactivity series.
- C11.5** Name the three raw materials added to the top of a blast furnace and state the purpose of each.
- C11.6** Write the equation for the reduction of iron(III) oxide in the blast furnace.
- C11.7** Why is cryolite added in the extraction of aluminium?
- C11.8** Give two reasons why alloys are often more useful than pure metals.
- C11.9** Explain, using atoms, why alloys are harder than pure metals.
- C11.10** State the uses of (a) copper, (b) zinc, (c) bronze.

EXAM-STYLE QUESTION · C11 · [10 marks]

Iron is extracted from its ore, haematite (iron(III) oxide), in a blast furnace.

- (a) Name **two** other raw materials, apart from haematite, that are added to the blast furnace. [2]
- (b) Write a balanced equation for the reaction in which iron(III) oxide is reduced to iron by carbon monoxide. [2]
- (c) Explain how the limestone helps to remove the sand (silicon dioxide) impurity. [3]
- (d) Mild steel is an alloy of iron. State what is meant by an alloy and one use of mild steel. [2]
- (e) Suggest one environmental problem caused by mining iron ore. [1]

C12 Electricity and Chemistry

Syllabus reference: **C12.1 to C12.11**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe **electrolysis** and draw a labelled **electrolytic cell**.
- Distinguish between **molten** and **aqueous** electrolytes and predict the **products**.
- Write **electrode equations**, including those for the manufacture of **aluminium, chlorine and sodium hydroxide**.
- Describe **electroplating**.

CORE CONCEPT

Electrolysis is the **breaking down of an ionic compound, when molten or in aqueous solution, by passing an electric current through it**. The compound that is broken down is the **electrolyte**. The conducting rods that carry the current in and out are the **electrodes**: the **anode** is the **positive** electrode and the **cathode** is the **negative** electrode.

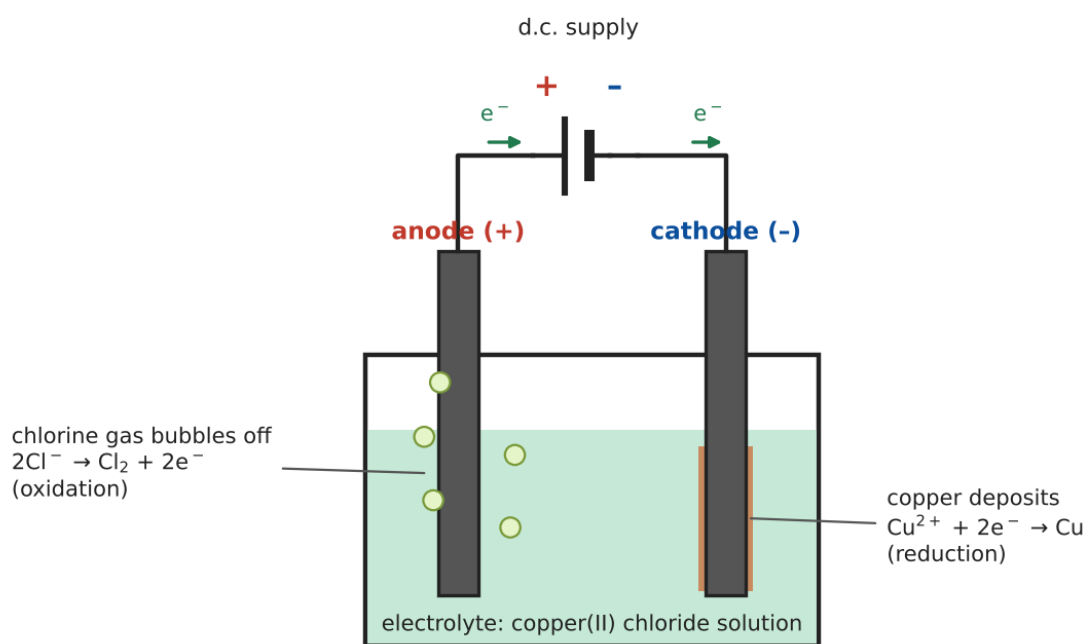


Figure C12.1 An electrolytic cell for the electrolysis of aqueous copper(II) chloride using inert graphite electrodes.

- The electrolyte conducts because its **ions are free to move**. **Positive ions (cations)** move to the **cathode**; **negative ions (anions)** move to the **anode**.
- At the **cathode** ions **gain electrons (reduction)**. At the **anode** ions **lose electrons (oxidation)**.
- General principle: metals or hydrogen** are formed at the **negative electrode (cathode)**; **non-metals** such as **oxygen or the halogens** are formed at the **positive electrode (anode)**.
- A **molten** compound contains **only the ions of that compound**. An **aqueous solution** also contains **H⁺ and OH⁻** ions from water, so there is a **choice** of ions at each electrode.

Electrolyte	At the cathode (-)	At the anode (+)
Molten lead(II) bromide	$\text{Pb}^{2+} + 2\text{e}^- \rightarrow \text{Pb}$ (lead metal)	$2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{e}^-$ (bromine)

Electrolyte	At the cathode (–)	At the anode (+)
Aqueous copper(II) chloride (inert electrodes)	$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$ (copper)	$2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$ (chlorine)
Concentrated aqueous sodium chloride (brine)	$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ (hydrogen)	$2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$ (chlorine)
Dilute sulfuric acid (electrolysis of water)	$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$	$4\text{OH}^- \rightarrow 2\text{H}_2\text{O} + \text{O}_2 + 4\text{e}^-$
Molten aluminium oxide in cryolite	$\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$	$2\text{O}^{2-} \rightarrow \text{O}_2 + 4\text{e}^-$

Predicting the products

- **Molten binary compound:** the **metal** forms at the cathode and the **non-metal** at the anode.
- **Aqueous solution, at the cathode:** a metal **below hydrogen** in the reactivity series (e.g. copper, silver) is deposited. A metal **above hydrogen** (e.g. sodium, potassium) stays as ions, and **hydrogen** is formed instead.
- **Aqueous solution, at the anode:** **chloride, bromide and iodide** ions give the **halogen**. If no halide is present (e.g. sulfates, nitrates), **hydroxide ions are discharged** and **oxygen** forms.

Electrolysis of dilute sulfuric acid is really the electrolysis of **water**: $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2$. **Hydrogen collects at the cathode and oxygen at the anode in a 2 : 1 volume ratio.**

Manufacture of chlorine and sodium hydroxide. Concentrated sodium chloride solution (brine) is electrolysed. **Chlorine** forms at the anode, **hydrogen** at the cathode, and **sodium hydroxide solution** is left behind (from the Na^+ and OH^- ions). The three products are all useful: chlorine for water treatment and bleach, sodium hydroxide for soap and paper, hydrogen as a fuel and for making ammonia.

Electroplating

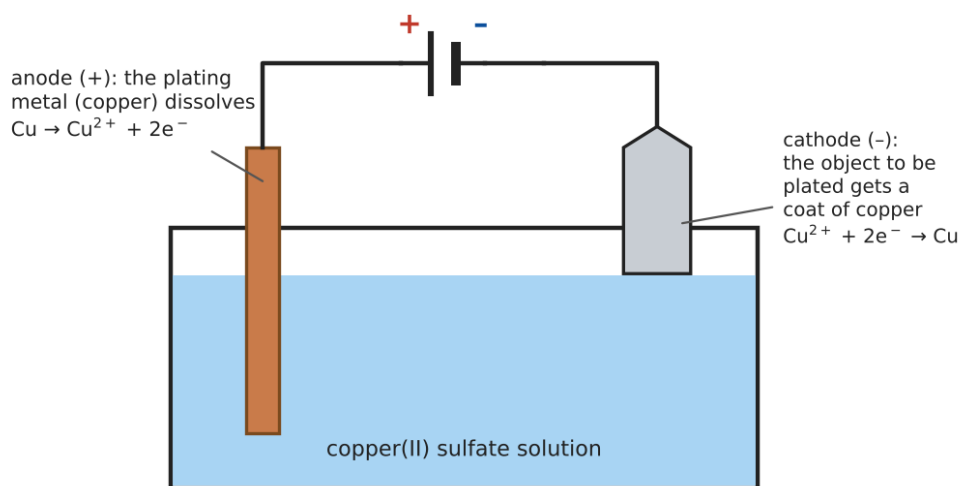


Figure C12.2 Electroplating a key with copper. The key is the cathode and the plating metal is the anode.

Electroplating coats a metal object with a thin layer of another metal using electrolysis. The **object to be plated is the cathode**, the **plating metal is the anode** and the **electrolyte is a solution of a salt of the plating metal**. It is used to **protect from corrosion** and to **improve appearance** (e.g. chromium on car bumpers, silver-plated cutlery, tin-plated food cans). The anode dissolves and the cathode grows, so the concentration of the electrolyte stays constant.

EXAM TIP

Use **OIL RIG** to check electrode equations: at the **anode** electrons are **lost** (oxidation) and appear on the **right-hand side**; at the **cathode** electrons are **gained** and appear on the **left-hand side**.

Exercise C12: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C12.1** Define electrolysis and name the electrode where oxidation happens.
- C12.2** Why can ionic compounds conduct electricity when molten but not when solid?
- C12.3** What is the difference between a molten compound and an aqueous solution as an electrolyte?
- C12.4** Name the products at each electrode when molten lead(II) bromide is electrolysed.
- C12.5** Write the electrode equations for the electrolysis of aqueous copper(II) chloride.
- C12.6** Explain why hydrogen, and not sodium, is formed at the cathode when sodium chloride solution is electrolysed.
- C12.7** Name the three products of the electrolysis of concentrated sodium chloride solution and give a use of each.
- C12.8** Why do the carbon anodes have to be replaced in the manufacture of aluminium?
- C12.9** A steel spoon is to be silver-plated. State which electrode the spoon is, what the anode is made of, and the electrolyte.

EXAM-STYLE QUESTION · C12 · [10 marks]

A teacher electrolyses aqueous copper(II) sulfate solution using copper electrodes and then using inert graphite electrodes.

- (a) Name the products formed at each graphite electrode. [2]
- (b) State what the teacher sees happening to the blue colour of the solution when graphite electrodes are used, and explain why. [2]
- (c) Write an equation for the reaction at the cathode. [1]
- (d) With copper electrodes, state what happens to the mass of the anode and to the colour of the solution. [2]
- (e) Describe how this method could be used to copper-plate a steel key. [3]

C13 Non-metals

Syllabus reference: **C13.1 to C13.7**

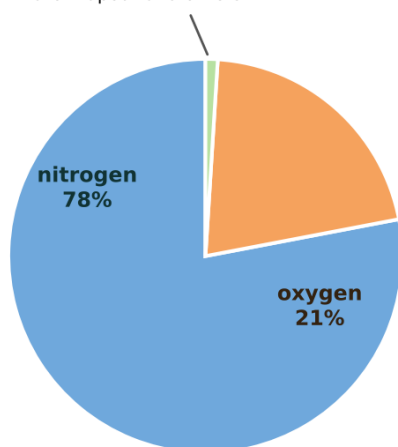
BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the **composition of air**, its **separation**, **air pollutants**, **global warming** and the **ozone layer**.
- Describe **hard and soft water** and how **water is purified**.
- Describe the **preparation, properties and uses** of hydrogen, oxygen and carbon dioxide.
- Describe **rusting**, the **Haber process**, **fertilisers**, **allotropes of carbon** and the **limestone industry**.

C13.1 Air and pollution

Composition of dry air by volume

argon 0.9%, carbon dioxide 0.04%,
water vapour and others



Fractional distillation of liquid air

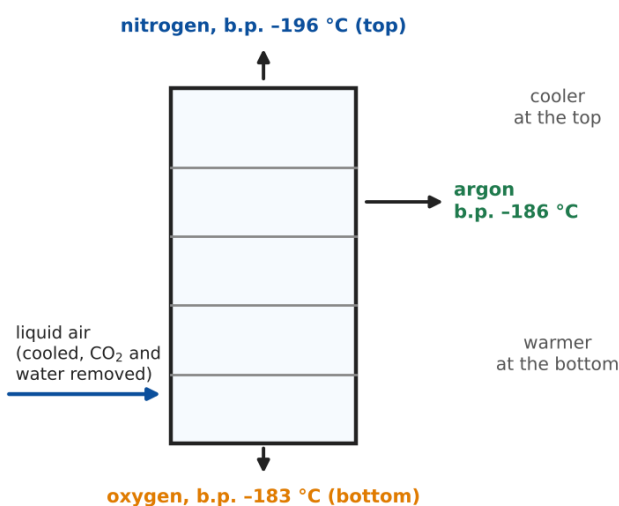


Figure C13.1 Air is a mixture of gases, separated by fractional distillation of liquid air.

Dry air is **78% nitrogen**, **21% oxygen**, about **0.9% argon** and **0.04% carbon dioxide**. To separate them, air is **filtered, cooled and compressed** until it becomes **liquid** (carbon dioxide and water are removed first because they freeze). The liquid air is warmed in a **fractionating column** and the gases boil off at their **different boiling points**: **nitrogen (-196 °C)** first, then **argon (-186 °C)**, and **oxygen (-183 °C)** last. Uses: nitrogen (making ammonia, freezing food), oxygen (hospitals, welding), argon (lamps).

Pollutant	Source	Harmful effect
Carbon monoxide CO	Incomplete combustion of fuels, car exhausts	Poisonous : combines with haemoglobin so blood carries less oxygen
Sulfur dioxide SO ₂	Burning fossil fuels containing sulfur ; volcanoes	Acid rain : damages buildings (limestone, marble), kills plants and fish; causes breathing problems
Oxides of nitrogen NO _x	Car engines (air heated to high temperature), lightning	Acid rain; breathing problems; smog
Lead compounds	Leaded petrol	Damage the brain and nervous system, especially in children
CFCs (chlorofluorocarbons)	Old aerosols and refrigerators	Destroy the ozone layer , so more UV reaches the Earth (skin cancer, crop damage)

- Catalytic converters** in car exhausts contain **platinum, palladium and rhodium**. They change **carbon monoxide and oxides of nitrogen** into harmless **carbon dioxide and nitrogen**: $2\text{CO} + 2\text{NO} \rightarrow 2\text{CO}_2 + \text{N}_2$

N_2 .

- **Global warming:** carbon dioxide (and methane) in the atmosphere **absorbs infra-red radiation** from the Earth's surface and traps heat (the **greenhouse effect**). Burning fossil fuels and cutting down forests increases CO_2 , causing **rising global temperatures**, melting ice and sea-level rise.
- **Ozone** high in the atmosphere **absorbs harmful ultraviolet (UV) radiation** from the Sun, protecting living things.

C13.2 Water

- **Test for water:** it turns **anhydrous copper(II) sulfate** from white to blue, or **blue cobalt(II) chloride paper** to pink.
- **Hard water** contains dissolved **calcium (Ca^{2+})** and **magnesium (Mg^{2+})** ions. It does not lather easily with soap and forms **scum**. **Soft water** has few or none of these ions and lathers easily.
- **Temporary hardness** is caused by **calcium hydrogencarbonate** and is removed by **boiling** (calcium carbonate **scale** forms). **Permanent hardness** is caused by **calcium or magnesium sulfate/chloride** and is **not removed by boiling**.
- **Softening:** **boiling** (temporary hardness only), **distillation**, adding **washing soda (sodium carbonate)**, or an **ion exchanger** that swaps Ca^{2+} and Mg^{2+} for sodium or hydrogen ions.
- **Advantages of hard water:** calcium helps **teeth and bones** and may reduce heart disease; it tastes better. **Disadvantages:** wastes **soap**, forms **scum**, and produces **scale** in kettles, boilers and pipes, which wastes energy and blocks pipes.
- **Purifying water:** **screening and filtration** (remove solids), **sedimentation** (suspended particles settle, helped by adding aluminium sulfate), then **chlorination** (chlorine **kills bacteria**).

C13.3 to C13.5 Hydrogen, oxygen and carbon dioxide

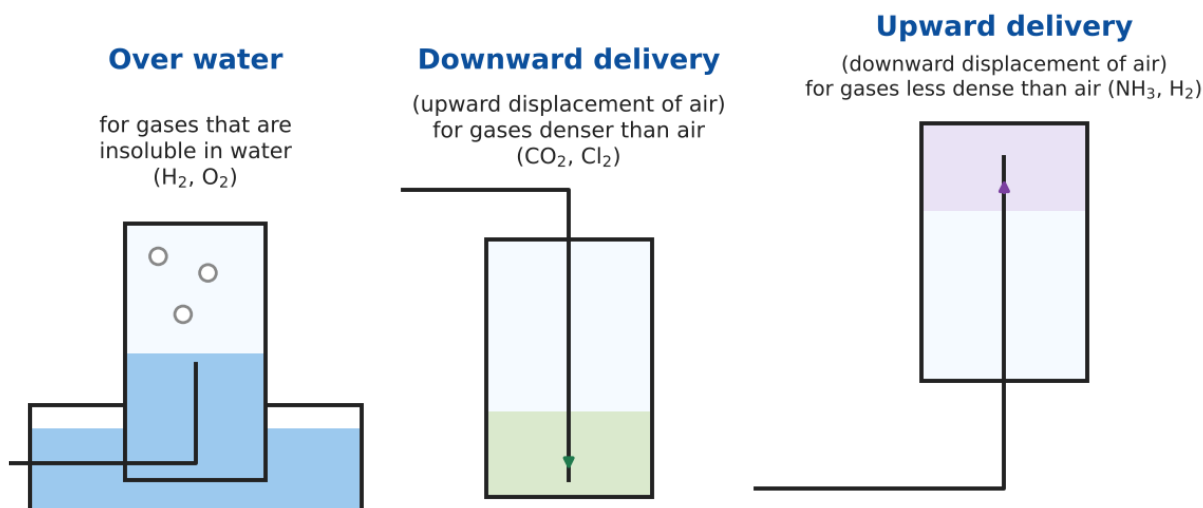


Figure C13.2 Three ways of collecting a gas.

	Hydrogen H_2	Oxygen O_2	Carbon dioxide CO_2
Preparation	Zinc (or magnesium) + dilute hydrochloric acid: $Zn + 2HCl \rightarrow ZnCl_2 + H_2$	Hydrogen peroxide + manganese(IV) oxide catalyst : $2H_2O_2 \rightarrow 2H_2O + O_2$; or heat potassium manganate(VII)	Marble chips + dilute hydrochloric acid: $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$
Collection	Over water, or upward delivery (less dense than air)	Over water	Downward delivery (denser than air)

	Hydrogen H ₂	Oxygen O ₂	Carbon dioxide CO ₂
Properties	Colourless, odourless, least dense gas , flammable; burns with a squeaky pop	Colourless, odourless, slightly soluble; supports combustion ; relights a glowing splint	Colourless, odourless, denser than air , slightly soluble (weak acid); does not support combustion ; limewater turns milky
Uses	Making ammonia , margarine (hardening oils), rocket fuel	Oxygen tents and hospitals , welding with acetylene, steel making	Fire extinguishers , fizzy drinks , dry ice for cooling

Hydrogen is also formed at the cathode when **water is electrolysed**. **Combustion of elements in oxygen**: magnesium burns with a **brilliant white flame** to form magnesium oxide; sulfur burns with a blue flame forming sulfur dioxide; carbon forms carbon dioxide. **Carbon dioxide** is formed by **complete combustion** of carbon-containing fuels, by **respiration**, and when an **acid reacts with a carbonate**.

Respiration, combustion and rusting

- **Respiration**: glucose + oxygen → carbon dioxide + water (**energy released** in living cells).
- **Combustion**: a fuel burns in oxygen, releasing heat and light.
- **Rusting**: iron reacts with **oxygen and water** to form **hydrated iron(III) oxide (rust)**.

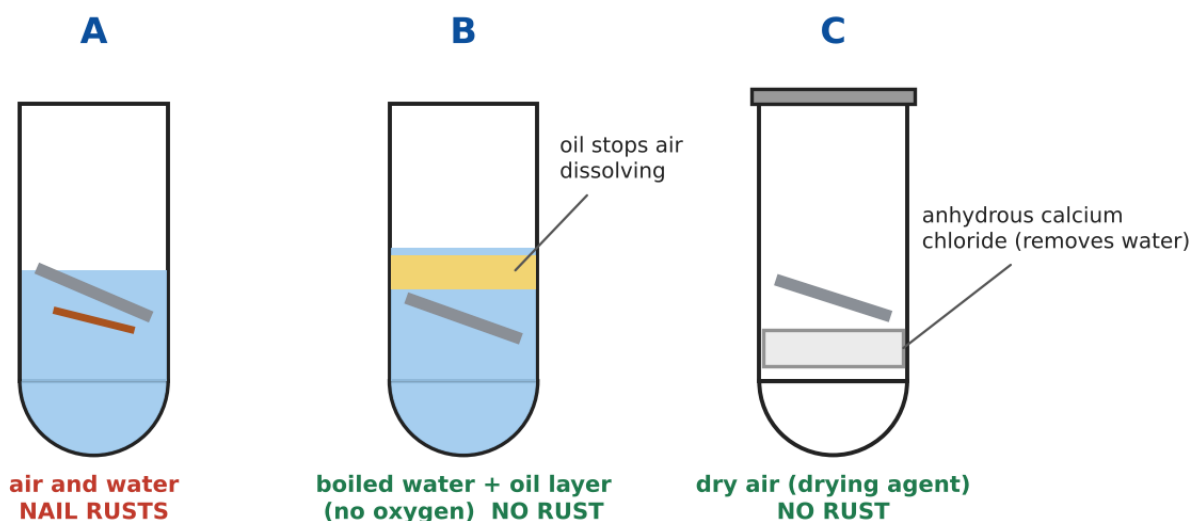


Figure C13.3 Investigating the conditions necessary for rusting: both air (oxygen) and water are needed.

Preventing rusting: keep out **oxygen and water** with **paint, oil/grease or plastic coatings**; **galvanising** (coating with zinc); tin-plating. **Sacrificial protection**: a **more reactive metal (zinc or magnesium)** is attached to iron. It **corrodes in preference to the iron** ($\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$), so the iron is protected even if the coating is scratched. It is used on ship hulls, pipelines and galvanised roofs.

C13.6 Nitrogen, ammonia and fertilisers

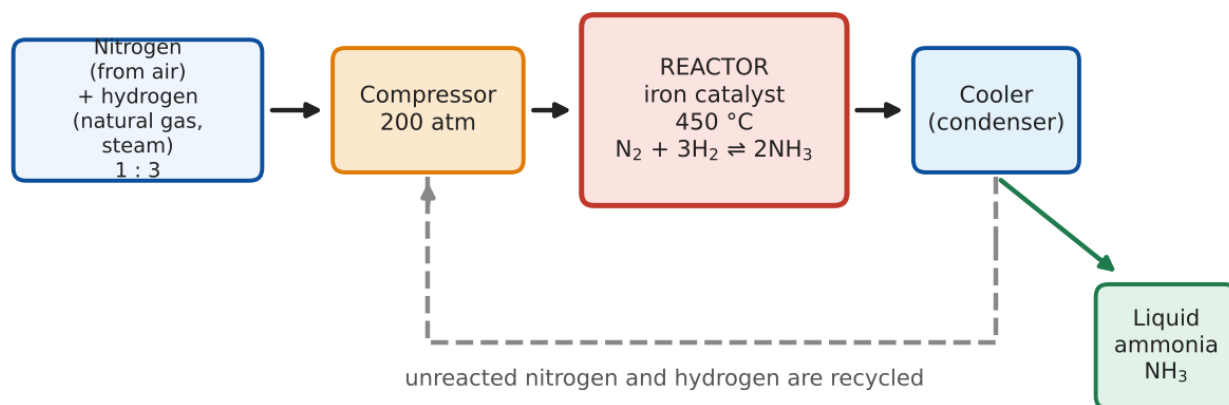


Figure C13.4 The Haber process for making ammonia.

Haber process: $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$ (reversible and exothermic). **Conditions:** iron catalyst, about 450 °C and about 200 atmospheres. Nitrogen comes from the air; hydrogen from natural gas (methane) and steam. Ammonia is condensed to a liquid and removed; unreacted nitrogen and hydrogen are **recycled**.

Condition	Reason
High pressure (200 atm)	Four gas molecules become two, so a high pressure increases the yield and the rate (but very high pressure is expensive and dangerous)
Moderate temperature (450 °C)	A lower temperature would give a higher yield (exothermic) but the reaction would be too slow ; 450 °C is a compromise between rate and yield
Iron catalyst	Speeds up the reaction; it does not change the yield

Uses of ammonia: making **fertilisers** (ammonium sulfate, ammonium nitrate) and **nitric acid**. Plants need **nitrogen** (healthy leaves and stems; for making proteins), **phosphorus** (roots and early growth) and **potassium** (flowers, fruit and disease resistance). **NPK fertilisers** supply all three.

C13.7 Carbon, limestone and carbonates

- Allotropy** is the **existence of an element in two or more different forms in the same physical state**, with different arrangements of atoms. The allotropes of carbon are **diamond, graphite and graphene** (see C7).
- Limestone** (calcium carbonate) is decomposed in a **lime kiln at about 900 to 1000 °C**: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. Calcium oxide is **quicklime**; adding water gives **slaked lime**: $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2$.
- Uses:** lime and slaked lime **neutralise acidic soil** and **acidic industrial waste**; limestone is used in the **blast furnace** (to remove silica), in making **glass** (with sand and sodium carbonate) and in making **cement** (with clay).
- Ease of decomposition of metal carbonates:** the **more reactive** the metal, the **more stable** its carbonate. Sodium and potassium carbonates do **not** decompose with a Bunsen flame; calcium, magnesium, zinc and **copper(II) carbonate** do ($\text{green CuCO}_3 \rightarrow \text{black CuO} + \text{CO}_2$).

Exercise C13: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- C13.1** State the percentage composition of dry air (nitrogen, oxygen, others).
- C13.2** Explain how nitrogen and oxygen are separated from liquid air.
- C13.3** Name two air pollutants, one source of each and one harmful effect.
- C13.4** State what a catalytic converter does and the metals it contains.
- C13.5** Describe the test for water.
- C13.6** Explain the difference between temporary and permanent hardness and how each is removed.
- C13.7** Describe how hydrogen is made in the laboratory and give the test.
- C13.8** Give the conditions in the Haber process and explain why a compromise temperature is used.
- C13.9** Explain how galvanising protects iron from rusting.
- C13.10** Write equations for (a) the decomposition of limestone, (b) the reaction of quicklime with water.

EXAM-STYLE QUESTION · C13 · [9 marks]

Iron nails are placed in three test tubes: A (air and water), B (boiled water covered by a layer of oil) and C (dry air with anhydrous calcium chloride). The tubes are left for one week.

- | | |
|--|-----|
| (a) State in which tube(s) the nail rusts. | [1] |
| (b) Explain why the nails in B and C do not rust. | [2] |
| (c) State the two substances needed for rusting. | [2] |
| (d) Describe two ways of preventing iron from rusting. | [2] |
| (e) Explain why a block of zinc attached to the hull of a steel ship protects the ship even when the paint is scratched. | [2] |

C14 Organic Chemistry

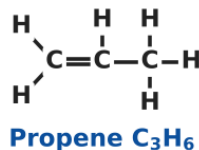
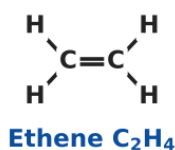
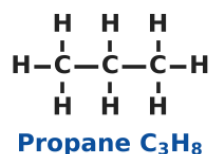
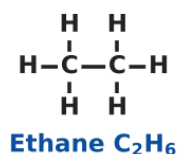
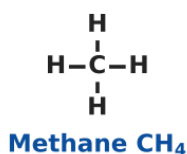
Syllabus reference: **C14.1 to C14.9**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Name and draw **alkanes, alkenes, alcohols and carboxylic acids** (up to six carbons) and distinguish molecular and structural formulae.
- Describe **petroleum**, its **fractional distillation**, and the **uses and hazards of the fractions**.
- Describe **homologous series, cracking**, and the properties and reactions of **alkanes, alkenes, ethanol and ethanoic acid**.
- Describe **addition and condensation polymers**, and the problems caused by **non-biodegradable plastics**.

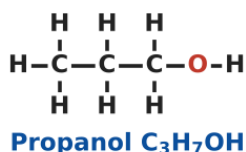
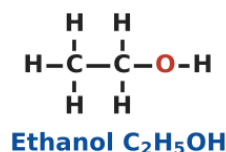
Organic chemistry is the study of **carbon compounds**. A **hydrocarbon** contains **only carbon and hydrogen**. Organic compounds belong to **homologous series**, which are families of compounds with **the same general formula and similar chemical properties** because they contain the same **functional group** (the atom or group that decides the chemical properties).

Homologous series	Ending	General formula	Functional group	First members
Alkanes	-ane	C_nH_{2n+2}	C–C single bonds only (saturated)	methane CH_4 , ethane C_2H_6 , propane C_3H_8 , butane C_4H_{10} , pentane C_5H_{12} , hexane C_6H_{14}
Alkenes	-ene	C_nH_{2n}	C=C double bond (unsaturated)	ethene C_2H_4 , propene C_3H_6 , butene C_4H_8
Alcohols	-ol	$C_nH_{2n+1}OH$	–OH	methanol CH_3OH , ethanol C_2H_5OH , propanol C_3H_7OH
Carboxylic acids	-oic acid	$C_nH_{2n+1}COOH$	–COOH	methanoic acid $HCOOH$, ethanoic acid CH_3COOH , propanoic acid C_2H_5COOH



Alkanes (top row): only single bonds, saturated.
Alkenes (bottom row): contain a C=C double bond, unsaturated.

Figure C14.1 Structural (displayed) formulae of alkanes and alkenes.



Alcohols: -OH group
 Carboxylic acids: -COOH group
 Esters: -COO- linkage

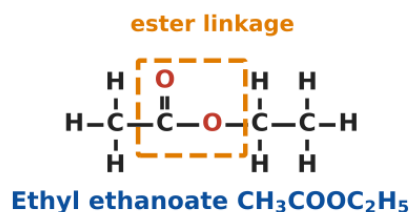
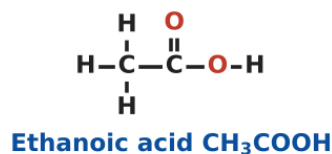


Figure C14.2 Structural formulae of alcohols, a carboxylic acid and an ester.

The **molecular formula** shows the **number of each kind of atom** (e.g. C_2H_6). The **structural formula** shows **how the atoms are arranged** (CH_3CH_3), and a **displayed formula** shows **every bond**. A **homologous series** has these characteristics: the **same general formula**, **similar chemical properties**, a **gradual change in physical properties** (melting and boiling points increase with chain length), and **each member differs from the next by CH_2** .

Fuels and petroleum

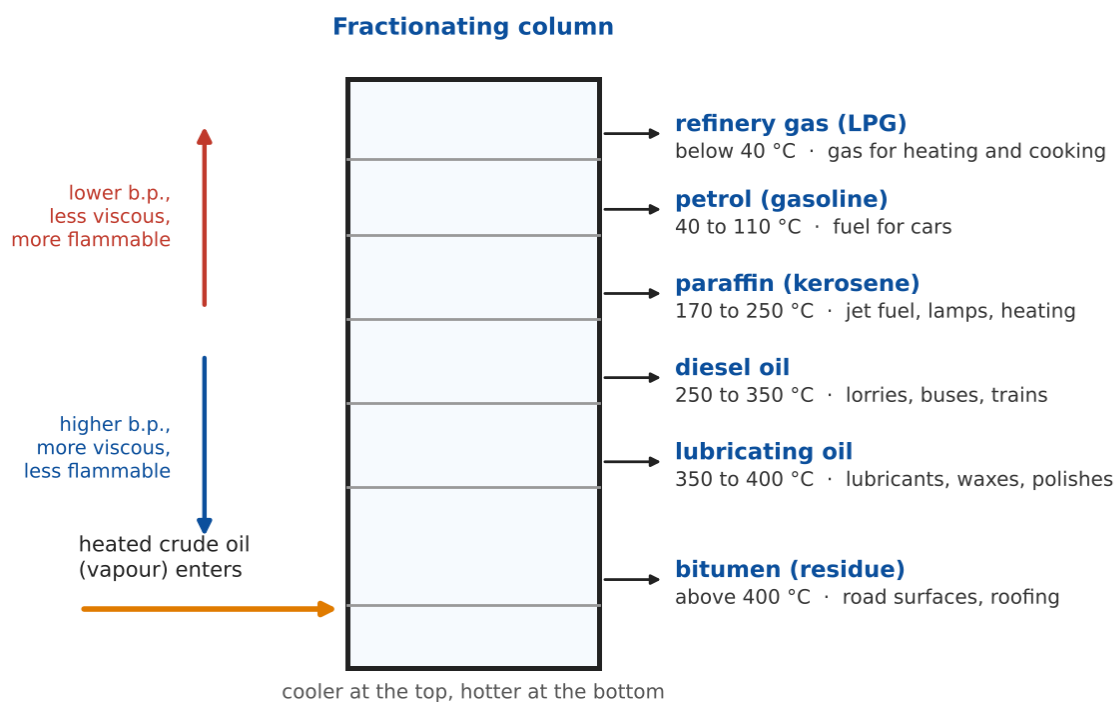


Figure C14.3 Fractional distillation of petroleum (crude oil).

The fossil fuels are **coal**, **natural gas** and **petroleum**. **Methane** is the main constituent of **natural gas**. **Petroleum** is a **mixture of hydrocarbons**, separated in a **fractionating column** into **fractions** with different boiling-point ranges. **Hazards:** the fractions are **flammable** (fires and explosions); burning them produces

carbon dioxide (global warming), **carbon monoxide** (toxic), **sulfur dioxide** (acid rain) and **soot**; **oil spills** damage marine life, birds and coastlines.

Alkanes and alkenes

- **Alkanes are saturated and fairly unreactive.** They **burn** completely in plenty of air: $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$; in a limited supply of air, incomplete combustion forms **carbon monoxide** and **soot**. They also react with chlorine in ultraviolet light (**substitution**): $\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}$.
- **Trends in alkanes:** as the chain gets **longer**, the **melting point, boiling point and density increase** (stronger forces between larger molecules), and the state changes from **gas (C_1 to C_4) to liquid to solid**. Predict the structure of a longer alkane from $\text{C}_n\text{H}_{2n+2}$: octane ($n = 8$) is C_8H_{18} .
- **Cracking breaks long-chain alkanes into shorter alkanes and alkenes** (and sometimes hydrogen) using **heat, or a hot catalyst (about 500 °C, aluminium oxide or silica)**. Example: $\text{C}_{10}\text{H}_{22} \rightarrow \text{C}_8\text{H}_{18} + \text{C}_2\text{H}_4$. It is important because it gives **more petrol** (high demand) and **alkenes for making plastics and alcohol**.
- **Alkenes are unsaturated and more reactive.** They undergo **addition reactions** across the $\text{C}=\text{C}$ bond: with **bromine** ($\text{C}_2\text{H}_4 + \text{Br}_2 \rightarrow \text{C}_2\text{H}_4\text{Br}_2$), with **hydrogen** (nickel catalyst: $\text{C}_2\text{H}_4 + \text{H}_2 \rightarrow \text{C}_2\text{H}_6$) and with **steam** (phosphoric acid catalyst, high temperature and pressure: $\text{C}_2\text{H}_4 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{H}_5\text{OH}$). They burn with a smoky flame.
- **Test to distinguish saturated from unsaturated:** shake with **bromine water**. An **alkene turns it from orange-brown to colourless**; an alkane does **not** change it.

Alcohols and carboxylic acids

- **Ethanol** is made by **(1) adding steam to ethene** (catalyst, about 300 °C, 60 atmospheres) and **(2) fermentation**: sugar (glucose) is broken down by **yeast enzymes**, in the **absence of air at about 25 to 35 °C**: $\text{C}_6\text{H}_{12}\text{O}_6 \rightarrow 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2$. Fermentation is important in **making wine and beer** and in producing fuel ethanol from **sugar cane**.
- **Properties of ethanol:** it **burns** ($\text{C}_2\text{H}_5\text{OH} + 3\text{O}_2 \rightarrow 2\text{CO}_2 + 3\text{H}_2\text{O}$) and can be **dehydrated** to ethene by passing the vapour over hot aluminium oxide. **Uses:** **solvent, fuel, sterilisation** (antiseptic), and **alcoholic drinks**. **Advantage as a fuel over petrol:** it is **renewable** (made from plant sugar) and burns more cleanly.
- **Ethanoic acid** forms when ethanol is **oxidised** by **acidified potassium dichromate(VI)** (orange to green) or by **bacteria in air** (wine turns to vinegar). It is a **weak acid** that reacts with metals, bases and carbonates like other acids.
- **Esters:** ethanoic acid reacts with ethanol (with concentrated sulfuric acid as a catalyst) to form **ethyl ethanoate** (an ester) and **water**: $\text{CH}_3\text{COOH} + \text{C}_2\text{H}_5\text{OH} \rightleftharpoons \text{CH}_3\text{COOC}_2\text{H}_5 + \text{H}_2\text{O}$. Esters are **sweet-smelling** and are used as **flavourings and perfumes**. The **ester linkage** is $-\text{COO}-$.

Macromolecules (polymers)

Addition polymerisation: poly(ethene)



Condensation polymerisation: nylon (and terylene)



monomers join by amide links ($-\text{CO}-\text{NH}-$) in nylon, or ester links ($-\text{COO}-$) in terylene, losing H_2O each time

Figure C14.4 Addition polymerisation of ethene and condensation polymerisation.

A **polymer** (macromolecule) is a **very large molecule built from many small repeating units called monomers**. **Synthetic** polymers: **poly(ethene)**, **nylon** (a polyamide) and **terylene** (a polyester). **Natural** polymers: **carbohydrates** (made from sugar units), **proteins** (amino acids) and **fats** (fatty acids and glycerol).

	Addition polymerisation	Condensation polymerisation
Monomers	Unsaturated (contain $\text{C}=\text{C}$), e.g. ethene	Contain two functional groups each, e.g. diamine + dicarboxylic acid (nylon); diol + dicarboxylic acid (terylene)
Products	Polymer only	Polymer + small molecule (water)
Links	Carbon-carbon chain	Amide $-\text{CO}-\text{NH}-$ (nylon, protein) or ester $-\text{COO}-$ (terylene, fats)
Example	$n \text{CH}_2=\text{CH}_2 \rightarrow -(\text{CH}_2-\text{CH}_2)_n-$	Nylon, terylene, proteins, carbohydrates, fats

Non-biodegradable plastics cannot be broken down by microorganisms, so they **remain in the environment** for hundreds of years: they **fill landfill sites**, **harm animals** that eat or are trapped by them, **block drains and waterways**, and give off **toxic gases** when burned. Recycling and using biodegradable materials reduce the problem.

Exercise C14: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

C14.1 Name the compounds (a) C_2H_6 , (b) C_3H_6 , (c) CH_3OH , (d) CH_3COOH .

C14.2 State the general formula of (a) alkanes and (b) alkenes, and give the molecular formula of the alkane with 7 carbons.

C14.3 Define a homologous series and give two characteristics.

C14.4 Describe how petroleum is separated, and name two fractions with their uses.

C14.5 Explain why cracking of long-chain alkanes is important.

C14.6 Write the equation for the complete combustion of ethane.

C14.7 Describe a test to distinguish ethene from ethane.

C14.8 Describe two methods of making ethanol and the conditions for each.

C14.9 Name the products when ethanoic acid reacts with ethanol, and state a use of the ester.

C14.10 State one difference between addition and condensation polymerisation, and explain why non-biodegradable plastics are a problem.

EXAM-STYLE QUESTION · C14 · [10 marks]

Ethene (C_2H_4) is made by cracking larger hydrocarbons obtained from petroleum.

- (a) Name the process used to separate petroleum into fractions. [1]
- (b) Explain what is meant by cracking, and why it is carried out. [3]
- (c) Draw the displayed formula of ethene. [1]
- (d) Describe what you would see when ethene is shaken with bromine water, and name the type of reaction. [2]
- (e) Ethene can be used to make poly(ethene). Name this type of reaction and explain why poly(ethene) causes environmental problems. [3]

PART B

Physics

Topics P1 to P15

P1 Measurement and Density

Syllabus reference: **P1.1 to P1.8**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Name **physical quantities and their SI units**, and use **rulers, vernier callipers, micrometers, clocks and balances**.
- Find the **volume of regular and irregular objects** (displacement method).
- Define and calculate **density**, and decide whether an object **floats or sinks**.
- Give answers to a suitable number of **significant figures**.

Physics is about measuring things carefully. A **physical quantity** is anything that can be measured; it is stated as a **number and a unit**. The **SI** (international) system uses **base units**; all other units are built from them.

Quantity	Symbol	SI unit	Unit symbol
Length	l, d, h	metre	m
Mass	m	kilogram	kg
Time	t	second	s
Temperature	T, θ	kelvin (kelvin scale) or degree Celsius	K, °C
Area	A	square metre	m^2
Volume	V	cubic metre	m^3 (also cm^3 , dm^3)
Density	ρ	kilogram per cubic metre	kg/m^3 (or g/cm^3)
Speed / velocity	v	metre per second	m/s

Prefixes: kilo (k) = 1000; centi (c) = 1/100; milli (m) = 1/1000; micro (μ) = 1/1 000 000. So 1 km = 1000 m, 1 m = 100 cm, 1 g = 0.001 kg, $1 \text{ m}^3 = 1\,000\,000 \text{ cm}^3$.

P1.2 to P1.5 Measuring instruments

Instrument	Use	Typical precision
Metre rule / tape	Length of everyday objects. Read with your eye directly above the mark to avoid parallax error .	1 mm
Vernier callipers	Outside and inside diameters, depth; main scale plus vernier scale.	0.1 mm (0.01 cm)
Micrometer screw gauge	Thickness of a wire or sheet; turn the ratchet so the object is not squeezed. Check for a zero error .	0.01 mm
Stopwatch / clock	Time intervals. To measure a pendulum period , time 20 oscillations and divide by 20 to reduce reaction-time error.	0.01 s (digital)
Balance	Mass of solids and liquids (find the mass of a liquid by subtracting the empty container).	0.1 g or better
Measuring cylinder	Volume of liquids; read the bottom of the meniscus at eye level.	1 cm^3

Volume of a regular solid: length $\times$ width $\times$ height (a cuboid), or $\pi r^2 h$ (a cylinder). **Volume of an irregular solid (displacement method):** the volume of liquid it pushes aside equals its own volume.

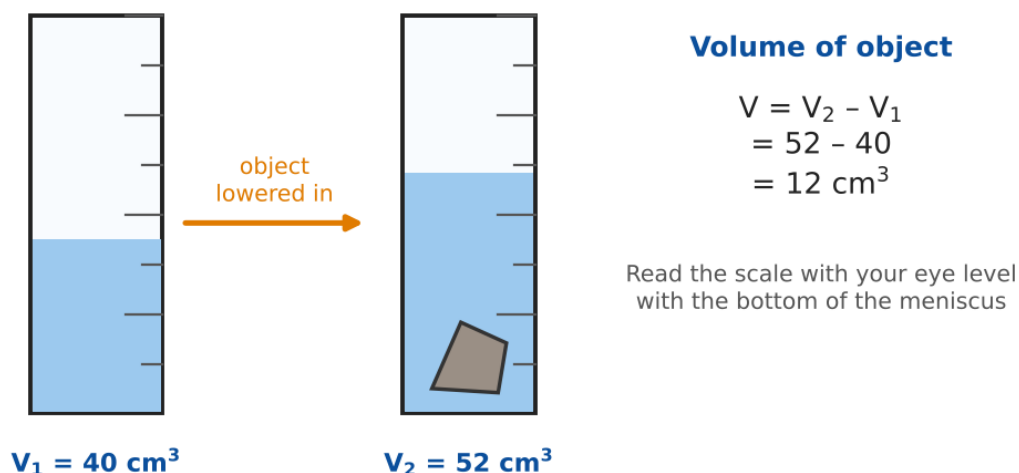


Figure P1.1 Finding the volume of an irregular object by displacement.

P1.6 and P1.7 Density

CORE CONCEPT

Density is the **mass per unit volume** of a substance. $\rho = m \div V$, so $m = \rho V$ and $V = m \div \rho$. Units: kg/m^3 or g/cm^3 . Water has a density of **1000 kg/m³** (1 g/cm³).

WORKED EXAMPLE: Density of a metal block

A metal block has a mass of **540 g** and measures 5.0 cm × 4.0 cm × 3.0 cm. **Volume** = 5.0 × 4.0 × 3.0 = **60 cm³**. **Density** = $m \div V = 540 \div 60 = \mathbf{9.0 \text{ g/cm}^3}$ (= 9000 kg/m³).

To find the density of a liquid: mass an empty measuring cylinder; add a known volume of liquid; mass again. Density = (mass of liquid) ÷ (volume). **To find the density of an irregular solid:** measure its mass on a balance and its volume by displacement, then divide.

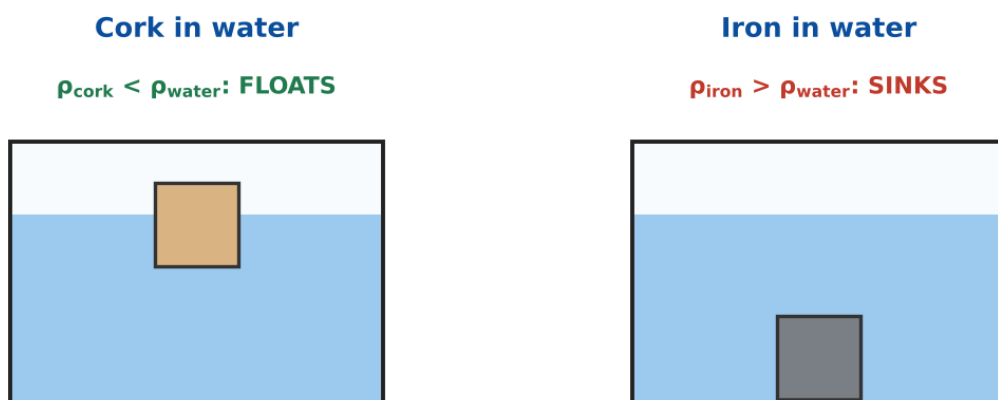


Figure P1.2 An object floats when its density is less than that of the liquid.

An object **floats** in a liquid if it has a **lower density** than the liquid, and **sinks** if its density is **higher**. Oil floats on water (lower density); iron sinks in water but floats on mercury.

P1.8 Significant figures

A result should not be given with more accuracy than the data allows. **Significant figures (s.f.)** are the digits from the first non-zero digit onward: **0.0452** has 3 s.f.; **3 050** has 3 s.f. (the last zero is not significant unless stated); **6.80** has 3 s.f. When you multiply or divide, give the answer to the **same number of s.f. as the least precise value** used. Example: $540 \div 60 = 9.0$ (2 s.f.).

EXAM TIP

Always **write the formula, substitute with units, then give the answer with its unit**. A numerical answer with no unit loses a mark.

Exercise P1: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P1.1** Convert (a) 2.5 km to m, (b) 450 g to kg, (c) 3.2 m^3 to cm^3 .
- P1.2** Name the best instrument for measuring the diameter of a thin wire.
- P1.3** A pendulum completes 20 oscillations in 32 s. Calculate its period.
- P1.4** Explain why timing 20 swings gives a more accurate period than timing one swing.
- P1.5** A stone raises the water level in a measuring cylinder from 50 cm^3 to 68 cm^3 . Its mass is 45 g. Calculate its volume and density.
- P1.6** Calculate the mass of 0.002 m^3 of mercury of density $13\,600 \text{ kg/m}^3$.
- P1.7** A block of wood floats in water but sinks in kerosene. Compare the density of wood with water and kerosene.
- P1.8** State the number of significant figures in (a) 0.0070, (b) 1250, (c) 4.05.
- P1.9** Round 0.0367 to 2 s.f. and 6.847 to 3 s.f.
- P1.10** Describe how to find the mass of 50 cm^3 of cooking oil.

EXAM-STYLE QUESTION · P1 · [7 marks]

A learner wants to find the density of an irregularly shaped piece of rock.

- (a) State the instrument used to measure the mass of the rock. [1]
- (b) Describe how the volume of the rock is found using a measuring cylinder and water. [3]
- (c) The mass is 156 g and the volume is 20 cm^3 . Calculate the density. [2]
- (d) Explain why the rock sinks in water. [1]

P2 Motion

Syllabus reference: **P2.1 to P2.11**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Define and use **speed, velocity and acceleration**; distinguish **scalar and vector** quantities.
- Draw and interpret distance–time and speed–time graphs**; find acceleration from a gradient and distance from an area.
- State that **$g = 10 \text{ m/s}^2$** and describe **free fall, air resistance and terminal velocity**.

CORE CONCEPT

Speed = distance $\div$ time ($v = d \div t$), unit **m/s**. **Average speed** = total distance $\div$ total time. **Velocity** is speed in a stated direction. Speed is a **scalar** (size only); velocity is a **vector** (size and direction). **Acceleration** is the rate of change of velocity: $a = (v - u) \div t$, unit **m/s²**.

Here **u** is the **initial velocity**, **v** the **final velocity** and **t** the **time taken**. A **negative acceleration (deceleration)** means the object is slowing down. A **vector** needs a direction, such as *10 m/s north*; a **scalar** does not, such as *10 m/s*.

WORKED EXAMPLE: Average speed and acceleration

A car travels **150 km** in **2.5 h**: average speed = $150 \div 2.5 = 60 \text{ km/h}$ (= 16.7 m/s). A cyclist speeds up from **2 m/s** to **10 m/s** in **4 s**: $a = (10 - 2) \div 4 = 2 \text{ m/s}^2$.

P2.5 to P2.7 Motion graphs

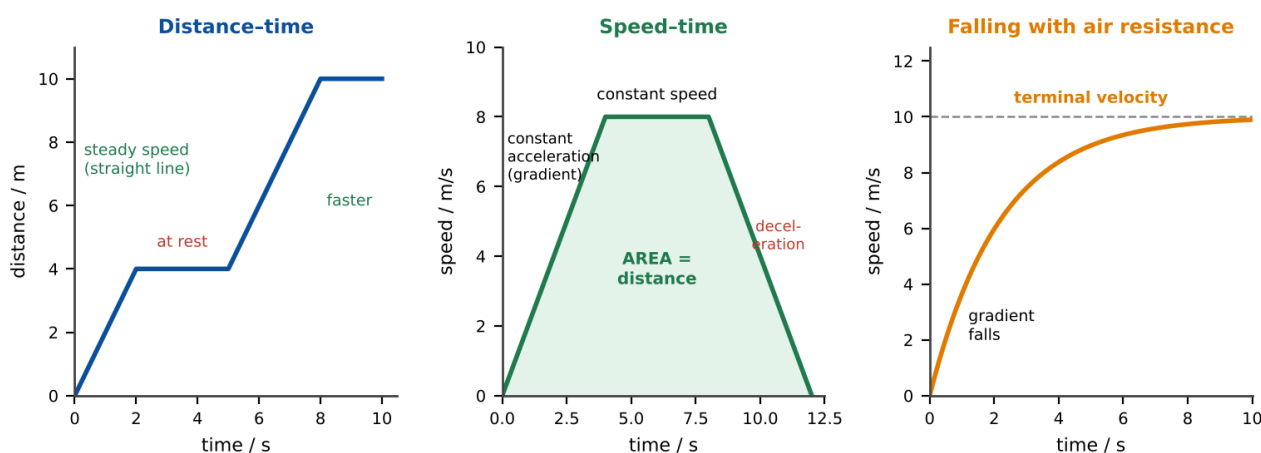


Figure P2.1 Distance–time and speed–time graphs.

Graph	What it shows	Gradient	Area under graph
Distance–time	Straight line = constant speed ; horizontal line = at rest ; steeper = faster ; curve = changing speed	Speed	Not used
Speed–time	Horizontal line = constant speed ; straight sloping line = constant acceleration ; line falling to zero = deceleration ; flat at zero = at rest	Acceleration	Distance travelled

WORKED EXAMPLE: Using a speed–time graph

A train accelerates uniformly from rest to **20 m/s in 10 s**, then moves at constant speed for **20 s**.

Acceleration = gradient = $20 \div 10 = 2 \text{ m/s}^2$. **Distance** = area: $\frac{1}{2} \times 10 \times 20 + 20 \times 20 = 100 + 400 = 500 \text{ m}$. For a trapezium: area = $\frac{1}{2} (a + b) \times h$.

EXAM TIP

On a speed–time graph, **read the gradient as acceleration and the area as distance**. On a distance–time graph the gradient is **speed**. Do **not** mix them up. A **curved** speed–time graph means the acceleration is **not constant**; a steeper curve means a larger acceleration at that time.

P2.8 to P2.11 Free fall and terminal velocity

Near the Earth, all objects falling freely (with no air resistance) have the **same constant acceleration** of free fall, **$g = 10 \text{ m/s}^2$** . A falling object gains **10 m/s of speed every second**. In air, **air resistance** (a force that opposes motion) increases with speed.

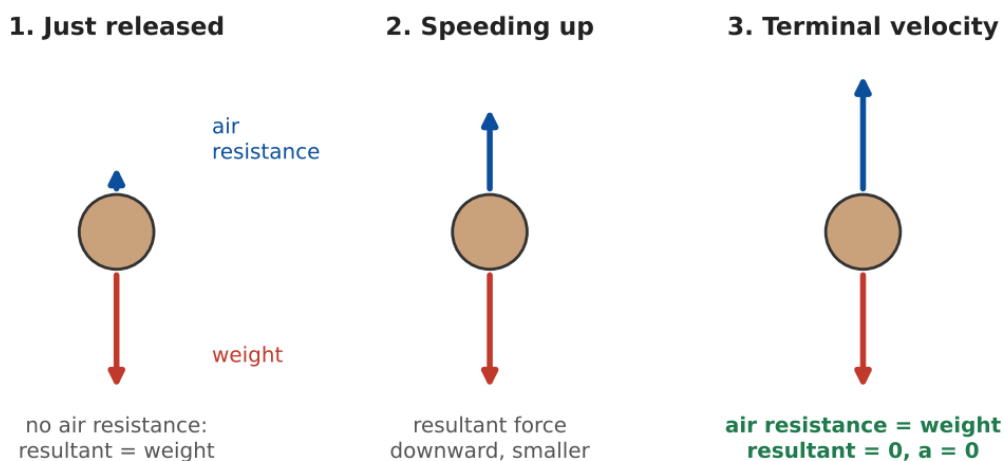


Figure P2.2 Forces on a falling object (e.g. a skydiver or hailstone).

- **At the start** the speed is small, so air resistance is small and the object **accelerates** at nearly g .
- As **speed increases**, air resistance **increases**, so the **resultant force and the acceleration decrease**.
- When **air resistance = weight**, the resultant force is **zero**: the object falls at a **constant speed called terminal velocity**.
- **Parachutes** have a large area, so air resistance is large and the **terminal velocity is small**, allowing a safe landing. **Hailstones** reach terminal velocity, which is why they do not kill people.

Exercise P2: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P2.1** A bus travels 90 km in 1.5 h. Calculate its average speed in km/h and m/s.
- P2.2** State the difference between speed and velocity.
- P2.3** A car accelerates from 5 m/s to 25 m/s in 8 s. Calculate its acceleration.
- P2.4** A cyclist moves at 6 m/s for 20 s. Find the distance travelled.
- P2.5** Describe the motion shown by a horizontal line on (a) a distance–time graph and (b) a speed–time graph.

- P2.6** A speed–time graph rises uniformly from 0 to 12 m/s in 6 s and then stays constant for 4 s. Calculate the total distance.
- P2.7** A stone is dropped from rest. Calculate its speed after 3 s (ignore air resistance).
- P2.8** A ball is dropped and takes 2 s to reach the ground (no air resistance). Find the height.
- P2.9** Explain why a skydiver reaches terminal velocity.
- P2.10** Explain why opening a parachute slows the skydiver.

EXAM-STYLE QUESTION · P2 · [10 marks]

The graph below (described) shows the speed of a car. It accelerates uniformly from 0 to 15 m/s in 5 s, travels at 15 m/s for 10 s and then decelerates uniformly to rest in 5 s.

- | | |
|---|-----|
| (a) Calculate the acceleration during the first 5 s. | [2] |
| (b) Describe the motion between 5 s and 15 s. | [1] |
| (c) Calculate the total distance travelled. | [3] |
| (d) Calculate the average speed for the whole journey. | [2] |
| (e) State why the speed of a falling raindrop becomes constant. | [2] |

P3 Mass, Weight, Forces and Moments

Syllabus reference: **P3.1 to P3.4**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Distinguish **mass and weight**; use $W = mg$.
- Describe **extension–load** experiments, **Hooke's law** and the **limit of proportionality**.
- Describe **friction** and use $F = ma$.
- Calculate **moments**, state the **principle of moments**, and describe **centre of mass** and **stability**.

P3.1 Mass and weight

	Mass	Weight
Meaning	The amount of matter in a body	The force of gravity on a body
Type	Scalar	Vector (acts downwards)
Unit	kg	newton (N)
Measured with	A balance (beam or electronic)	A spring balance / newton meter
Changes with place?	No	Yes (weight on the Moon is about 1/6 of that on Earth)

CORE CONCEPT

Weight = mass × gravitational field strength: $W = m g$, with $g = 10 \text{ N/kg}$ (equal to 10 m/s^2) on Earth. A 5 kg mass weighs $5 \times 10 = 50 \text{ N}$. **Inertia** is the **property of a mass to resist changes in its motion**; the greater the mass, the greater the inertia.

A **balance** compares the weight of an unknown mass with the weight of known masses, so it gives the **same reading anywhere** (the two weights change together). A spring balance measures the weight directly, so it reads **differently on the Moon**.

P3.2 Springs and elasticity

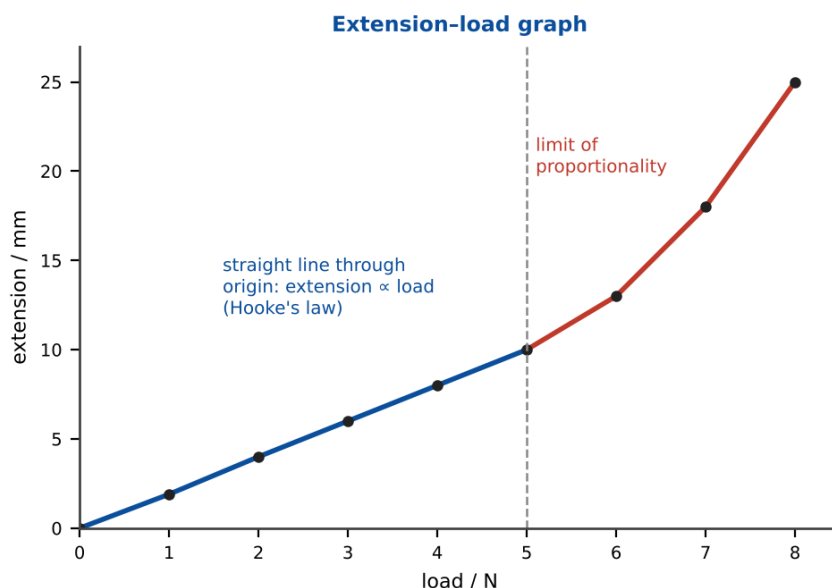
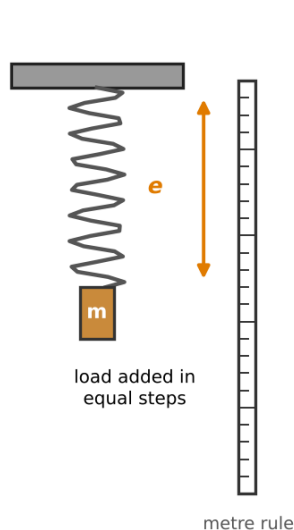


Figure P3.1 An extension–load experiment and its graph.

An object is **elastic** if it **returns to its original shape** when the deforming force is removed. For a spring the **extension $e = (\text{stretched length} - \text{original length})$** . **Hooke's law:** the extension is **directly proportional to the load** ($F = k e$, where k is the **spring constant** in N/m) **up to the limit of proportionality**. Beyond that point the graph curves, the spring is permanently stretched and **does not return to its original length**.

WORKED EXAMPLE: Using proportionality

A spring extends by **6 mm** when the load is **3 N** (within the limit). The **extension for 5 N** = $6 \times 5 \div 3 = 10$ mm. **Spring constant $k = F \div e = 3 \div 0.006 = 500$ N/m.**

P3.3 Forces and motion

- A **force** is a **push or a pull** (unit: **newton, N**). A force can **change the speed, direction or shape** of a body.
- **Resultant force** is the single force that has the same effect as all forces acting. If the resultant is **zero**, a body at rest stays at rest and a moving body keeps moving at **constant velocity (Newton's first law)**.
- **$F = m a$** (resultant force = mass $\times$ acceleration). A resultant force of 1 N gives a mass of 1 kg an acceleration of 1 m/s^2 .
- **Friction** is a force that **opposes motion** between surfaces in contact. It produces **heat** and **wear**.
Advantages: brakes and tyre grip, walking, holding objects. **Disadvantages:** wears parts, wastes energy as heat; reduced by **lubrication (oil, grease), polishing, wheels, ball bearings or streamlining**.

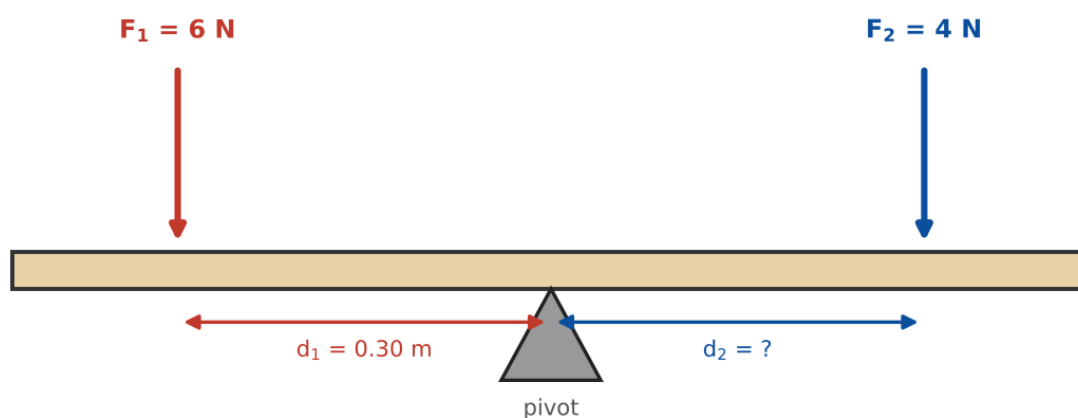
WORKED EXAMPLE: $F = ma$

A car of mass **1200 kg** has a driving force of **3000 N** and friction of **600 N**. **Resultant force** = $3000 - 600 = 2400 \text{ N}$. **$a = F \div m = 2400 \div 1200 = 2 \text{ m/s}^2$.**

P3.4 Moments, centre of mass and stability

CORE CONCEPT

The **moment of a force** is its **turning effect**. **Moment = force $\times$ perpendicular distance from the pivot**; unit **N m**. **Principle of moments:** when a body is in **equilibrium** (balanced), the **sum of the clockwise moments = the sum of the anticlockwise moments** about any pivot. Examples: spanner, see-saw, door, wheelbarrow, scissors.



$$\text{Balanced: } F_1 d_1 = F_2 d_2 \rightarrow 6 \times 0.30 = 4 \times d_2 \rightarrow d_2 = 0.45 \text{ m}$$

Figure P3.2 A balanced beam: $F_1 d_1 = F_2 d_2$.

Centre of mass is the **point where the whole weight of the body appears to act**. For a uniform object (a metre rule) it is at the **middle**. To find the **centre of mass of a plane lamina**: hang it from a pin through a hole near its edge; hang a **plumb line** from the same pin and **draw the vertical line** on the lamina. Repeat from at least **two other holes**. The **lines cross at the centre of mass**.

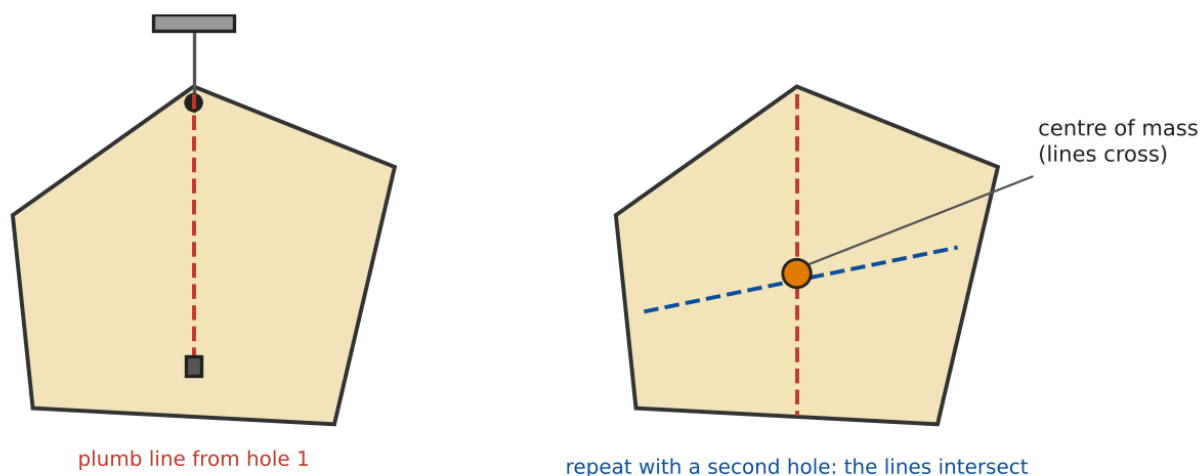


Figure P3.3 Finding the centre of mass of a plane lamina using a plumb line.

Stability: an object is **more stable** if it has a **low centre of mass** and a **wide base**; it topples when the **vertical line through the centre of mass falls outside the base**. Racing cars and double-decker buses have a low centre of mass and wide wheelbase, and a heavy base on a lamp stabilises it.

EXAM TIP

Verifying the principle of moments: balance a metre rule on a pivot at its midpoint, hang masses on either side, and show that **weight $\times$ distance (clockwise) = weight $\times$ distance (anticlockwise)**. Always measure distances **from the pivot to the line of action of the force**.

Exercise P3: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P3.1** Calculate the weight of a 65 kg learner on Earth ($g = 10 \text{ N/kg}$).
- P3.2** State two differences between mass and weight.
- P3.3** A spring of original length 10.0 cm is 14.0 cm long with a 2 N load. Find the extension and the length with a 3 N load (within limit).
- P3.4** What does the limit of proportionality mean?
- P3.5** A resultant force of 60 N acts on a 15 kg trolley. Calculate the acceleration.
- P3.6** Give two advantages and two disadvantages of friction.
- P3.7** Calculate the moment of a 25 N force acting 0.40 m from a pivot.
- P3.8** A 4 N weight is 0.50 m to the left of a pivot. At what distance on the right must a 5 N weight be placed to balance?
- P3.9** Explain why a low centre of mass makes a vehicle more stable.
- P3.10** Describe how to find the centre of mass of an irregular piece of card.

EXAM-STYLE QUESTION · P3 · [9 marks]

A uniform metre rule is balanced on a pivot at the 50 cm mark. A 3.0 N weight hangs at the 20 cm mark and a 2.0 N weight hangs at the 75 cm mark.

- (a) State what is meant by the moment of a force. [1]
- (b) Calculate the clockwise moment of the 2.0 N weight about the pivot. [2]
- (c) Calculate the anticlockwise moment of the 3.0 N weight. [2]
- (d) State whether the rule is balanced and explain. [2]
- (e) Calculate the distance from the pivot at which the 2.0 N weight must be placed to balance the rule. [2]

P4 Work, Energy and Power

Syllabus reference: **P4.1 to P4.4**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Calculate **work done** = force $\times$ distance.
- Describe **forms of energy**, **energy conversions** and the **conservation of energy**.
- Calculate **kinetic energy** ($\frac{1}{2}mv^2$) and **gravitational potential energy** (mgh).
- Calculate **efficiency** and **power**, and describe **energy resources**.

CORE CONCEPT

Work is done when a **force moves an object in the direction of the force**: $W = F \times d$ (newtons $\times$ metres = **joules, J**). Work done is energy transferred. **Energy** is the **capacity to do work** (unit **joule, J**). **Power** is the **rate of doing work (rate of transferring energy)**: $P = W \div t = E \div t$, unit **watt (W)** = 1 J/s.

WORKED EXAMPLE: Work and power

A learner lifts a **20 N** box through **1.5 m** in **3 s**. **Work** = $F \times d = 20 \times 1.5 = 30 \text{ J}$. **Power** = $W \div t = 30 \div 3 = 10 \text{ W}$.

P4.2 and P4.3 Forms of energy and conservation

Form of energy	Description / example
Kinetic	Energy of motion (a moving car)
Gravitational potential	Energy stored because of height (water in a dam)
Elastic (strain) potential	Stored in a stretched or compressed spring or bow
Chemical	Stored in fuels, food and batteries
Thermal (heat)	Energy of hot objects (particles moving faster)
Electrical, light, sound	Energy carried by current, light and sound waves
Nuclear	Stored in the nuclei of atoms

CORE CONCEPT

Law of conservation of energy: energy cannot be created or destroyed; it is transferred from one form to another and the **total energy stays the same**. **Kinetic energy**: $k.e. = \frac{1}{2} m v^2$. **Gravitational potential energy**: $p.e. = m g h$ (change in p.e. when height changes by h).

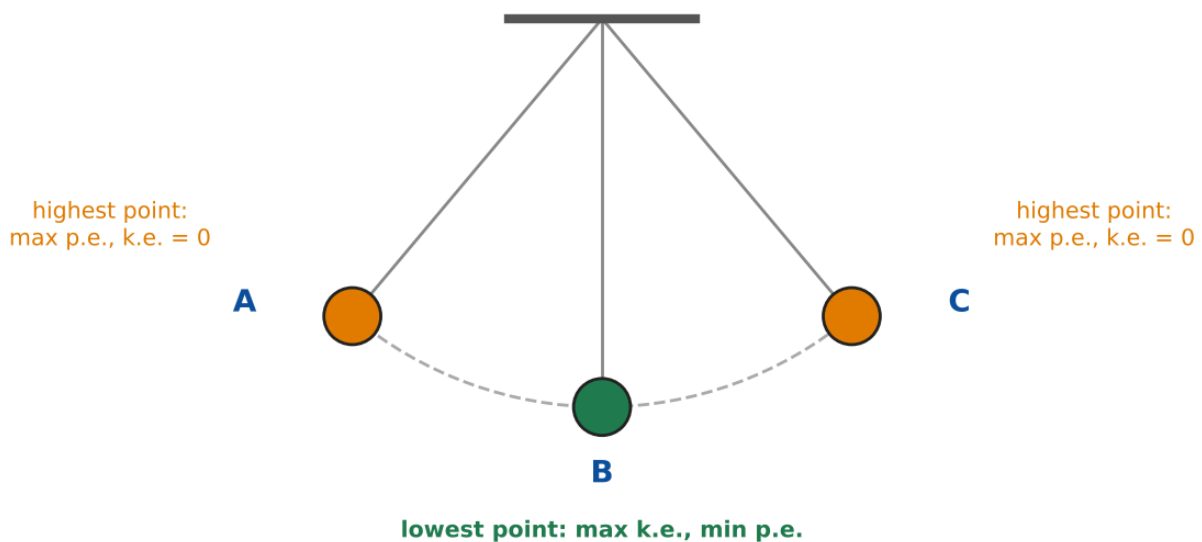


Figure P4.1 Energy changes in a swinging pendulum: p.e. $\rightleftharpoons$ k.e.

WORKED EXAMPLE: k.e. and p.e.

A **2.0 kg** ball is dropped from **5.0 m**. Loss in p.e. = $mgh = 2.0 \times 10 \times 5.0 = \mathbf{100 \text{ J}}$. All of this becomes k.e. at the bottom: $\frac{1}{2} m v^2 = 100$, so $v^2 = 100$, $v = \mathbf{10 \text{ m/s}}$. A **1200 kg** car moving at **20 m/s** has k.e. = $\frac{1}{2} \times 1200 \times 20^2 = \mathbf{240\,000 \text{ J}}$.

Efficiency

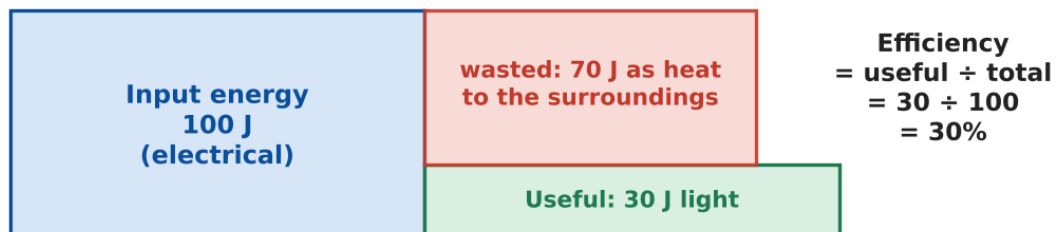


Figure P4.2 Energy transfer in a filament lamp: most energy is wasted as heat.

Efficiency = useful energy output $\div$ total energy input ($\times 100\%$) or **useful power output $\div$ total power input**. No machine is 100% efficient because some energy is always **transferred to the surroundings as heat (and sound)**, often as a result of **friction** or the resistance of wires. Wasted energy is **dissipated**, not destroyed.

P4.3.4 Energy resources

Source	How electricity is obtained	Renewable?
Fossil fuels (coal, oil, gas)	Burn fuel: chemical → heat → steam → turbine → generator	No ; produce CO ₂
Hydroelectric (water)	Falling water turns a turbine: p.e. → k.e. → electrical	Yes
Wind	Wind turns turbine blades connected to a generator	Yes
Geothermal	Heat from hot rocks makes steam that turns turbines	Yes
Solar	Solar cells (light → electrical) or solar panels heating water (nuclear fusion in the Sun is the source)	Yes
Nuclear fission	Splitting uranium nuclei releases heat → steam → turbine	No ; produces radioactive waste

Exercise P4: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P4.1** A force of 80 N moves a trolley 6.0 m in the direction of the force. Calculate the work done.
- P4.2** Name the energy change in (a) a battery-powered torch, (b) a falling stone, (c) a wind turbine.
- P4.3** Calculate the k.e. of a 0.50 kg ball moving at 8.0 m/s.
- P4.4** Calculate the p.e. gained by a 60 kg climber going up 15 m.
- P4.5** A pump lifts 200 kg of water through 12 m in 40 s. Calculate its useful power.
- P4.6** A motor takes 500 J of electrical energy and does 350 J of useful work. Calculate its efficiency.
- P4.7** Explain why no machine is 100% efficient.
- P4.8** State the law of conservation of energy.
- P4.9** Give two advantages of renewable energy over fossil fuels.
- P4.10** A 1 kW heater runs for 2 hours. How many joules of energy are transferred?

EXAM-STYLE QUESTION · P4 · [9 marks]

A 0.20 kg stone is thrown vertically upwards from the ground with a speed of 12 m/s. Ignore air resistance. $g = 10 \text{ m/s}^2$.

- | | |
|---|-----|
| (a) Calculate the initial kinetic energy of the stone. | [2] |
| (b) State the kinetic energy at the highest point. | [1] |
| (c) Calculate the maximum height reached. | [3] |
| (d) State the energy transformation as the stone rises. | [1] |
| (e) Explain why the stone would not reach this height in air. | [2] |

P5 Waves, Light and Sound

Syllabus reference: P5.1 to P5.4

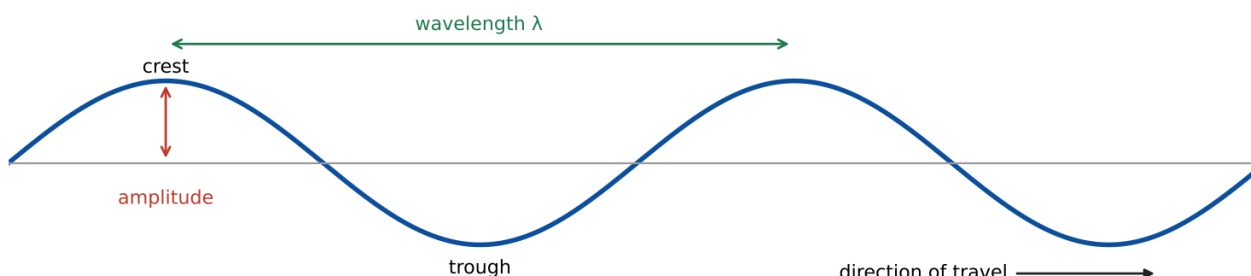
BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe **wave motion**; distinguish **transverse and longitudinal waves**; use $v = f\lambda$.
- Describe **reflection, refraction and diffraction** of waves.
- Describe **images in plane mirrors, refraction of light** ($n = \sin i \div \sin r$) and **converging lenses**.
- Describe the **electromagnetic spectrum**, its **uses and dangers**, and **sound waves**.

P5.1 Wave motion

A **wave** is a **disturbance that transfers energy from one place to another without transferring matter**. The particles of the medium only vibrate about fixed positions.

Transverse wave: vibrations at 90° to the direction of travel (light, water, e.m. waves)



Longitudinal wave: vibrations parallel to the direction of travel (sound, springs)

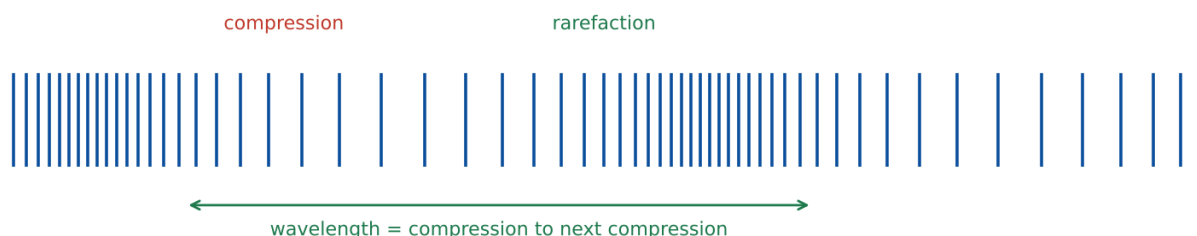


Figure P5.1 Transverse and longitudinal waves.

Term	Meaning	Unit
Amplitude, a	Maximum displacement from the rest position (energy of the wave)	m
Wavelength, λ	Distance between two successive identical points (crest to crest)	m
Frequency, f	Number of complete waves passing a point per second	hertz (Hz)
Period, T	Time for one complete wave; $T = 1 \div f$	s
Wave speed, v	Distance travelled by a wave crest per second	m/s
Wavefront	A line joining points in the same phase (e.g. crests); wavefronts are perpendicular to the direction of travel	

$$\text{wave speed } v = f \times \lambda$$

WORKED EXAMPLE: Wave speed

A wave has a frequency of **50 Hz** and a wavelength of **0.30 m**. Speed $v = f \lambda = 50 \times 0.30 = \mathbf{15 \text{ m/s}}$. A sound of frequency 440 Hz in air (330 m/s) has a wavelength $\lambda = v \div f = 330 \div 440 = \mathbf{0.75 \text{ m}}$.

Transverse waves vibrate at **right angles** to the direction of travel: **water waves, light and all electromagnetic waves, waves on a rope**. **Longitudinal waves** vibrate **parallel** to the direction of travel and form **compressions and rarefactions**: **sound, and a push–pull on a slinky spring**.

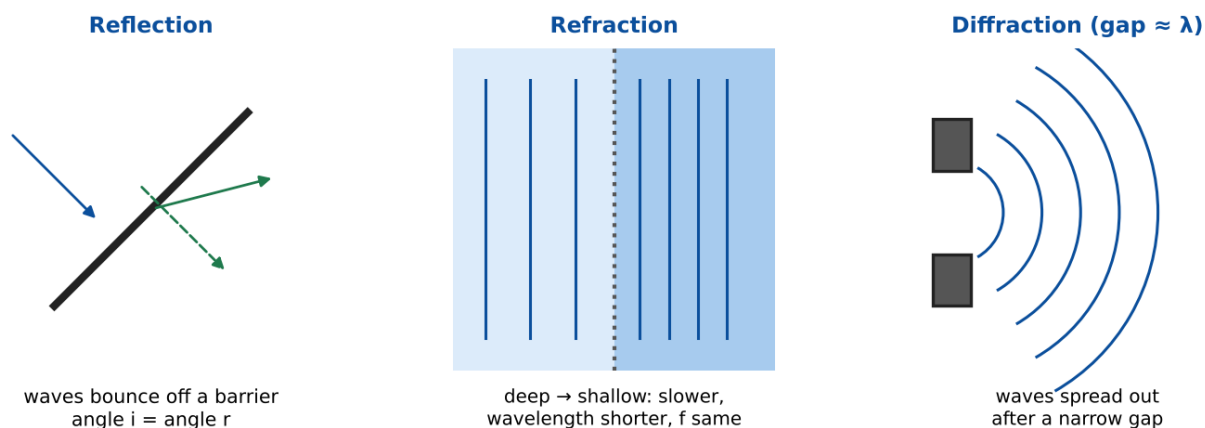


Figure P5.2 Reflection, refraction and diffraction of water waves in a ripple tank.

- **Reflection:** waves **bounce back** from a barrier; **angle of incidence = angle of reflection**; speed, frequency and wavelength are **unchanged**.
- **Refraction:** waves **change speed and direction** when they pass from deep to shallow water; the **wavelength changes** but the **frequency stays the same**. In shallow water waves **slow down** and bunch up.
- **Diffraction:** waves **spread out** when they pass through a **gap or round an obstacle**; it is **most noticeable when the gap is about one wavelength** (a narrow gap) and small for a wide gap. Applications: **radio waves diffract round hills and buildings**, so you can receive them behind obstacles; sound passes through doorways.

P5.2 Light

Light travels in straight lines at $3.0 \times 10^8 \text{ m/s}$ in a vacuum. **Law of reflection:** the **angle of incidence = the angle of reflection**, measured from the **normal** (the line at 90° to the surface). The incident ray, the reflected ray and the normal all lie in the **same plane**.

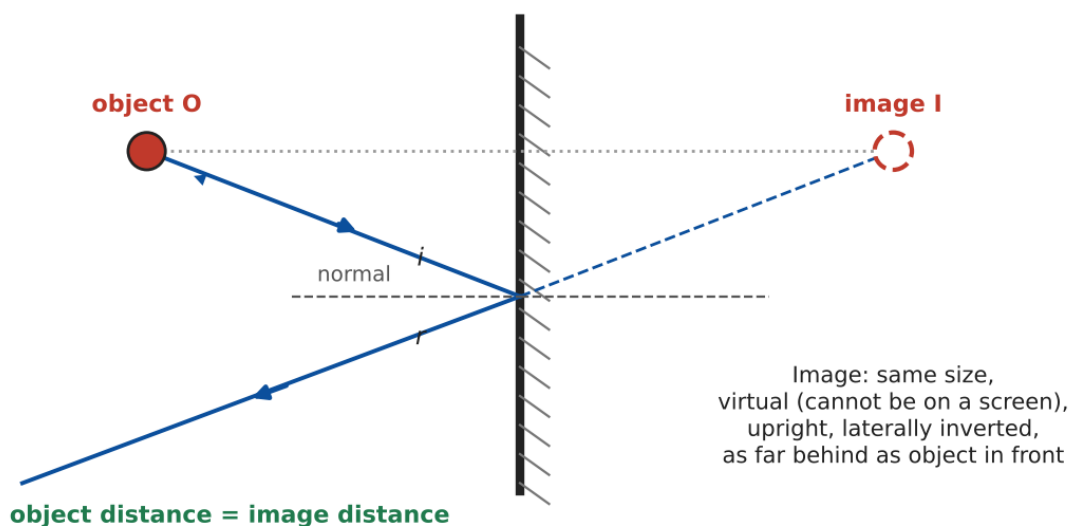


Figure P5.3 An image formed by a plane mirror.

To locate the image in a plane mirror: place a pin O in front of the mirror; look at its image and place two more pins in line with it; the lines through the pin positions **cross behind the mirror** at the image.

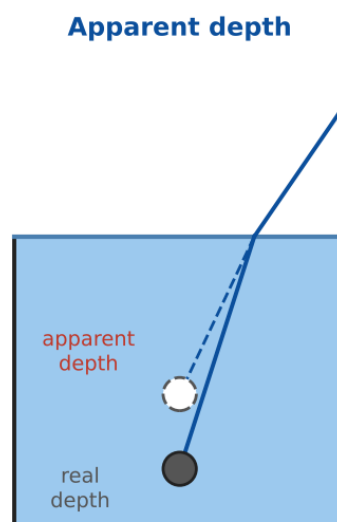
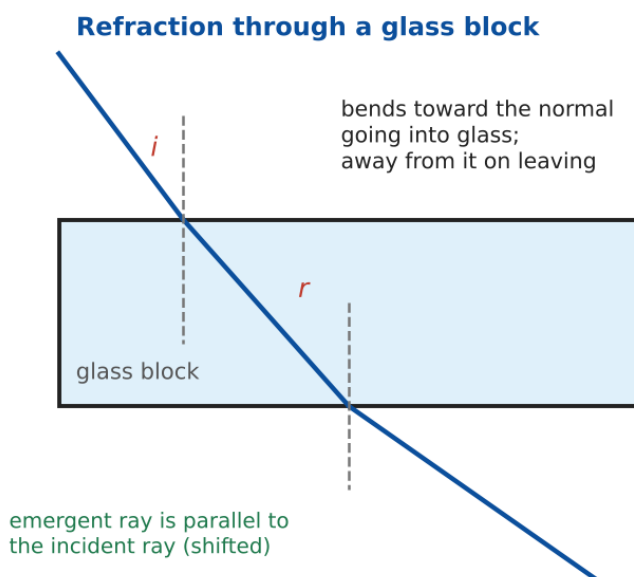


Figure P5.4 Refraction of light in a glass block and apparent depth.

CORE CONCEPT

Refraction is the change in direction of light when it passes between media of different optical density, because its speed changes. Light **bends towards the normal** when it slows down (air → glass/water) and **away** when it speeds up. **Refractive index** $n = \sin i \div \sin r$ (i in air, r in the medium). It has **no units**. Also $n = (\text{speed of light in air}) \div (\text{speed in the medium})$.

WORKED EXAMPLE: Refractive index

A ray hits glass with $i = 50^\circ$ and $r = 30^\circ$. $n = \sin 50^\circ \div \sin 30^\circ = 0.766 \div 0.500 = 1.53$.

Apparent depth: a pool looks **shallower** than it really is because light from the bottom **bends away from the normal** as it leaves the water, so the rays seem to come from a **higher point**. **Thin lenses:** a **convex (converging) lens** is thick in the middle and **brings parallel rays together at the principal focus F**; a **concave (diverging) lens** is thin in the middle and **spreads parallel rays out**. The **focal length f** is the

distance from the lens centre to F.

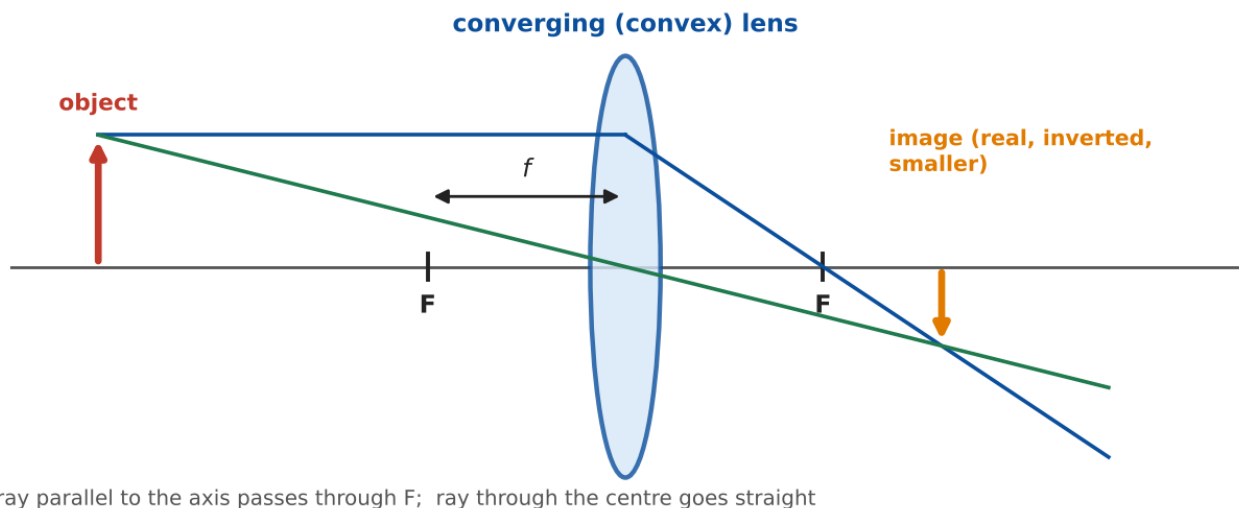
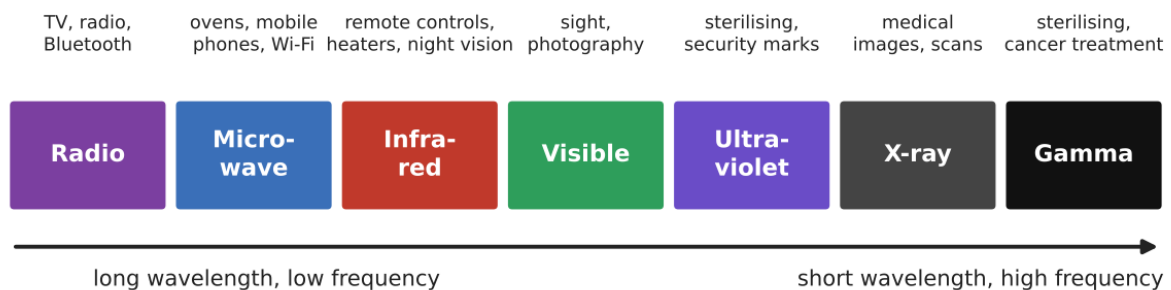


Figure P5.5 Ray diagram for a converging lens.

To find the focal length: focus the image of a distant object (e.g. a window) on a screen; the **lens-to-screen distance is f** . A **convex lens used as a magnifying glass** holds the object **closer than F** ; the image is **virtual, upright and magnified**. Rules for rays: a ray **parallel** to the axis goes through F ; a ray through the **centre** passes straight through.

P5.3 The electromagnetic spectrum



All e.m. waves are transverse and travel at 3.0×10^8 m/s in a vacuum (the speed of light)

Figure P5.6 The electromagnetic spectrum.

Wave	Uses	Dangers
Radio	Broadcasting, communication, Bluetooth	None known at normal levels
Microwaves	Ovens, mobile phones , satellites, Wi-Fi	Internal heating of body cells
Infra-red	Remote controls , heaters, thermal imaging, night vision	Skin burns
Visible light	Seeing, photography, optical fibres	Very bright light damages the eye
Ultraviolet	Sterilising, security marking , sun beds	Skin cancer , eye damage
X-rays	Medical images of bones, airport security	Damage and mutation of cells, cancer
Gamma rays	Sterilising food and equipment, cancer treatment	Cancer and cell damage

All electromagnetic waves **travel at the same speed in a vacuum (3.0×10^8 m/s)**, are **transverse**, can travel through a vacuum, and **carry energy**. From radio to gamma, **frequency and energy increase while wavelength decreases**.

P5.4 Sound

- **Sound** is a **longitudinal wave** produced by **vibrations**; it **needs a medium** (solid, liquid or gas) because the particles pass the vibration on. It **cannot travel in a vacuum** (the bell-in-a-jar experiment).
- **Audible range: about 20 Hz to 20 000 Hz** for humans. **Ultrasound** is above 20 000 Hz.
- **Pitch** depends on **frequency** (higher frequency = higher pitch). **Loudness** depends on **amplitude** (larger amplitude = louder).
- **Speed of sound** is about **330 m/s in air**, faster in liquids (about 1500 m/s in water) and fastest in solids (about 5000 m/s in steel).
- An **echo** is a **reflection of sound**. **Speed of sound = distance $\div$ time**. To measure it, **stand 100 m from a large wall and clap**; time the interval to the echo (distance travelled = 2×100 m).

WORKED EXAMPLE: Echo

A learner hears an echo **0.60 s** after clapping, **100 m** from a wall. Distance there and back = 200 m.
Speed = $200 \div 0.60 = 333$ m/s.

Exercise P5: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P5.1** Define (a) wavelength and (b) frequency.
- P5.2** A wave has frequency 20 Hz and wavelength 2.5 m. Calculate its speed.
- P5.3** Give one example each of a transverse and a longitudinal wave.
- P5.4** State what happens to the wavelength and speed of a water wave moving into shallower water.
- P5.5** A ray strikes a plane mirror at 35° to the normal. State the angle of reflection and the angle between the incident and reflected rays.
- P5.6** A ray passes from air into glass with $i = 45^\circ$, $r = 28^\circ$. Calculate n .
- P5.7** Explain why a swimming pool looks shallower than it is.
- P5.8** State two properties of all electromagnetic waves.
- P5.9** Name the part of the electromagnetic spectrum used in (a) a TV remote, (b) sterilising food, (c) a mobile phone.
- P5.10** A thunderclap is heard 3.0 s after the lightning flash. Calculate the distance to the storm (speed of sound = 330 m/s).

EXAM-STYLE QUESTION · P5 · [10 marks]

A ray of light enters a rectangular glass block from air at an angle of incidence of 60° . The angle of refraction is 35° .

- (a) Define refraction. [1]
- (b) Calculate the refractive index of the glass. [3]
- (c) Describe the path of the ray as it leaves the block on the opposite parallel side. [2]
- (d) State two differences between light and sound waves. [2]
- (e) A sound wave has a frequency of 660 Hz and travels at 330 m/s. Calculate its wavelength. [2]

P6 Thermal Physics

Syllabus reference: P6.1 to P6.4

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe **thermal expansion** using the **kinetic theory** and its uses.
- Describe how **thermometers** work (**range, sensitivity, linearity**; fixed points; thermocouple).
- Describe **melting, boiling, evaporation** and energy changes at **changes of state**.
- Describe **conduction, convection and radiation**, with examples and experiments.

P6.1 Thermal expansion

When a substance is **heated**, its **particles vibrate (or move) faster and push slightly further apart**, so it **expands**; when cooled it **contracts**. **Gases expand the most** (very weak forces between particles), **liquids** expand more than **solids** (strong forces hold solid particles together). Different solids also expand by different amounts.

- **Consequences:** gaps are left in **railway lines, bridges and pavements**; **overhead power cables sag** in hot weather; hot glass can crack.
- **Uses:** a **bimetallic strip** (two metals joined) bends when heated because one metal expands more; it is used in **thermostats and fire alarms**; fitting a metal tyre by heating it.

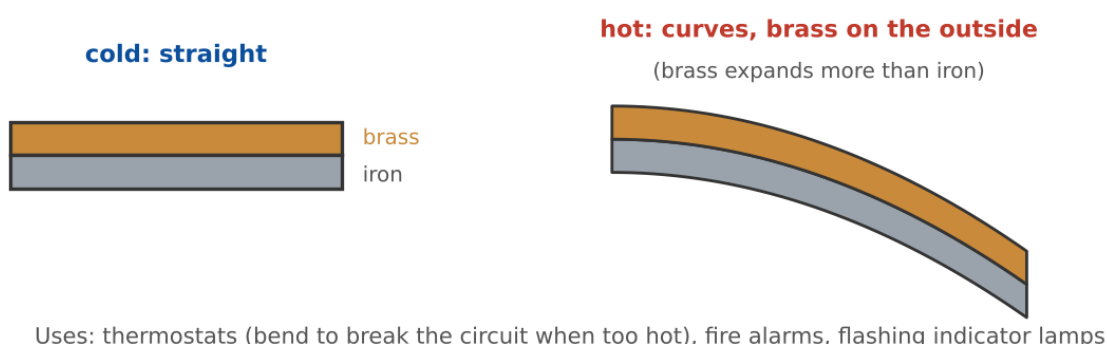


Figure P6.1 A bimetallic strip bends when heated.

P6.2 Measuring temperature

A **thermometer** uses a **property that changes regularly with temperature**: the **volume of a liquid**, the **pressure of a gas**, the **resistance of a wire** or the **e.m.f. of a thermocouple**. **Fixed points** are used to calibrate: the **lower fixed point** is **0 °C (melting point of pure ice)** and the **upper fixed point** is **100 °C (boiling point of pure water at standard pressure, in steam)**. Divide the distance between them into 100 equal parts.

Term	Meaning	How to improve
Range	The lowest to highest temperature it can measure	Choose the right liquid (mercury –39 °C to 350 °C; alcohol to –115 °C)
Sensitivity	Change in reading per degree : a large change in the liquid's length for a small temperature change	Narrower bore and larger bulb

Term	Meaning	How to improve
Linearity	Equal changes of temperature give equal changes in the reading (evenly spaced scale)	Choose a liquid that expands evenly

Liquid-in-glass thermometer: a **glass bulb** with a thin wall (so it responds quickly) and a **narrow capillary tube**. **Mercury** is poisonous, so a broken mercury thermometer must be **cleaned up with care and disposed of safely**. A **thermocouple** has **two different metals joined at two junctions**; a temperature difference makes an **e.m.f./current** that a voltmeter reads. It can measure **very high temperatures** and temperatures that **change quickly**, because the junction has a small mass and responds rapidly.

P6.3 Changes of state

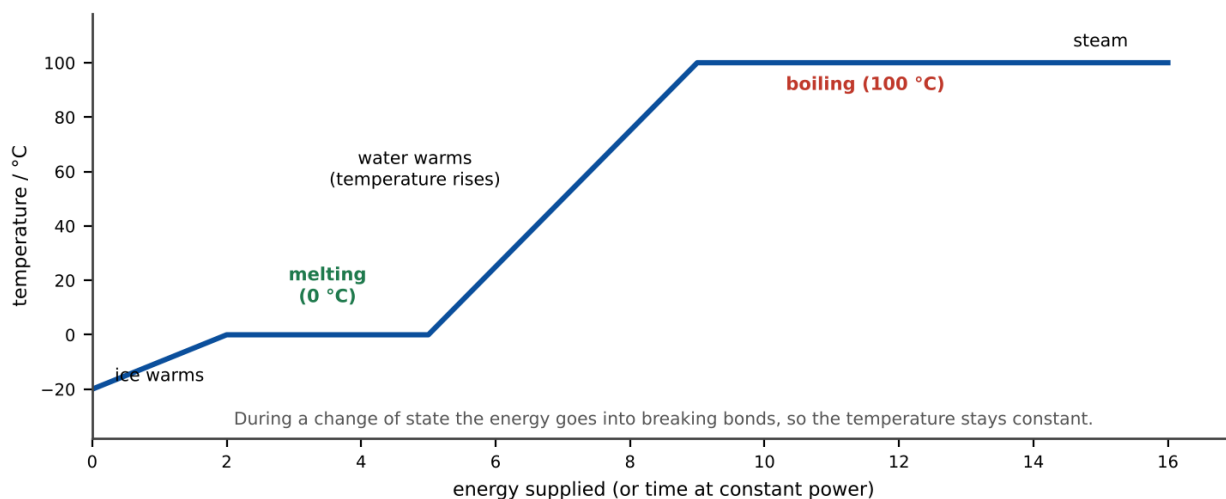


Figure P6.2 Heating curve for water.

Melting point and **boiling point** are the fixed temperatures at which a substance melts or boils. At these temperatures **energy is absorbed without a rise in temperature**: it is used to **overcome the forces between particles** (the latent heat). **Evaporation** occurs at the **surface** of a liquid at **any temperature**, only the faster particles escape, and it causes **cooling**. **Boiling** occurs **throughout the liquid at one fixed temperature**, with bubbles of vapour forming. Evaporation is faster at a **higher temperature**, with a **larger surface area**, and with **air movement** (wind).

P6.4 Transfer of thermal energy

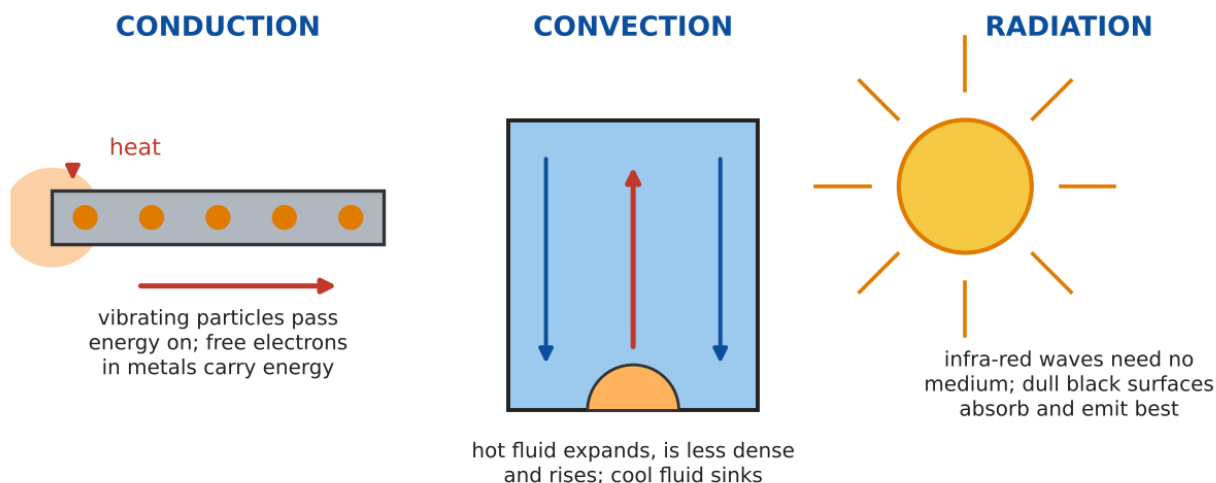


Figure P6.3 The three methods of heat transfer.

Method	How it works	Where it occurs	Examples
Conduction	Hot particles vibrate more and pass energy to neighbours; in metals free electrons carry energy quickly	Solids (best in metals); poor in liquids and gases	Frying pan, a spoon in hot tea; insulators : wool, wood, plastic, air
Convection	Hot fluid expands, becomes less dense and rises ; cooler, denser fluid sinks, forming convection currents	Liquids and gases only	Kettle, room heater, sea breezes , heating a room
Radiation	Infra-red electromagnetic waves ; needs no medium	Through a vacuum too	Heat from the Sun, a fire, a toaster

- **Radiation:** dull, black surfaces are good absorbers and good emitters; shiny, white surfaces are poor absorbers and poor emitters and good reflectors. That is why a vacuum flask has silvered, shiny surfaces and a vacuum between its walls (no conduction or convection) and a stopper (reduces convection and evaporation).
- **Experiments:** conduction — match heads on metal rods fall off in order; convection — a potassium manganate(VII) crystal in water shows currents; radiation — compare the temperature rise of black and silver cans filled with hot water.
- **Everyday uses:** radiators painted black on a sheet at the back, white or silver roofs in hot countries, cooking pots with insulated handles, fibreglass loft insulation.

Exercise P6: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P6.1** Explain, in terms of particles, why a solid expands when heated.
- P6.2** Why do gases expand more than solids for the same temperature rise?
- P6.3** Describe how a bimetallic strip works.
- P6.4** State the upper and lower fixed points of the Celsius scale.
- P6.5** State what is meant by the sensitivity of a thermometer and how it can be increased.
- P6.6** Why is a thermocouple suited to measuring the temperature of a flame?
- P6.7** Explain why the temperature stays constant while ice melts, even though heat is supplied.
- P6.8** State two differences between evaporation and boiling.
- P6.9** Explain how a vacuum flask keeps drinks hot.
- P6.10** Why are cooking pots made of metal with plastic handles?

EXAM-STYLE QUESTION · P6 · [10 marks]

A learner heats water in a metal pan on a stove and then pours it into a vacuum flask.

- (a) Name the main way heat passes through the metal base of the pan. [1]
- (b) Explain how the water in the pan is heated evenly by convection. [3]
- (c) Explain how the vacuum flask reduces heat loss by conduction, convection and radiation. [3]
- (d) Explain why the temperature of boiling water stays at 100 °C although energy is still being supplied. [2]
- (e) State why a dull black pan heats up faster than a shiny one over a flame. [1]

P7 Static Electricity

Syllabus reference: P7.1 to P7.7

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe how objects become **charged by friction** (electron transfer).
- State that **like charges repel and unlike charges attract**; charge is measured in **coulombs**.
- Describe the **gold-leaf electroscope** and **lightning**.

CORE CONCEPT

Atoms contain **positive protons** (in the nucleus) and **negative electrons** (outside). An atom is neutral when the charges cancel. **Only electrons move** from one material to another. An object that **gains electrons becomes negatively charged**; one that **loses electrons becomes positively charged**. Charge is measured in coulombs (C).

Charge is measured in coulombs (C)

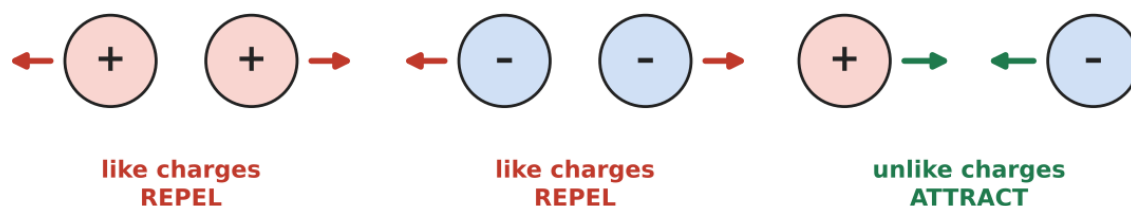


Figure P7.1 Like charges repel; unlike charges attract.

Charging by friction: when two **insulators** are rubbed together, **electrons are transferred** from one to the other. A **polythene rod rubbed with a cloth** gains electrons (**negative**) and the cloth loses them (**positive**); a **perspex (acetate) rod** loses electrons and becomes **positive**. **Metals** can be charged only if they are **insulated** (held by an insulating handle), otherwise the charge flows away to earth through the person. A charged object **attracts uncharged small objects** (such as paper) by **induction**: the charged rod repels like charges to the far side, leaving the unlike charge nearest to the rod, and **attraction wins** because it is nearer.

P7.2 and P7.6 Detecting charge: the electroscope

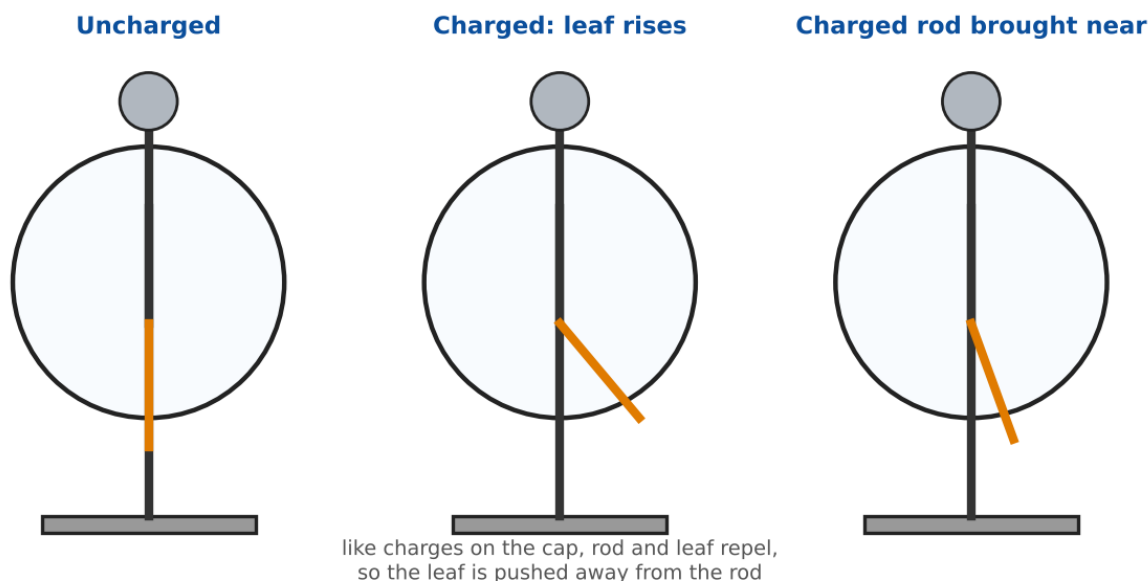


Figure P7.2 The gold-leaf electroscope.

- A **gold-leaf electroscope** has a **metal cap, rod and thin gold leaf** inside a case. When a charged object touches the cap, **charge flows onto the rod and leaf; both have the same charge and repel, so the leaf rises.**
- **More charge gives a larger divergence.** To test the sign of a charge: charge the electroscope with a known sign, then bring up the unknown object. If the **leaf rises further**, the charges are **alike**; if it **falls**, they are **unlike**.
- **Discharging:** touch the cap with a finger (charge flows to earth).
- **Conductors** (metals, graphite, salt water) allow charge to flow; **insulators** (plastics, dry air, glass, rubber) do not.

P7.7 Lightning

In a thundercloud, **ice particles rub together** and charge **separates**: the **base of the cloud becomes negatively charged** and the ground below positive by induction. When the **potential difference is large enough**, air **ionises and conducts**, and a huge **spark (lightning)** flows between cloud and ground. A **lightning conductor** is a **pointed metal rod** joined to the earth; it provides a **path to the ground** and protects buildings. **Safety:** avoid open ground, tall trees and water; shelter in a building or hard-topped car.

EXAM TIP

In explanations, always say **electrons move (not protons)**, name **which object gains and which loses electrons**, and give the **sign of each charge**.

Exercise P7: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P7.1** State what is transferred when a polythene rod is rubbed with a cloth and the sign of the charge on the rod.
- P7.2** State the law of electrostatic forces.
- P7.3** Explain why a charged comb picks up small pieces of paper.
- P7.4** A positively charged rod is brought near the cap of an uncharged electroscope. Describe and explain what happens to the leaf.
- P7.5** A negatively charged electroscope has its leaf up. A rod is brought near and the leaf falls. State the sign of the rod.
- P7.6** Why must a metal rod be held with an insulating handle to charge it?
- P7.7** Define the coulomb in terms of current.
- P7.8** Explain how a lightning conductor protects a building.
- P7.9** Describe how lightning is produced.
- P7.10** Name one useful and one dangerous effect of static electricity.

EXAM-STYLE QUESTION · P7 · [8 marks]

A polythene rod is rubbed with a dry cloth and then held near the cap of an uncharged gold-leaf electroscope without touching it.

- (a) Explain, in terms of electrons, how the rod becomes charged. [2]
- (b) State the sign of the charge on the cloth. [1]
- (c) Describe and explain what happens to the leaf when the rod is brought close to the cap. [3]
- (d) State what happens when the rod is removed. [1]
- (e) Give one precaution to avoid a spark when refuelling an aircraft. [1]

P8 Current Electricity

Syllabus reference: **P8.1** and **P8.2**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Define **current**, **e.m.f.** and **potential difference**; use $I = Q \div t$.
- Use **ammeters** and **voltmeters**.
- Define **resistance**, use $V = IR$, and interpret **V-I graphs**; know the factors affecting resistance.

CORE CONCEPT

Electric current is the **rate of flow of charge**: $I = Q \div t$ (current in **amperes, A**; charge in **coulombs, C**; time in **seconds, s**). **Conventional current** flows from the **positive to the negative** terminal of the source. **Electrons** (the real charge carriers in metals) flow the **opposite way**, from **negative to positive**.

WORKED EXAMPLE: $I = Q \div t$

A current of **0.50 A** flows for **2 minutes**. **Charge** $Q = I t = 0.50 \times 120 = 60 \text{ C}$. A charge of 90 C passes in 30 s: $I = 90 \div 30 = 3.0 \text{ A}$.

	e.m.f.	Potential difference (p.d.)
Definition	Energy supplied by the source to each coulomb of charge driven round a complete circuit	Energy transferred (to other forms) by each coulomb passing through a component
Where	Across the cell/battery	Across components (resistor, lamp)
Unit	Volt, V ($1 \text{ V} = 1 \text{ J/C}$)	Volt, V
Measured with	A voltmeter across the source	A voltmeter in parallel with the component

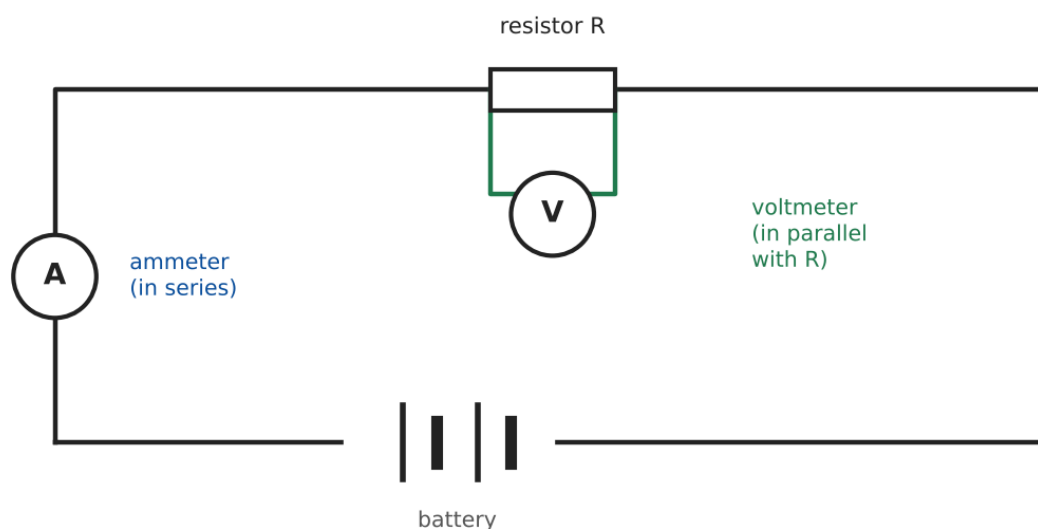


Figure P8.1 An ammeter is connected in series; a voltmeter is connected in parallel.

P8.2 Resistance

CORE CONCEPT

Resistance is the **opposition to the flow of current**: $R = V \div I$ (ohm, Ω). Rearranged: $V = I R$. A component has a resistance of 1Ω if a p.d. of 1 V makes a current of 1 A flow through it.

WORKED EXAMPLE: Using $V = IR$

A resistor has **6.0 V** across it and a current of **0.30 A**. $R = V \div I = 6.0 \div 0.30 = \mathbf{20 \Omega}$. A 50Ω resistor with 0.20 A has $V = IR = 50 \times 0.20 = \mathbf{10 \text{ V}}$.

Experiment to find the V–I characteristic of a resistor: connect a resistor in series with an **ammeter** and a **variable resistor (or variable supply)**, with a **voltmeter in parallel** with the resistor. **Change the current in steps**, record **V and I** each time and **plot V against I**. For a metal conductor at constant temperature the graph is a **straight line through the origin**, so $V \propto I$: it is **ohmic** (Ohm's law).

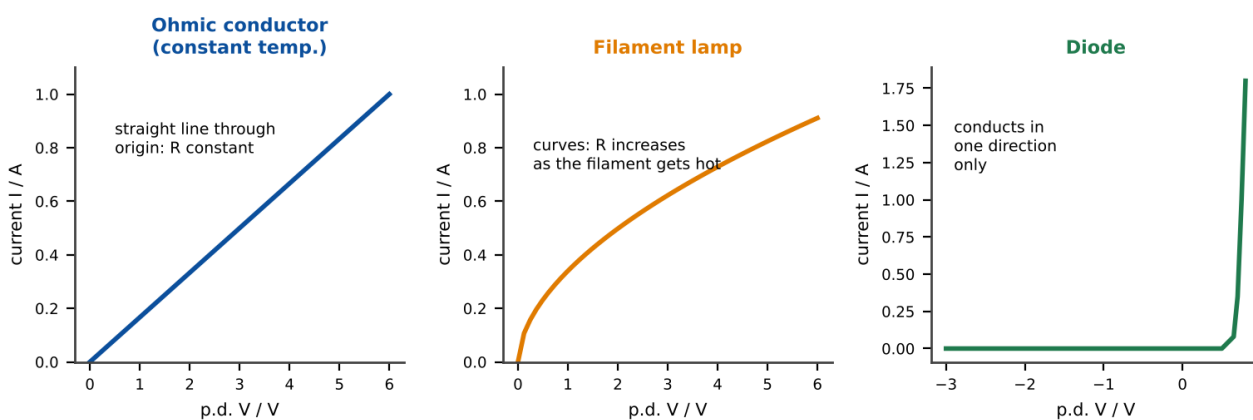


Figure P8.2 V–I characteristics.

- **Ohmic conductor:** a straight line through the origin. **Resistance is constant.**
- **Filament lamp:** the curve **flattens** as the current rises because the filament **gets hot and its resistance increases**.
- **Diode:** conducts only when connected one way round (**forward bias**); **very high resistance in the reverse direction**.
- **Factors affecting resistance of a wire:** length ($R \propto L$: **double the length, double the resistance**), cross-sectional area ($R \propto 1 \div A$: **thicker wire has less resistance**), material and temperature.

EXAM TIP

Draw the **voltmeter in parallel** and the **ammeter in series**. A voltmeter has a **very high resistance** and an ammeter a **very low resistance**, so neither changes the circuit.

Exercise P8: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P8.1** A current of 2.5 A flows for 4.0 s. Calculate the charge.
- P8.2** Calculate the current when 240 C passes in 2 minutes.
- P8.3** State the direction of conventional current and electron flow.
- P8.4** Distinguish between e.m.f. and p.d.
- P8.5** A lamp has a p.d. of 12 V and a current of 0.50 A. Calculate its resistance.
- P8.6** Calculate the p.d. across a $15\ \Omega$ resistor carrying 0.40 A.
- P8.7** A wire has a resistance of $8\ \Omega$. State the resistance of a wire of the same material of twice the length and the same area.
- P8.8** Explain why the graph for a filament lamp is a curve.
- P8.9** Describe how to connect a voltmeter to measure the p.d. across a resistor.
- P8.10** State two factors which affect the resistance of a metal wire.

EXAM-STYLE QUESTION · P8 · [10 marks]

A learner investigates a resistor R using a battery, a variable resistor, an ammeter and a voltmeter.

- (a) Draw (describe) how the ammeter and voltmeter are connected. [2]
- (b) The ammeter reads 0.25 A when the voltmeter reads 5.0 V. Calculate R. [2]
- (c) State the shape of the V–I graph for R and what it shows. [2]
- (d) The resistor is replaced with a resistor of the same material, twice as long and half the cross-sectional area. State the new resistance. [2]
- (e) Calculate the charge passing through the resistor in 30 s when the current is 0.25 A. [2]

P9 Electric Circuits

Syllabus reference: **P9.1** and **P9.2**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Recognise **circuit symbols** and draw and interpret **circuit diagrams**.
- State the rules for **current** and **p.d.** in **series** and **parallel** circuits.
- Calculate the **combined resistance** of resistors in series and parallel.

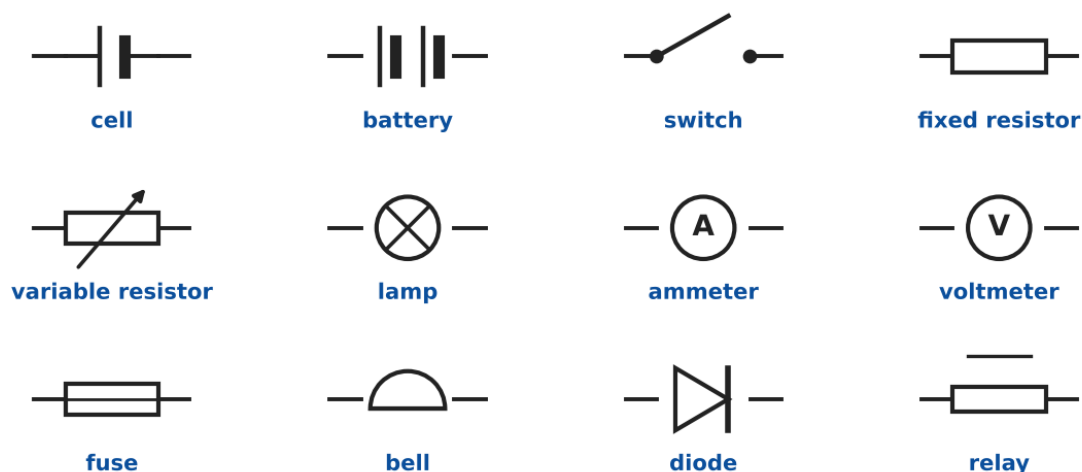


Figure P9.1 Circuit symbols used in this syllabus.

A **fuse** protects a circuit by **melting when the current is too large**. A **relay** is a switch operated by an **electromagnet**: a small current in its coil switches a **separate circuit carrying a large current**. A **diode** allows current in **one direction only** (arrow direction).

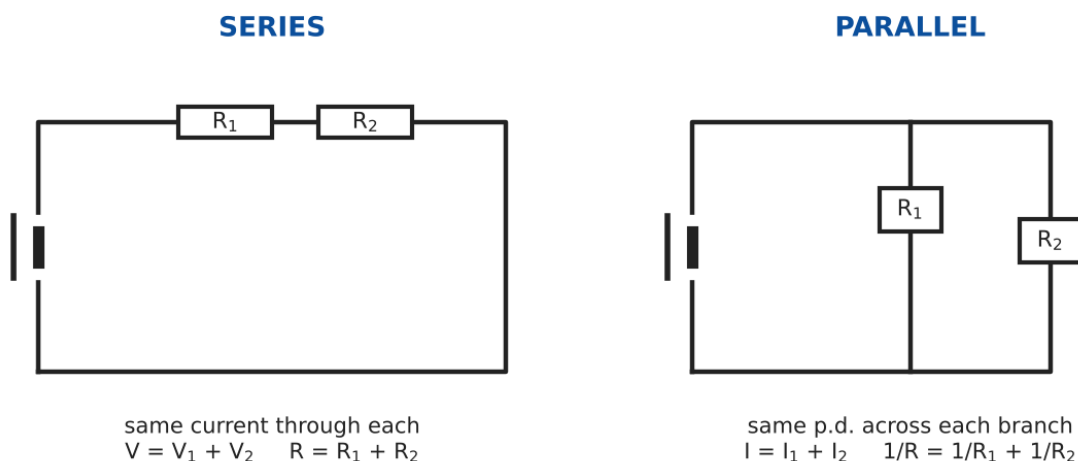


Figure P9.2 Resistors in series and parallel.

	Series circuit	Parallel circuit
Current	The same at every point	Source current = sum of branch currents: $I = I_1 + I_2$; each branch current is smaller than the source current

	Series circuit	Parallel circuit
p.d.	Source p.d. = sum of the p.d.s across components: $V = V_1 + V_2$	Same p.d. across each branch (equal to the source p.d.)
Combined resistance	$R = R_1 + R_2$ (larger than any one resistor)	$1/R = 1/R_1 + 1/R_2$, or $R = R_1 R_2 \div (R_1 + R_2)$ (smaller than either resistor)
If one lamp is removed	All lamps go out (broken circuit)	The other branches still work

WORKED EXAMPLE: Series circuit

Resistors of **4 Ω** and **6 Ω** are in series with a **10 V** battery. **$R = 4 + 6 = 10 \Omega$** ; **$I = V \div R = 10 \div 10 = 1.0 \text{ A}$** .
p.d. across the 4 Ω resistor = $IR = 1.0 \times 4 = 4 \text{ V}$; across the 6 Ω resistor = **6 V** ($4 + 6 = 10 \text{ V}$ ✓).

WORKED EXAMPLE: Parallel circuit

Resistors of **6 Ω** and **3 Ω** are in parallel with a **12 V** battery. **Combined $R = (6 \times 3) \div (6 + 3) = 2 \Omega$** .
Branch currents: $12 \div 6 = 2 \text{ A}$ and $12 \div 3 = 4 \text{ A}$. Source current = $2 + 4 = 6 \text{ A}$ ($= 12 \div 2$ ✓).

EXAM TIP

In **parallel**, the **combined resistance is always smaller** than the smallest resistor, a useful check on your answer. Two equal resistors R in parallel give **$R/2$** .

Advantages of parallel wiring in homes: each appliance gets the **full mains voltage**, each can be switched on and off **separately**, and if one fails the others **still work**. **Lamps in series** share the voltage, so they are **dimmer**.

Exercise P9: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P9.1** Name the circuit components represented by (a) a circle with A, (b) a circle with a cross, (c) a triangle with a bar.
- P9.2** State the function of a fuse.
- P9.3** Calculate the combined resistance of 15 Ω , 25 Ω and 10 Ω in series.
- P9.4** Calculate the combined resistance of 12 Ω and 4 Ω in parallel.
- P9.5** Two 10 Ω resistors are connected in parallel across a 6 V battery. Calculate the current from the battery.
- P9.6** In a series circuit with 9 V supply, a 6 Ω resistor and a 3 Ω resistor. Find the p.d. across the 3 Ω resistor.
- P9.7** State why household appliances are connected in parallel.
- P9.8** Ammeter A1 in the main circuit reads 3 A; branch ammeter A2 reads 1.2 A. Find the current in the other branch.
- P9.9** What happens to the resistance of the circuit when another resistor is added in parallel?
- P9.10** Explain why a variable resistor can be used to dim a lamp.

EXAM-STYLE QUESTION · P9 · [9 marks]

A 12 V battery is connected to a $20\ \Omega$ resistor in series with a parallel combination of a $30\ \Omega$ resistor and a $60\ \Omega$ resistor.

- (a) Calculate the combined resistance of the $30\ \Omega$ and $60\ \Omega$ resistors. [2]
- (b) Calculate the total resistance of the circuit. [1]
- (c) Calculate the current from the battery. [2]
- (d) Calculate the p.d. across the parallel combination. [2]
- (e) Calculate the current in the $60\ \Omega$ resistor. [2]

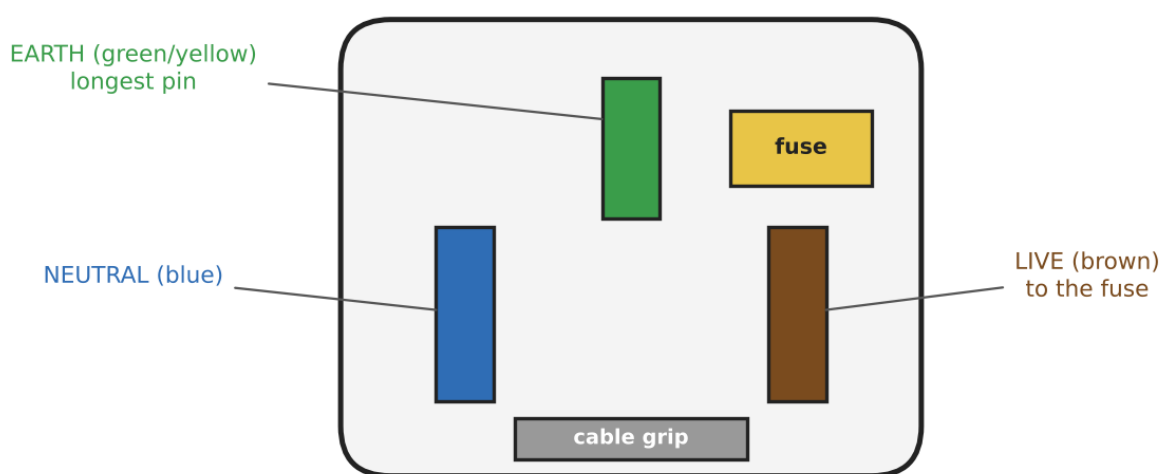
P10 Practical Electricity and Safety

Syllabus reference: **P10.1 to P10.7**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Wire a **three-pin plug**; state the uses of electricity in **heating, lighting and motors**.
- Use **$P = IV$** and **$E = IVt$** .
- Describe **semiconductors, LEDs and fluorescent lamps**.
- Describe **electrical hazards and safety devices**.

P10.1 The three-pin plug



Three-pin plug (back view, earth pin at the top)

Figure P10.1 A three-pin plug.

- **Live wire: brown**, connected to the **fused pin** (the right-hand pin when you look into the open back with the earth pin at the top). **Neutral: blue**. **Earth: green and yellow stripes**, connected to the **longest, top pin**.
- The **cable grip** holds the cable firmly so the wires are **not pulled out**. Wires must be **firmly connected with no bare copper showing**.
- The **fuse** is in the **live wire**, so the appliance is **dead** when the fuse blows. Use a **fuse with the correct rating**, a little above the normal current (e.g. 3 A, 5 A, 13 A).

P10.2 and P10.3 Power and energy

CORE CONCEPT

Electrical power is the **rate of transferring electrical energy**: **$P = IV$** (watts = amperes $\times$ volts).
Electrical energy: **$E = Pt = IVt$** (joules). The kilowatt-hour: **$1 \text{ kWh} = 1 \text{ kW} \times 1 \text{ h} = 3\,600\,000 \text{ J}$** .

WORKED EXAMPLE: Power, current and fuse

A kettle is rated **2300 W** at **230 V**. **Current $I = P \div V = 2300 \div 230 = 10 \text{ A}$** (so a **13 A** fuse suits it). In **3 minutes** it uses **$E = Pt = 2300 \times 180 = 414\,000 \text{ J}$** . In **2 hours** it uses **$2.3 \text{ kW} \times 2 \text{ h} = 4.6 \text{ kWh}$** ; at **E2 per kWh** the cost is **E9.20**.

- **Heating:** a **high-resistance wire (nichrome)** gets hot when current passes (kettle, toaster, iron). **Lighting:** filament lamps (inefficient, mostly heat), **fluorescent** and **LED** lamps (efficient). **Motors:** electrical energy → kinetic energy (fans, pumps).
- **Lamps in a house are connected in parallel:** each lamp has the full mains voltage and works independently.

P10.4 and P10.5 Semiconductors and energy-saving lamps

- A **semiconductor** (silicon, germanium) conducts **better than an insulator but worse than a metal**. **Doping** with small amounts of another element creates **n-type** (extra electrons) or **p-type** (shortage of electrons, called holes) material. A **p-n junction** forms a **diode**.
- **Fluorescent lamps** contain **mercury vapour at low pressure**. **Electric current excites the mercury atoms**, which emit **ultraviolet**; the **phosphor coating** inside the tube turns this into **visible light**. They are **about 4 to 5 times more efficient** than filament lamps and last longer.
- **LEDs (light-emitting diodes)** are more efficient and last longest (see P15).

P10.6 and P10.7 Hazards and safety

Hazard	Danger	Safety measure
Damaged insulation	Exposed live wire: electric shock or short circuit	Replace damaged cable; use double insulation (plastic casing)
Overheated cables	Fire: too many appliances on one socket (overload) or thin cable	Use correct fuse , correct cable thickness ; do not overload sockets
Damp conditions	Water conducts, lowering resistance: shock	Keep electrical appliances dry ; no switches in bathrooms; use a circuit breaker (RCD)
Broken fluorescent lamp	Mercury vapour is poisonous	Ventilate; clean up with gloves and dispose of safely

- **Fuse:** a thin wire that **melts** if the current exceeds its rating, breaking the circuit. **Circuit breaker:** an electromagnetic switch that **trips** and can be reset.
- **Earthing:** the metal case of an appliance is connected to the **earth pin**. If a **live wire touches the case**, a **large current** flows to earth, **blowing the fuse** and making the case **safe**.
- **Double insulation:** the appliance has an **insulating plastic case** so there is **no need for an earth wire** (symbol: two squares). **Switches** are placed in the **live wire** so the appliance is **dead when it is off**.

Exercise P10: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P10.1** State the colours of the live, neutral and earth wires.
- P10.2** Explain why the fuse is placed in the live wire.
- P10.3** A heater is rated 1500 W at 230 V. Calculate the current and choose a fuse from 3 A, 5 A, 13 A.
- P10.4** A 60 W lamp is used for 5 hours. Calculate the energy in kWh and joules.
- P10.5** A 12 V motor with a current of 3.0 A runs for 10 s. Calculate the electrical energy.
- P10.6** Explain how earthing protects the user of a metal-cased kettle.
- P10.7** Give two reasons why parallel circuits are used for house lighting.
- P10.8** Explain how a fluorescent lamp produces light.
- P10.9** State one hazard from (a) damaged insulation, (b) damp conditions.
- P10.10** What is double insulation?

EXAM-STYLE QUESTION · P10 · [9 marks]

An electric kettle is marked 230 V, 2.3 kW. It is connected to a three-pin plug containing a fuse.

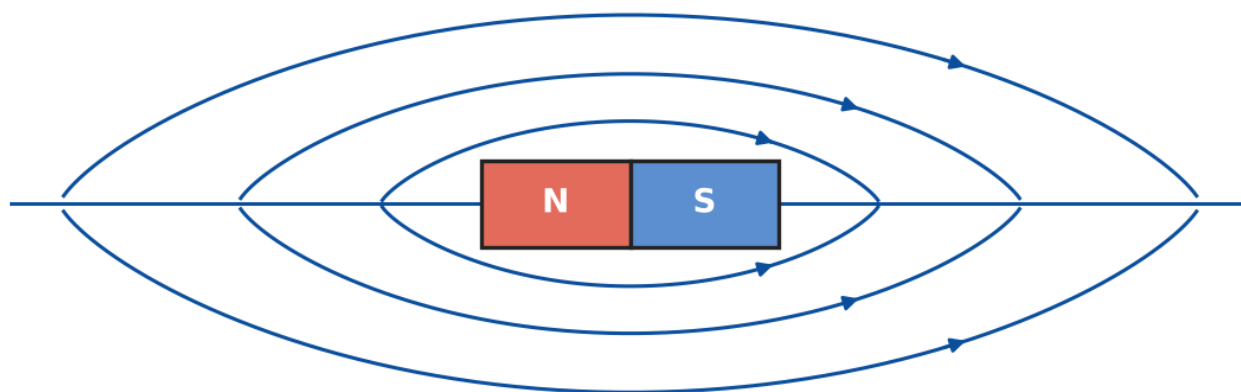
- (a) Calculate the current taken by the kettle. [2]
- (b) State the colour of the wire connected to the fuse. [1]
- (c) Explain why a 3 A fuse would not be suitable. [1]
- (d) Calculate the energy transferred in 4 minutes. [2]
- (e) Explain how the earth wire protects a user if the live wire touches the metal case. [3]

P11 Magnetism

Syllabus reference: **P11.1 to P11.6**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- State the **properties of magnets, magnetic induction and magnetic field lines**.
- Distinguish **magnetic (ferrous) and non-magnetic materials**, and **iron and steel**.
- Explain magnetism using the **domain theory**.
- A **magnet has two poles, north (N) and south (S)**, where the force is strongest. A freely suspended magnet **points north–south**.
- **Like poles repel; unlike poles attract. Repulsion is the only sure test for a magnet** (a magnet and an unmagnetised iron both attract the iron).
- **Magnetic materials (iron, steel, nickel and cobalt)** are attracted by magnets and can be magnetised; **non-magnetic materials** (copper, aluminium, plastics, wood) are not. A material attracted to a magnet is **ferrous**.
- **Magnetic induction:** a magnetic material becomes a temporary magnet when it is **near or touching a magnet**. The end nearest the magnet gets the **opposite pole**, so it is **attracted**.
- A **magnetic field** is a region where a magnetic material or another magnet **experiences a force**. The direction of the field is the direction in which a **free north pole** would move.



Field lines run from N to S outside the magnet and are closest together at the poles

Figure P11.1 Magnetic field lines around a bar magnet.

Plotting a field: place a bar magnet on paper; use a **small plotting compass** (or iron filings sprinkled on card to show the pattern). Mark the compass needle positions, join the dots and add arrows from **N to S**. Between **two unlike poles** the lines go straight from one to the other; between **two like poles** they bend away from each other, with a **neutral point** in the middle where the field is zero.

	Iron (soft)	Steel (hard)
Magnetising	Easy to magnetise	Harder to magnetise
Keeping magnetism	Loses it quickly (temporary magnets)	Keeps it (permanent magnets)

	Iron (soft)	Steel (hard)
Uses	Electromagnet cores, relays, transformer cores	Permanent magnets, compass needles

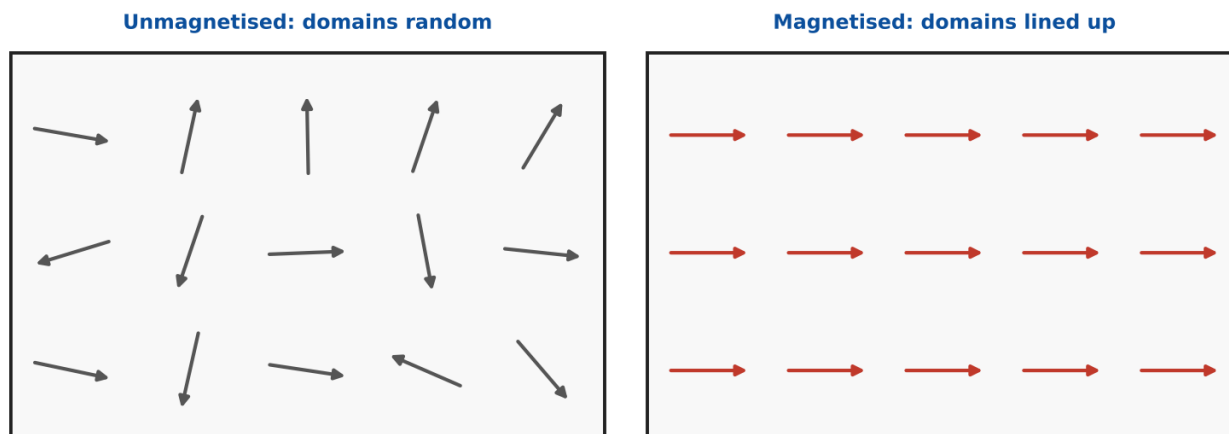


Figure P11.2 Domain theory of magnetism.

Domain theory: a magnetic material is made of tiny regions called **domains**, each a small magnet. In an **unmagnetised** material the domains **point in random directions** and their effects cancel. In a **magnetised** material the domains **line up** in the same direction. **Magnetising:** stroke with a magnet or place in a **solenoid with a d.c. current**. **Demagnetising:** hammering, **heating** or placing in a solenoid carrying **decreasing a.c.** shakes the domains into random directions. **Cutting a magnet** gives two smaller magnets, each with N and S poles, because **each piece still contains aligned domains**.

EXAM TIP

A **magnetic screen** (soft iron ring) protects instruments by **concentrating field lines** through the iron rather than the space inside it.

Exercise P11: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P11.1** State the law of magnetic poles.
- P11.2** Which materials are magnetic: copper, nickel, steel, aluminium, cobalt?
- P11.3** Explain why repulsion is the only certain test for a magnet.
- P11.4** Describe how to plot the magnetic field of a bar magnet using a compass.
- P11.5** State one use each for iron and steel in magnetism.
- P11.6** A bar magnet is broken in two. State the poles at the break.
- P11.7** Explain, using domains, the difference between magnetised and unmagnetised steel.
- P11.8** Describe two ways of demagnetising a magnet.
- P11.9** What is magnetic induction?
- P11.10** Why is soft iron used for electromagnet cores?

EXAM-STYLE QUESTION · P11 · [7 marks]

A learner has a bar magnet, a steel nail and a copper rod.

- (a) State which of the two rods can be magnetised. [1]
- (b) Describe how to magnetise the steel nail using the bar magnet. [2]
- (c) Explain, using domains, why the nail is now magnetised. [2]
- (d) State a test to show that the nail is a magnet and not just a piece of iron. [1]
- (e) State one way to demagnetise the nail. [1]

P12 Digital Electronics and Logic Gates

Syllabus reference: **P12.1 to P12.5**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Distinguish **analogue** and **digital** signals.
- Describe and use **NOT, AND, OR, NAND** and **NOR** gates, their **symbols** and **truth tables**.
- Design and interpret **simple logic circuits**.

An **analogue signal** varies **continuously** and can take **any value** within a range (e.g. a sound wave, a thermometer). A **digital signal** has **only two states**, **high (1, 'on', about 5 V)** and **low (0, 'off', 0 V)** and is used by computers and logic circuits. Digital signals are **less affected by noise** and can be **regenerated** without loss.

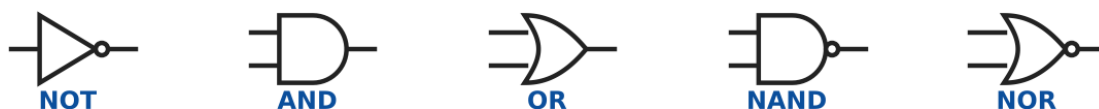
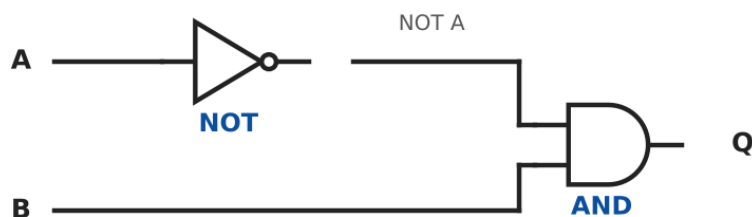


Figure P12.1 Logic gate symbols.

Logic gates are circuits that make decisions from digital inputs. A **truth table** lists the output for every combination of inputs.

A	B	NOT A	AND	OR	NAND	NOR
0	0	1	0	0	1	1
0	1	1	0	1	1	0
1	0	0	0	1	1	0
1	1	0	1	1	0	0

- **NOT** (inverter): has **one input** and **reverses** it (output = opposite of input).
- **AND**: output is **1 only when both inputs are 1**. **OR**: output is **1 when either or both inputs are 1**.
- **NAND** = AND followed by NOT: output is **0 only when both inputs are 1** (the **opposite of AND**). **NOR** = OR followed by NOT: output is **1 only when both inputs are 0**.
- The **small circle (bubble)** on a symbol means **NOT**.



$$Q = (\text{NOT } A) \text{ AND } B$$

Figure P12.2 A combination of gates: $Q = (\text{NOT } A) \text{ AND } B$.

A	B	NOT A	$Q = (\text{NOT } A) \text{ AND } B$
0	0	1	0
0	1	1	1
1	0	0	0
1	1	0	0

EXAM TIP

For a combination, **add a column for every intermediate point** in the circuit, working left to right.

Example application: a burglar alarm that sounds if it is dark (NOT light sensor) AND the door is open uses a NOT gate and an AND gate.

Exercise P12: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P12.1** State the difference between an analogue and a digital signal.
- P12.2** Give the output of a NOT gate when the input is 1.
- P12.3** State when the output of (a) an AND gate and (b) a NOR gate is 1.
- P12.4** Complete: $A = 1$, $B = 0$. Give the output of AND, OR, NAND, NOR.
- P12.5** What does the small circle at the output of a gate symbol mean?
- P12.6** A NAND gate has its two inputs joined together. Which gate does it behave as?
- P12.7** Draw the truth table for an OR gate followed by a NOT gate.
- P12.8** Design a circuit for a lamp that comes on if a switch is pressed AND it is dark. Name the gates.
- P12.9** State two advantages of digital signals.
- P12.10** $Q = (A \text{ OR } B) \text{ AND NOT-}C$. Find Q for $A = 0$, $B = 1$, $C = 0$.

EXAM-STYLE QUESTION · P12 · [8 marks]

A logic circuit has inputs A and B joined to an AND gate. The output of the AND gate is connected to the input of a NOT gate, whose output is Q.

- (a) Name the single gate that has the same action as this combination. [1]
- (b) Complete the truth table for A = 0, 0, 1, 1 and B = 0, 1, 0, 1 for Q. [3]
- (c) State the output for A = 1 and B = 1. [1]
- (d) Explain the difference between analogue and digital signals. [2]
- (e) Give one use of a logic gate circuit. [1]

P13 Electromagnetic Effects

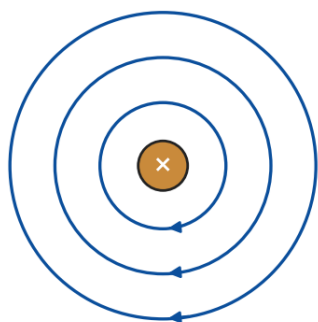
Syllabus reference: **P13.1 to P13.4**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the **magnetic field of a current-carrying wire and a solenoid**; compare **electromagnets and permanent magnets**.
- Describe **electromagnetic induction** and the **a.c. generator**.
- Describe the **force on a current-carrying conductor** and the **d.c. motor**.
- Describe the **transformer** and **high-voltage transmission**.

P13.1 Electromagnets

Straight wire: circular field
(current into the page)



Solenoid: field like a bar magnet

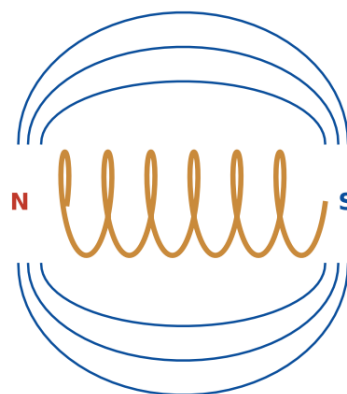


Figure P13.1 The magnetic field of a straight wire and a solenoid.

A **current-carrying wire** has a **circular magnetic field** around it. The field is **stronger when the current is larger** and **closer to the wire**. A **solenoid** (a long coil) has a field like a **bar magnet**. An **electromagnet** is a solenoid wound round a **soft iron core**.

- **Factors increasing the strength of an electromagnet:** a **larger current**, **more turns** of wire, and a **soft iron core**.
- **Electromagnets can be switched on and off** and their strength changed; **permanent magnets** (steel) cannot. **Uses:** **electric bells**, **relays**, **scrap-yard cranes**, **circuit breakers**, **loudspeakers**.

P13.2 Electromagnetic induction

CORE CONCEPT

Electromagnetic induction: an **e.m.f.** is induced in a conductor whenever the magnetic field through it changes (a wire cutting field lines, or a magnet moving in or out of a coil). **Lenz's law:** the direction of the induced e.m.f. (and current) opposes the change that produces it.

- **Experiment:** move a bar magnet in and out of a coil connected to a **sensitive galvanometer**. The needle **deflects** while the magnet moves, **in opposite directions** when it moves in and out, and does **nothing** when the magnet is still.
- **Factors increasing the induced e.m.f.:** **faster movement**, a **stronger magnet**, **more turns** on the coil.

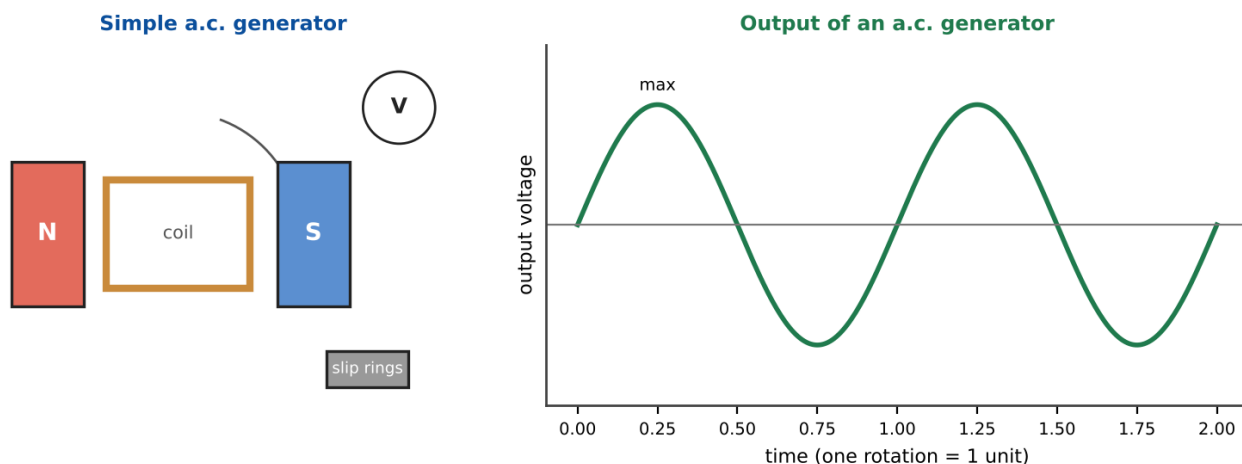


Figure P13.2 A simple a.c. generator and the output voltage–time graph.

In an **a.c. generator**, a **coil rotates in a magnetic field**; the wires cut field lines, so an **e.m.f. is induced**. **Slip rings and carbon brushes** connect the coil to the external circuit without twisting the wires. The output is **alternating (a.c.)**: it is **maximum when the coil is horizontal (cutting lines fastest)** and **zero when vertical**. A **diode** can act as a **rectifier**, allowing current in one direction only, so **a.c. is changed to d.c. (half-wave)**.

P13.3 The motor effect

A **current-carrying wire in a magnetic field experiences a force** (the **motor effect**). The force is **at right angles to both the field and the current** (Fleming's left-hand rule: **First finger = Field, seCond finger = Current, thuMb = Motion**). The force reverses if the current or the field is reversed. It is greater with a larger current or a stronger field.

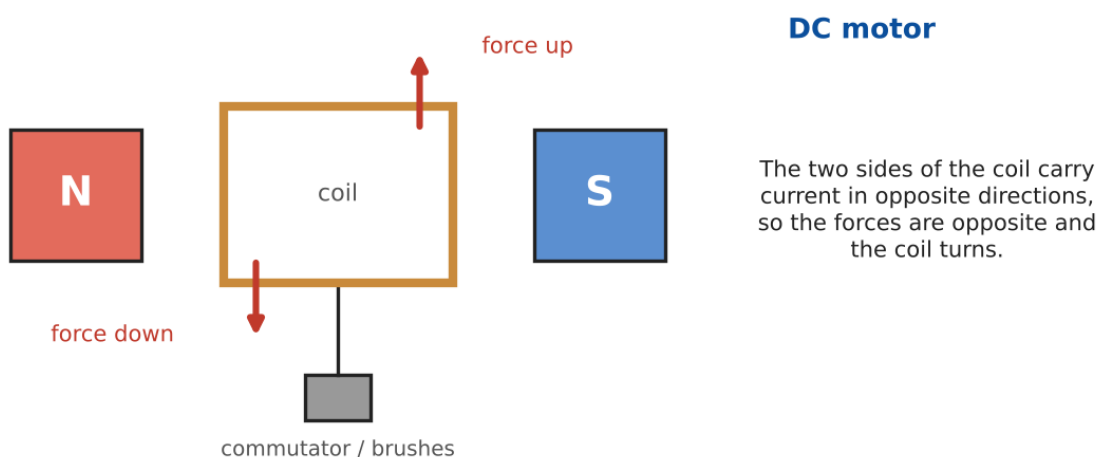


Figure P13.3 A simple d.c. motor.

In a **d.c. motor**, a **coil in a magnetic field has current flowing in opposite directions on its two sides**, giving forces in **opposite directions** and a **turning effect**. The **commutator (split ring)** reverses the current every half turn so the coil keeps turning in the same direction. The turning effect is increased by **more turns, a larger current, a stronger magnet**. **Applications:** fans, hairdryers, electric gates, power tools.

P13.4 Transformers

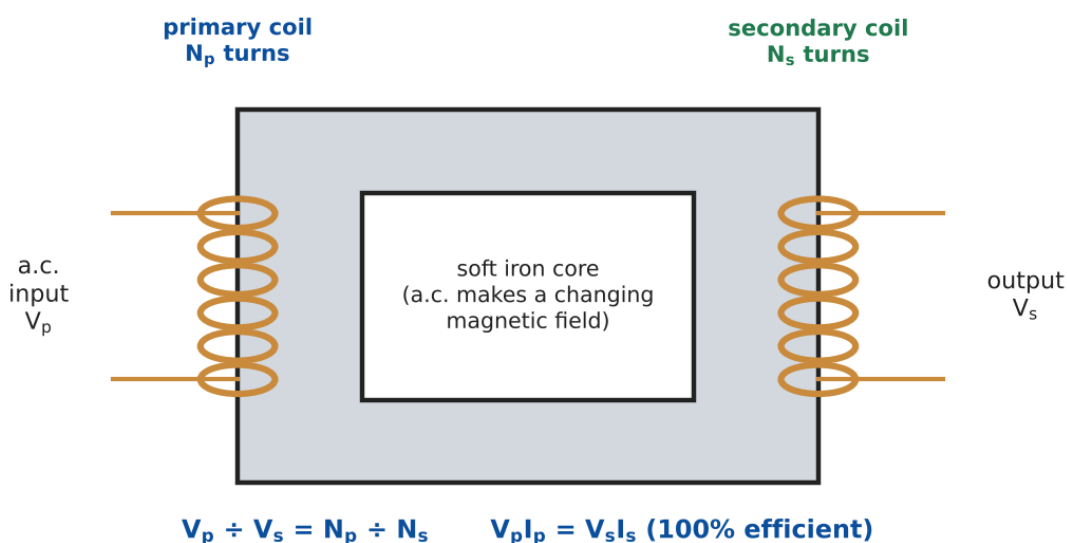


Figure P13.4 A transformer.

A **transformer** changes an **alternating voltage** to a bigger or smaller value. An **alternating current** in the **primary coil** produces a **changing magnetic field** in the **iron core**, which **induces an alternating e.m.f.** in the **secondary coil**. It does not work with d.c. (no changing field).

$$V_p \div V_s = N_p \div N_s \text{ and } V_p I_p = V_s I_s$$

- **Step-up transformer:** $N_s > N_p$, output voltage larger. **Step-down:** $N_s < N_p$, output voltage smaller.
- **Power is not increased:** for an **ideal (100% efficient) transformer**, **power in = power out**, so $V_p I_p = V_s I_s$; a step-up transformer has a **smaller output current**.
- **High-voltage transmission:** power stations use **step-up transformers** to transmit at **high voltage** (e.g. 132 kV) and **low current**; **step-down transformers** reduce the voltage near homes. **Smaller current means less energy wasted as heat ($I^2 R$)** in the cables, so **thinner, cheaper cables** can be used.

WORKED EXAMPLE: Transformer

A transformer has **200 turns** on the primary and **50 turns** on the secondary. With **240 V** input: $V_s = 240 \times 50 \div 200 = \mathbf{60 \text{ V}}$ (a **step-down**). If the secondary current is **2.0 A**, power = $60 \times 2.0 = \mathbf{120 \text{ W}}$, so primary current = $120 \div 240 = \mathbf{0.50 \text{ A}}$.

Exercise P13: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P13.1** State three ways of increasing the strength of an electromagnet.
- P13.2** Give one advantage of an electromagnet over a permanent magnet.
- P13.3** State what happens when a magnet is pushed into a coil connected to a galvanometer and then held still.
- P13.4** State two ways of increasing the induced e.m.f.
- P13.5** What is the purpose of slip rings in an a.c. generator?
- P13.6** A wire carrying current is placed in a magnetic field. State two ways to reverse the direction of the force.
- P13.7** Explain the function of the commutator in a d.c. motor.
- P13.8** A transformer has 1000 primary turns and 50 secondary turns; the input is 230 V. Find the output.

P13.9 A 12 V, 3.0 A step-down transformer is 100% efficient. Calculate the primary current when the primary voltage is 240 V.

P13.10 Explain why electricity is transmitted at high voltage.

EXAM-STYLE QUESTION · P13 · [10 marks]

A transformer has 400 turns on its primary coil and 100 turns on its secondary coil. The primary is connected to a 240 V a.c. supply.

- (a) State whether this is a step-up or step-down transformer. [1]
- (b) Calculate the output voltage. [2]
- (c) The secondary current is 2.0 A. Calculate the primary current, assuming 100% efficiency. [3]
- (d) Explain why the transformer does not work with a battery. [2]
- (e) State why power lines use high voltage. [2]

P14 Atomic and Nuclear Physics

Syllabus reference: **P14.1 to P14.3**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the **nucleus**, **nuclide notation** and **isotopes**.
- Describe **alpha**, **beta** and **gamma radiation** and **background radiation**.
- Write **decay equations** and use **half-life**.
- Describe the **uses and dangers** of radioactive materials.



A = nucleon number
= protons + neutrons

e.g. $^{14}_6\text{C}$: 6 protons,
 $14 - 6 = 8$ neutrons

Z = proton number
= number of protons

isotopes: same Z,
different A ($^{12}_6\text{C}$, $^{14}_6\text{C}$)

Figure P14.1 Nuclide notation.

The **nucleus** contains **protons** (positive) and **neutrons** (neutral), together called **nucleons**. The **proton number Z** is the number of protons; the **nucleon number A** is **protons + neutrons**. A **nuclide** is a particular type of nucleus, written ^A_ZX . **Isotopes** are **atoms of the same element (same Z) with different numbers of neutrons (different A)**. They have the **same chemical properties**. **Uses of isotopes**: carbon-14 for **dating** old objects; cobalt-60 for **cancer treatment and sterilising**; iodine-131 as a **medical tracer**; uranium-235 as **nuclear fuel**.

P14.2 Radioactivity

Radioactive decay is the **spontaneous and random** emission of radiation from the **unstable nucleus** of an atom to become more stable. It is **random**: it is impossible to predict when a particular nucleus will decay, and it is **not affected by temperature, pressure or chemical changes**. **Background radiation** is the low level of radiation always present, from **rocks (radon gas)**, **cosmic rays**, **food and medical sources**. It must be **subtracted** from measurements.

	Alpha (α)	Beta (β)	Gamma (γ)
Nature	Helium nucleus (2 protons + 2 neutrons)	A fast electron from the nucleus	Electromagnetic wave (high frequency)
Charge	+2	-1	0
Ionising power	Strongest	Medium	Weakest
Penetration	Weakest: a few cm of air; stopped by paper	Stopped by a few mm of aluminium	Strongest: reduced by thick lead or concrete
Deflection	Small, towards the negative plate	Large, towards the positive plate (opposite direction)	Not deflected

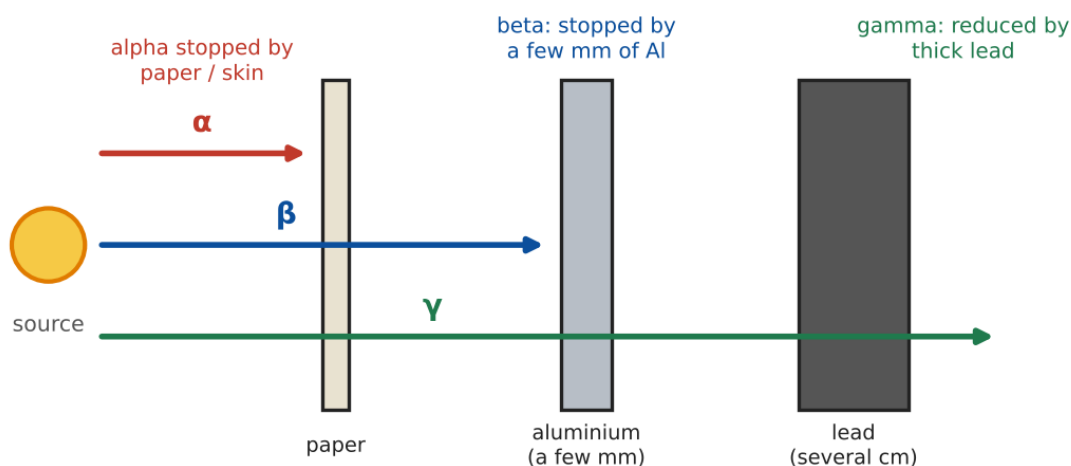


Figure P14.2 Penetrating power of alpha, beta and gamma radiation.

Detection: a **Geiger–Müller (GM) tube** and counter clicks each time radiation enters it; a **cloud chamber** shows **tracks**: alpha gives **thick straight tracks**, beta **thin, wavy tracks**. **Safety:** handle sources with **tongs**, **store in lead-lined boxes**, keep **away from the body**, limit **exposure time**, and use **shielding** (radiation can damage cells and cause **cancer**). **Nuclear power:** **uranium-235** undergoes **fission**; the energy released heats water to make steam for turbines.

P14.3 Decay equations and half-life

- **Alpha decay:** the nucleus loses 2 protons and 2 neutrons: **A falls by 4, Z falls by 2.** ${}_{92}^{238}\text{U} \rightarrow {}_{90}^{234}\text{Th} + {}_2^4\alpha$
- **Beta decay:** a neutron changes into a proton and an electron; the electron leaves: **A unchanged, Z rises by 1.** ${}_{6}^{14}\text{C} \rightarrow {}_{7}^{14}\text{N} + {}_{-1}^0\text{e}$
- **Gamma emission** does not change A or Z; the nucleus just **loses energy**.

CORE CONCEPT

Half-life is the **time taken for half of the radioactive nuclei in a sample to decay** (also the time for the **count rate to fall to half**). Each half-life, the amount left is multiplied by $\frac{1}{2}$: after n half-lives, the fraction left is $(\frac{1}{2})^n$.

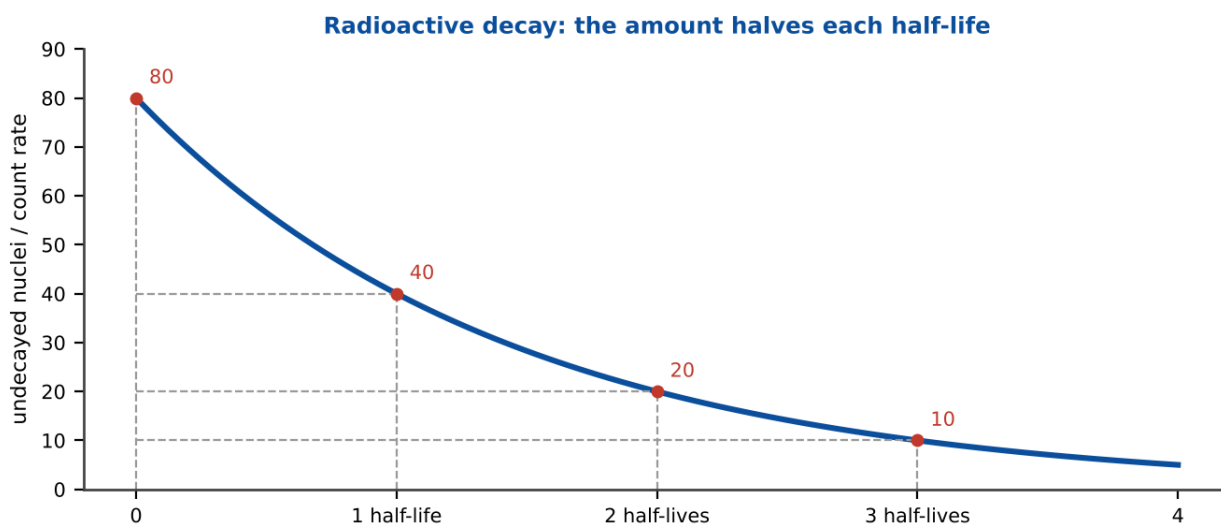


Figure P14.3 A decay curve: the activity halves every half-life.

WORKED EXAMPLE: Half-life

A sample has a count rate of **800 counts/min** and a half-life of **6 hours**. After **18 hours** (3 half-lives) the count rate is $800 \rightarrow 400 \rightarrow 200 \rightarrow \mathbf{100 \text{ counts/min}}$. From a graph: read the time for the activity to fall from 80 to 40; that time is the half-life.

EXAM TIP

Correct for background radiation by subtracting the background count rate from each measurement before finding half-life.

Exercise P14: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

P14.1 A nuclide is written $^{27}_{13}\text{Al}$. State the number of protons, neutrons and nucleons.

P14.2 Define isotopes and give an example.

P14.3 State two sources of background radiation.

P14.4 Name the type of radiation that (a) is stopped by paper, (b) is an electromagnetic wave, (c) is deflected strongly towards the positive plate.

P14.5 Complete: $^{226}_{88}\text{Ra} \rightarrow ^A_Z\text{Rn} + ^4_2\alpha$.

P14.6 Complete: $^{60}_{27}\text{Co} \rightarrow ^{60}_Z\text{Ni} + ^0_{-1}\text{e}$.

P14.7 A radioactive sample has a half-life of 10 days. What fraction remains after 30 days?

P14.8 The count rate of a source falls from 640 to 80 counts/min in 15 minutes. Find the half-life.

P14.9 State two safety precautions when using radioactive sources.

P14.10 Explain why gamma rays are used for sterilising medical equipment.

EXAM-STYLE QUESTION · P14 · [9 marks]

A radioactive source of americium emits alpha particles. A student places a GM tube 2 cm from the source.

- | | |
|--|-----|
| (a) State what an alpha particle is. | [1] |
| (b) Explain why the count rate falls to almost zero when a sheet of paper is placed between the source and the tube. | [2] |
| (c) The background count is 20 counts/min and the total with the source is 340 counts/min. Calculate the count rate from the source. | [2] |
| (d) Another source has an initial count rate of 480 counts/min (after correction) and a half-life of 4 minutes. Calculate the count rate after 12 minutes. | [3] |
| (e) Write down one safety precaution for storing radioactive sources. | [1] |

P15 Light-Emitting Diodes (LEDs)

Syllabus reference: **P15.1 to P15.3**

BY THE END OF THIS CHAPTER YOU SHOULD BE ABLE TO

- Describe the **structure of an LED (p-n junction)**.
- Describe the **principle of operation** of an LED.
- Explain how LEDs produce a **picture in flat-screen monitors**.

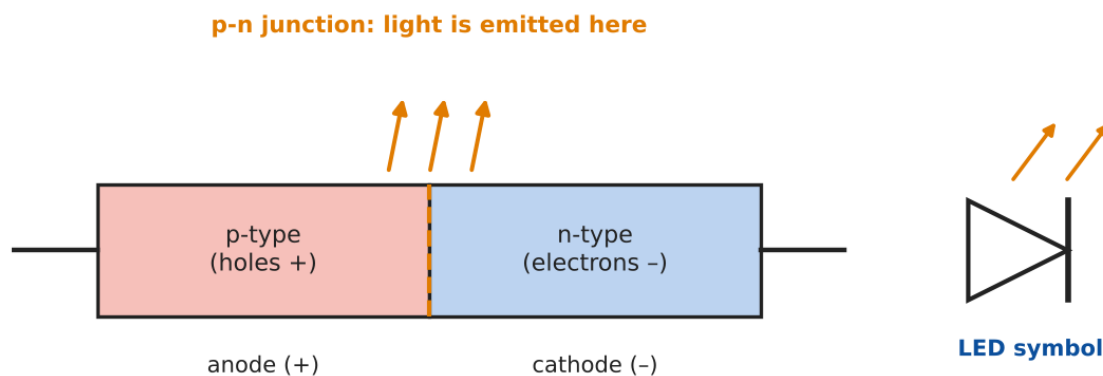
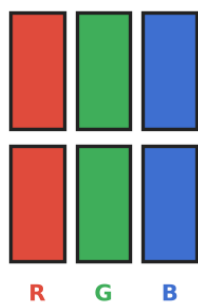


Figure P15.1 An LED has a p-n junction; light is emitted at the junction.

- An **LED (light-emitting diode)** is a **semiconductor diode** made of a **p-type** layer (rich in **holes**, which act as positive charge carriers) joined to an **n-type** layer (rich in **free electrons**). The boundary is the **p-n junction**.
- **Operation:** the LED must be **forward biased** (anode to +, cathode to -). **Electrons from the n-side and holes from the p-side move towards the junction and combine**. When an electron **falls into a hole**, it **releases energy as a photon of light**. The **colour depends on the semiconductor material** (the energy released).
- If connected the **wrong way round** (reverse biased), **no current flows** and **no light** is produced. A **series resistor** limits the current and protects the LED.
- **Advantages of LEDs:** **very efficient** (little energy wasted as heat), **long-lasting**, **robust**, switch on instantly, and **small**. They are used in **indicator lamps, torches, traffic lights, street lamps and TV/computer screens**.

one pixel = 3 LEDs



Flat-screen monitor



millions of pixels, each with red, green and blue LEDs. The brightness of each colour is controlled separately; mixing R, G, B gives any colour (all three on = white).

Figure P15.2 How an LED screen makes a picture.

A **flat-screen monitor or television** is made of a grid of millions of tiny **pixels**. Each pixel has **three LEDs (red, green and blue)**. A **controller** switches each LED on, at a **chosen brightness** many times a second. **Mixing different brightnesses of red, green and blue produces any colour**: all three at full brightness give **white**, none gives **black**. Because LEDs are **small and thin**, the screens can be **thin, bright and energy efficient**.

EXAM TIP

Be able to state: **forward bias** → **electrons and holes meet at the junction** → **energy released as light**.

Exercise P15: check your understanding

Answer in your exercise book, then check your work in the **Answer Key** at the back of this guide.

- P15.1** Name the two types of semiconductor in an LED.
- P15.2** Describe the charge carriers in n-type and p-type material.
- P15.3** Explain how an LED produces light.
- P15.4** State how the LED must be connected for it to light.
- P15.5** Why is a resistor connected in series with an LED?
- P15.6** State two advantages of LED lamps over filament lamps.
- P15.7** What colours of LED make up each pixel in a screen?
- P15.8** How can a screen show white?
- P15.9** Explain why an LED does not light when connected the wrong way round.
- P15.10** State what determines the colour of light from an LED.

EXAM-STYLE QUESTION · P15 · [8 marks]

A red LED is connected in series with a resistor and a 6 V battery.

- (a) State the name of the junction inside an LED. [1]
- (b) Explain how light is produced at the junction. [2]
- (c) State why a resistor is used. [1]
- (d) The battery is reversed. State and explain what happens. [2]
- (e) Explain how an LED screen produces coloured pictures. [2]

Mixed Practice Paper

Paper 1 style. Answer **all 20 questions**. Each question has four options, **A, B, C and D**. Choose the **one** correct answer and write its letter. Each question is worth **1 mark** (total **20 marks**). Allow **25 minutes**. Use $g = 10 \text{ m/s}^2$. The answers are in the **Answer Key**.

1. Which instrument measures the diameter of a thin wire most accurately?
A micrometer screw gauge
B metre rule
C vernier callipers
D measuring tape
2. A block has a mass of 120 g and a volume of 40 cm^3 . What is its density?
A 0.33 g/cm^3
B 3.0 g/cm^3
C 80 g/cm^3
D 4800 g/cm^3
3. A car accelerates uniformly from rest to 20 m/s in 5 s. What is its acceleration?
A 0.25 m/s^2
B 5 m/s^2
C 4 m/s^2
D 100 m/s^2
4. A resultant force of 12 N acts on a mass of 3 kg. What is the acceleration?
A 0.25 m/s^2
B 9 m/s^2
C 15 m/s^2
D 4 m/s^2
5. What is the kinetic energy of a 2 kg object moving at 3 m/s?
A 3 J
B 6 J
C 9 J
D 18 J
6. A wave has a frequency of 5 Hz and a wavelength of 0.4 m. What is its speed?
A 0.08 m/s
B 2 m/s
C 12.5 m/s
D 20 m/s
7. Light passes from air into glass with $i = 45^\circ$ and $r = 30^\circ$. What is the refractive index?
A 0.71
B 1.2
C 1.4
D 1.5
8. By which method does heat from the Sun reach the Earth?
A radiation
B conduction
C convection
D evaporation

9. A 6 V battery is connected across a 12 Ω resistor. What current flows?
- A 0.5 A
 - B 2 A
 - C 6 A
 - D 72 A
10. What is the combined resistance of two 6 Ω resistors in parallel?
- A 3 Ω
 - B 6 Ω
 - C 9 Ω
 - D 12 Ω
11. A heater takes 2 A from a 230 V supply. What is its power?
- A 115 W
 - B 232 W
 - C 920 W
 - D 460 W
12. A transformer has 100 primary turns and 25 secondary turns. The primary voltage is 240 V. What is the secondary voltage?
- A 10 V
 - B 60 V
 - C 96 V
 - D 960 V
13. A radioactive source has a half-life of 4 days. What fraction remains after 12 days?
- A 1/2
 - B 1/3
 - C 1/6
 - D 1/8
14. How many electrons are in a sodium ion, Na^+ (proton number 11)?
- A 11
 - B 12
 - C 10
 - D 23
15. How many moles are in 11 g of carbon dioxide ($M_r = 44$)?
- A 0.25
 - B 0.5
 - C 4
 - D 11
16. Which pH value shows a strong alkali?
- A 1
 - B 7
 - C 9
 - D 13
17. What is the test for hydrogen gas?
- A relights a glowing splint
 - B turns limewater milky
 - C burns with a squeaky pop
 - D bleaches damp litmus paper

18. Molten lead(II) bromide is electrolysed using inert electrodes. What forms at the cathode?

- A lead
- B bromine
- C hydrogen
- D oxygen

19. Which hydrocarbon decolourises bromine water?

- A ethane
- B ethene
- C methane
- D propane

20. Which catalyst is used in the Haber process?

- A nickel
- B iron
- C platinum
- D vanadium(V) oxide

YOUR SCORE

Total: _____ / 20. **18 to 20:** excellent. **14 to 17:** good, revise the topics you missed. **Below 14:** read the chapters again and repeat the exercises.

Appendix A: Symbols and Units

The quantities, symbols and units below follow the syllabus. Use SI units in calculations and write the unit after every numerical answer.

Quantity	Usual symbol	SI unit and symbol
length	l, d, h	metre, m
area	A	square metre, m^2
volume	V	cubic metre, m^3 ; also dm^3, cm^3
weight	W	newton, N
mass	m	kilogram, kg
time	t	second, s
density	ρ	kg/m^3 or g/cm^3
speed, velocity	u, v	m/s
acceleration	a	m/s^2
acceleration of free fall	g	$10\ m/s^2$ ($10\ N/kg$)
force	F	newton, N
work done, energy	W, E	joule, J
power	P	watt, W
frequency	f	hertz, Hz
wavelength	λ	metre, m
temperature	T, θ	kelvin, K; degree Celsius, $^{\circ}C$
charge	Q	coulomb, C
current	I	ampere, A
potential difference, e.m.f.	V, E	volt, V
resistance	R	ohm, Ω
amount of substance	n	mole, mol
relative atomic / molecular mass	A_r, M_r	no unit
concentration	c	mol/dm^3 or g/dm^3

Appendix B: Key Equations

Learn these equations. The syllabus expects you to **recall and use** them; they are not given on the paper.

Topic	Equation	Symbols and units
Density	$\rho = m \div V$	kg/m ³ ; kg; m ³
Speed	$v = d \div t$	m/s; m; s
Acceleration	$a = (v - u) \div t$	m/s ²
Weight	$W = m g$	N; kg; $g = 10 \text{ N/kg}$
Force	$F = m a$	N; kg; m/s ²
Hooke's law	$F = k e$	N; N/m; m
Moment	$\text{moment} = F \times d$	N m
Work	$W = F \times d$	J
Kinetic energy	$\text{k.e.} = \frac{1}{2} m v^2$	J
Potential energy	$\text{p.e.} = m g h$	J
Power	$P = E \div t = W \div t$	W
Efficiency	$(\text{useful output} \div \text{total input}) \times 100\%$	%
Wave speed	$v = f \lambda$	m/s; Hz; m
Refractive index	$n = \sin i \div \sin r$	no unit
Charge	$Q = I t$	C; A; s
Ohm's law	$V = I R$	V; A; Ω
Series resistors	$R = R_1 + R_2$	Ω
Parallel resistors	$1/R = 1/R_1 + 1/R_2$	Ω
Electrical power and energy	$P = I V$; $E = I V t$	W; J
Transformer	$V_p \div V_s = N_p \div N_s$; $V_p I_p = V_s I_s$	V; turns; A
Moles from mass	$n = m \div M_r$	mol; g
Moles of gas (r.t.p.)	$n = V \div 24$	mol; dm ³
Concentration	$c = n \div V$	mol/dm ³ ; mol; dm ³
Percentage composition	$(A_r \times \text{atoms} \div M_r) \times 100\%$	%

Answer Key

Answers to every exercise and exam-style question, in chapter order. In exam-style answers, **[1]** shows where a mark is earned. Accept any other correct answer.

Mixed practice paper (20 marks)

Q	Ans.	Working	Q	Ans.	Working
1	A	A micrometer reads to 0.01 mm.	11	D	$P = IV = 2 \times 230 = 460 \text{ W}$.
2	B	$\rho = 120 \div 40 = 3.0 \text{ g/cm}^3$.	12	B	$V_s = 240 \times 25 \div 100 = 60 \text{ V}$.
3	C	$a = (v - u) \div t = 20 \div 5 = 4 \text{ m/s}^2$.	13	D	12 days = 3 half-lives; $(\frac{1}{2})^3 = 1/8$.
4	D	$a = F \div m = 12 \div 3 = 4 \text{ m/s}^2$.	14	C	$11 - 1 = 10$ electrons.
5	C	k.e. = $\frac{1}{2} \times 2 \times 3^2 = 9 \text{ J}$.	15	A	$n = 11 \div 44 = 0.25 \text{ mol}$.
6	B	$v = f\lambda = 5 \times 0.4 = 2 \text{ m/s}$.	16	D	pH 13 is strongly alkaline.
7	C	$n = \sin 45^\circ \div \sin 30^\circ = 0.707 \div 0.5 = 1.4$.	17	C	Hydrogen burns with a squeaky pop.
8	A	Radiation does not need a medium.	18	A	Positive lead ions gain electrons at the cathode.
9	A	$I = V \div R = 6 \div 12 = 0.5 \text{ A}$.	19	B	Only the alkene (C=C) reacts.
10	A	$R = (6 \times 6) \div 12 = 3 \Omega$.	20	B	Iron is the catalyst for $\text{N}_2 + 3\text{H}_2 \rightleftharpoons 2\text{NH}_3$.

C1 Introduction to Chemistry

- C1.1** (a) pipette; (b) burette; (c) measuring cylinder.
- C1.2** (a) $2.5 \times 1000 = \mathbf{2500 \text{ cm}^3}$; (b) $350 \div 1000 = \mathbf{0.350 \text{ dm}^3}$.
- C1.3** Eye **level with the liquid surface**; read the **bottom** of the meniscus.
- C1.4** A reading error caused by viewing the scale from above or below the surface. Avoid it by keeping the **eye level with the meniscus**.
- C1.5** $26.35 - 2.10 = \mathbf{24.25 \text{ cm}^3}$.
- C1.6** Yes: all are within 0.10 cm^3 . Mean = $(23.80 + 23.85 + 23.75) \div 3 = \mathbf{23.80 \text{ cm}^3}$.
- C1.7** A pipette is **more accurate** because it has one fixed volume and a single graduation mark; the titration result depends on an exact volume of alkali.
- C1.8** Any two: rinse with the solution; use a funnel and then **remove** it; fill above 0; run liquid through the tap to remove any **air bubble** from the tip; clamp upright; read at eye level.

Exam-style question C1

- (a) measuring cylinder **[1]**; the pipette is more accurate / measures an exact volume **[1] [2]**
- (b) $25.40 - 1.20 \text{ [1]} = 24.20 \text{ cm}^3 \text{ [1] [2]}$
- (c) level with the bottom of the meniscus **[1]**
- (d) repeat the titration until two results are concordant and take the mean **[1]**

C2 Particulate Nature of Matter

- C2.1** Solid: particles **close together** in a **regular pattern**. Gas: particles **far apart** and **random**.
- C2.2** (a) melting; (b) condensing (condensation); (c) sublimation.
- C2.3** Gas particles are **far apart** (large gaps) so can be pushed closer; liquid particles are **already touching**.
- C2.4** The heat energy is used to **overcome the forces between the particles** (change state), not to increase their kinetic energy.

- C2.5** The **net movement of particles from a region of high concentration to a region of low concentration** due to random motion.
- C2.6** Particles of the purple solid and water particles **move randomly and mix** (diffusion), moving from higher to lower concentration until evenly spread.
- C2.7** NH_3 has a **lower relative molecular mass** ($17 < 36.5$), so it **diffuses faster** and travels further before meeting the HCl .
- C2.8** Random zig-zag movement of smoke particles; it shows that gas molecules are **moving randomly and colliding** with the smoke particles.

Exam-style question C2

- (a) diffusion [1]
(b) random [1], fast / in all directions, colliding with air molecules [1] [2]
(c) less time / faster [1]; molecules have more kinetic energy / move faster at higher temperature [1] [2]
(d) liquid: close together, irregular [1]; vapour: far apart, random [1] [2]

C3 Elements, Compounds and Mixtures

- C3.1** (a) A substance made of **only one type of atom**, which cannot be broken down chemically. (b) A substance of **two or more different elements chemically combined** in a fixed ratio.
- C3.2** Sea water **mixture**; carbon dioxide **compound**; sulfur **element**; brass **mixture**; sodium chloride **compound**; nitrogen **element**.
- C3.3** Mixture: **not chemically combined, variable composition, keeps properties** of its parts, **physical separation**. Compound: chemically combined, fixed ratio, new properties, chemical separation. (Any two.)
- C3.4** Carbon dioxide contains **two different elements** (carbon and oxygen) chemically bonded. O_2 contains **only oxygen atoms**.
- C3.5** Pull out the iron with a **magnet**: the elements can be separated physically and keep their own properties.
- C3.6** (a) O_2 , H_2 , Cl_2 or N_2 ; (b) H_2O , CO_2 or CH_4 .
- C3.7** A **solution**; separate by **evaporation** or **distillation**.
- C3.8** **Sodium, carbon and oxygen**; it is a **compound** (three different elements).

Exam-style question C3

- (a) two or more substances that are **not chemically combined** [1]
(b) **B** [1]; it contains only one type of atom [1] [2]
(c) **C** [1]; all the particles are identical molecules made of different atoms chemically joined in a fixed ratio [1] [2]
(d) it contains different types of particle (single atoms of both elements and molecules) not joined in a fixed ratio [1]
(e) the gases are not chemically combined [1]; the proportions can vary / each gas keeps its own properties [1] [2]

C4 Experimental Techniques

- C4.1** (a) filtration; (b) evaporation (crystallisation); (c) simple distillation; (d) **fractional distillation**.
- C4.2** Residue: the **insoluble solid left on the filter paper**. Filtrate: the **liquid that passes through** the filter paper.
- C4.3** Pencil is **insoluble in the solvent**, so it does not run up the paper and interfere with the results; ink would dissolve and move.
- C4.4** The sample is a **mixture of at least three substances**.
- C4.5** $R_f = 3.0 \div 6.0 = 0.50$.
- C4.6** It is **impure** (a mixture): a pure liquid has a sharp boiling point.
- C4.7** Their boiling points are **close** (78°C and 100°C). The **fractionating column** gives repeated condensing and evaporating so the more volatile ethanol reaches the top first.

C4.8 Heat to **evaporate some water** until saturated (a drop on a glass rod forms crystals); **leave to cool** so crystals form; **filter**; wash with a little cold water; **dry** between filter paper.

Exam-style question C4

- (a) draw a pencil line near the bottom of the paper [1]; place a spot of the colouring on the line [1]; stand the paper in solvent with the level below the line [1] [3]
- (b) the colouring is a mixture of (at least) two dyes [1]
- (c) run a spot of pure tartrazine on the same paper [1]; compare the distance moved / spots at the same height means same substance [1] [2]
- (d) pure water boils at exactly 100 °C [1]; a sharp, constant boiling point shows it is pure; impure liquids boil over a range or higher [1] [2]

C5 Physical and Chemical Change

- C5.1** Any three: **new substance formed**, difficult to reverse, **energy change**, colour change, gas given off, precipitate.
- C5.2** (a) physical; (b) **chemical**; (c) physical; (d) **chemical**; (e) physical.
- C5.3** A **bright white light** (energy released) and a **new substance** (white powder) with different properties.
- C5.4** No new substance is formed: the sugar can be **recovered by evaporating** the water.
- C5.5** magnesium + oxygen → **magnesium oxide**.
- C5.6** A **gas is given off** (bubbles/fizzing) and a new substance forms.
- C5.7** Physical: melting/freezing of ice. Chemical: burning wood / frying an egg / rusting.
- C5.8** The iron **combines with oxygen from the air** to form iron oxide; total mass of reactants (iron + oxygen) = mass of product.

Exam-style question C5

- (a) rusting (oxidation of iron) [1]
- (b) a new substance (brown rust) is formed [1]; it cannot easily be turned back into iron / properties are different from iron [1] [2]
- (c) iron has reacted with oxygen (and water) from the air [1]; the oxygen/water has joined the nail so total mass is conserved [1] [2]
- (d) e.g. cutting or bending it [1]; no new substance is formed, it is still iron [1] [2]

C6 The Periodic Table

- C6.1** (a) The number of **outer-shell electrons**. (b) The number of **electron shells**.
- C6.2** 7 outer electrons; 3 shells (electron arrangement 2,8,7).
- C6.3** Reactivity **increases** from Li to K. The outer electron is lost **more easily** as atoms get larger (further from the nucleus).
- C6.4** sodium + water → sodium hydroxide + hydrogen; $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$.
- C6.5** Caesium has a **lower melting point** and is **more reactive** (reacts explosively with water).
- C6.6** The solution turns **brown** (iodine forms). chlorine + potassium iodide → potassium chloride + iodine.
- C6.7** It is **unreactive (inert)**, so the hot tungsten filament does not burn.
- C6.8** Any two: **harder/stronger**, **higher melting points/densities**, **coloured compounds**, **variable oxidation states**, **catalysts**.

Exam-style question C6

- (a) melting point decreases [1]
- (b) any value below 63 °C (actual 39 °C) [1]
- (c) moves / floats on the surface [1]; fizzes / bubbles of gas [1]; lilac flame / melts into a ball [1] [3]
- (d) sodium hydroxide and hydrogen [1]; $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$ [2] [3]
- (e) they react with oxygen and water vapour in the air [1]

C7 Atomic Structure and Bonding

- C7.1** Proton +1, 1; neutron 0, 1; electron -1, negligible (1/1840).
- C7.2** 19 protons, 20 neutrons (39 - 19), 19 electrons.
- C7.3** (a) 2,6; (b) 2,8,2; (c) 2,8,8.
- C7.4** Atoms of the same element with the **same proton number but different neutron numbers**; they have the **same number of electrons**.
- C7.5** Mg atom (2,8,2) **loses two outer electrons** to form Mg^{2+} (2,8), which has a full outer shell.
- C7.6** HCl: one shared pair between H and Cl, with **three lone pairs** on Cl. CH_4 : C shares **four pairs**, one with each H (see Figure C7.3).
- C7.7** Diamond: each C is bonded to **four** others in a rigid 3-D lattice. Graphite: layers with **weak forces between layers**, so layers **slide**.
- C7.8** In the molten state the **ions are free to move**; in the solid they are **held in fixed positions** in the lattice.
- C7.9** **Delocalised electrons** can move and carry charge; **layers of ions slide** without breaking the metallic bonding.

Exam-style question C7

- (a) Na 2,8,1 [1]; Cl 2,8,7 [1] [2]
- (b) sodium atom loses 1 electron [1]; chlorine atom gains 1 electron [1]; forms Na^+ and Cl^- ions that attract (ionic bond) [1] [3]
- (c) strong electrostatic attraction between oppositely charged ions [1]; a lot of energy needed to overcome it [1] [2]
- (d) weak forces between molecules [1]; little energy needed to separate them (covalent bonds not broken) [1] [2]
- (e) O with two shared pairs to two H atoms [1]; two lone pairs on O [1] [2]

C8 Stoichiometry

- C8.1** (a) Na_2O ; (b) MgCl_2 ; (c) Al_2O_3 ; (d) $\text{Ca}(\text{OH})_2$; (e) $(\text{NH}_4)_2\text{SO}_4$.
- C8.2** (a) $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$; (b) $\text{H}_2 + \text{Cl}_2 \rightarrow 2\text{HCl}$; (c) $4\text{Fe} + 3\text{O}_2 \rightarrow 2\text{Fe}_2\text{O}_3$; (d) $\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$.
- C8.3** (a) $2 + 32 + 64 = 98$; (b) $24 + 2(16 + 1) = 58$.
- C8.4** $M_r = 2(56) + 3(16) = 160$; % Fe = $112 \div 160 \times 100 = 70\%$.
- C8.5** $11 \div 44 = 0.25 \text{ mol}$; volume = $0.25 \times 24 = 6 \text{ dm}^3$.
- C8.6** $n = 4.0 \div 40 = 0.10 \text{ mol}$; $V = 0.250 \text{ dm}^3$. (a) $c = 0.10 \div 0.250 = 0.40 \text{ mol/dm}^3$; (b) $0.40 \times 40 = 16 \text{ g/dm}^3$.
- C8.7** $n(\text{Mg}) = 12 \div 24 = 0.50 \text{ mol}$; ratio 1:1, so $n(\text{MgO}) = 0.50 \text{ mol}$; mass = $0.50 \times 40 = 20 \text{ g}$.
- C8.8** $n(\text{Mg}) = 0.10 \text{ mol}$; $n(\text{HCl}) = 1.0 \times 0.100 = 0.10 \text{ mol}$. Mg needs 0.20 mol HCl, so **HCl is limiting**. $n(\text{H}_2) = 0.05 \text{ mol}$; $V = 0.05 \times 24 = 1.2 \text{ dm}^3$.

Exam-style question C8

- (a) $40 + 12 + 48 = 100$ [1]
- (b) $25 \div 100 = 0.25 \text{ mol}$ [1]
- (c) mole ratio 1:1 so 0.25 mol CaO [1]; M_r CaO = 56 [1]; mass = $0.25 \times 56 = 14 \text{ g}$ [1] [3]
- (d) 0.25 mol CO_2 [1]; $0.25 \times 24 = 6 \text{ dm}^3$ [1] [2]
- (e) the amount of substance containing 6.02×10^{23} particles / M_r grams of the substance [1]

C9 Chemical Reactions

- C9.1** Its only combustion product is **water**; it produces **no carbon dioxide or other pollutants**.
- C9.2** **Magnesium/copper**; magnesium is **more reactive than zinc**, so the difference in reactivity is greater.
- C9.3** **Zinc** (more reactive); it **loses electrons** (oxidised).
- C9.4** (a) Gives out energy to surroundings (e.g. combustion); (b) takes in energy (e.g. thermal decomposition of calcium carbonate / photosynthesis).

- C9.5** More energy is released forming the new bonds than is absorbed breaking the old bonds.
- C9.6** $Q = 200 \times 4.2 \times 30 = 25\,200 \text{ J}$; per gram = $25\,200 \div 1.0 = 25\,200 \text{ J/g}$ (25.2 kJ/g).
- C9.7** Powder has a **larger surface area**, so more zinc particles are exposed and **collisions with acid occur more often**.
- C9.8** Particles move **faster**, so **more collisions per second**, and **more collisions have energy $\geq$ activation energy**.
- C9.9** Iron(III) oxide **loses oxygen** (and gains electrons): it is **reduced**.
- C9.10** Fine flour dust has a **very large surface area** and burns explosively when ignited, so a spark could cause an **explosion**.

Exam-style question C9

- (a) gas syringe (or inverted measuring cylinder over water) [1]
- (b) two curves rising and levelling [1]; powder curve steeper [1]; both level at the same final volume [1] [3]
- (c) larger surface area [1]; more particles exposed to the acid [1]; more frequent collisions per second [1] [3]
- (d) increase the temperature / use more concentrated acid [1]
- (e) the temperature rises [1]

C10 Acids, Bases and Salts

- C10.1** (a) a **proton donor**; (b) a **proton acceptor**; (c) a **soluble base**.
- C10.2** (a) **red**; (b) **green**; (c) **purple (violet)**.
- C10.3** $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$; **magnesium chloride**.
- C10.4** $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$.
- C10.5** Lime is **alkaline (a base)**, so it **neutralises** the acidity in the soil.
- C10.6** CO_2 : **acidic**; CaO : **basic**; CO : **neutral**; ZnO : **amphoteric**.
- C10.7** Add **excess zinc oxide** to warm acid; **filter** off the excess; **evaporate** to saturation; **cool** to crystallise; filter, wash and **dry**.
- C10.8** **Zinc ion Zn^{2+}** .
- C10.9** (a) acidify with dilute HCl/HNO_3 , add **barium chloride/nitrate**: white precipitate; (b) add dilute HNO_3 , then **silver nitrate**: white precipitate; (c) bubble through **limewater**: milky.
- C10.10** **Hydrogen**; it burns explosively with oxygen in air.

Exam-style question C10

- (a) to make sure all the acid has reacted / acid is completely used up [1]
- (b) filter [1]
- (c) heat/evaporate to the point of saturation [1]; leave to cool [1]; filter and dry the crystals [1] [3]
- (d) $\text{CuO} + \text{H}_2\text{SO}_4 \rightarrow \text{CuSO}_4 + \text{H}_2\text{O}$ [2] [2]
- (e) add sodium hydroxide solution [1]; light blue precipitate [1] [2]

C11 Metals

- C11.1** Any three: good conductors of heat/electricity, shiny, malleable, ductile, high melting points, high density, strong.
- C11.2** **sodium > magnesium > zinc > iron > copper**.
- C11.3** $\text{zinc} + \text{copper(II) sulfate} \rightarrow \text{zinc sulfate} + \text{copper}$. Brown/pink copper coats the zinc and the **blue solution fades**.
- C11.4** A thin, tough, **unreactive layer of aluminium oxide** sticks to the surface and **prevents further reaction**.
- C11.5** **Iron ore** (source of iron); **coke** (fuel and reducing agent, makes CO); **limestone** (removes silica as slag).
- C11.6** $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$.
- C11.7** It **lowers the melting point** of aluminium oxide, so less energy is needed.

- C11.8** Harder/stronger, more resistant to corrosion, can be made with properties for a specific use.
- C11.9** Atoms of **different sizes** disrupt the regular layers, so the **layers cannot slide** over each other.
- C11.10** (a) electrical wiring, cooking utensils; (b) galvanising, making brass; (c) statues, bells, medals.

Exam-style question C11

- (a) coke / carbon [1]; limestone [1] [2]
- (b) $\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2$ (formulae [1], balancing [1]) [2]
- (c) limestone decomposes to calcium oxide [1]; calcium oxide reacts with silicon dioxide [1]; forms slag (calcium silicate) which is removed [1] [3]
- (d) mixture of a metal with other element(s) [1]; e.g. car bodies / bridges / machinery [1] [2]
- (e) destruction of habitat/vegetation, dust, water pollution, scarring of land (any one) [1]

C12 Electricity and Chemistry

- C12.1** Breaking down an ionic compound (molten or aqueous) using electricity; oxidation is at the **anode**.
- C12.2** In the molten state the **ions are free to move**; in the solid they are **fixed in the lattice**.
- C12.3** Molten: only the ions of the compound. Aqueous: ions of the compound plus **H⁺ and OH⁻ from water**.
- C12.4** Cathode: **lead**; anode: **bromine**.
- C12.5** Cathode: $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$; anode: $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$.
- C12.6** Sodium is **more reactive than hydrogen**, so **Na⁺** stays in solution and **H⁺ is discharged**.
- C12.7** **Chlorine** (bleach, water treatment); **hydrogen** (fuel, ammonia); **sodium hydroxide** (soap, paper).
- C12.8** Oxygen formed at the anode **reacts with the hot carbon** to form carbon dioxide, so the anodes burn away.
- C12.9** The spoon is the **cathode**; the anode is **silver**; the electrolyte is a **silver salt solution** (silver nitrate).

Exam-style question C12

- (a) cathode: copper [1]; anode: oxygen [1] [2]
- (b) colour fades [1]; copper ions (Cu^{2+}) are being removed / deposited as copper [1] [2]
- (c) $\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$ [1]
- (d) anode loses mass / dissolves [1]; colour stays the same (Cu^{2+} replaced as fast as it is removed) [1] [2]
- (e) key is the cathode [1]; copper is the anode [1]; electrolyte is copper(II) sulfate solution [1] [3]

C13 Non-metals

- C13.1** Nitrogen **78%**; oxygen **21%**; others (argon, carbon dioxide) about **1%**.
- C13.2** **Fractional distillation**: nitrogen has the **lower boiling point** (-196°C) so boils off first; oxygen (-183°C) boils later.
- C13.3** e.g. **sulfur dioxide**, from burning coal, causes **acid rain**; **carbon monoxide**, from incomplete combustion, is **poisonous**.
- C13.4** Changes CO and NO_x into CO_2 and N_2 ; contains **platinum, palladium and rhodium**.
- C13.5** Add to **anhydrous copper(II) sulfate**: white to **blue**; or **cobalt(II) chloride paper**: blue to **pink**.
- C13.6** Temporary (calcium hydrogencarbonate): removed by **boiling**. Permanent (calcium/magnesium sulfate): **not** removed by boiling; use **ion exchange** or **sodium carbonate**.
- C13.7** **Zinc + dilute hydrochloric acid**; hold a **lighted splint** at the mouth of the tube: **squeaky pop**.
- C13.8** Iron catalyst, 450°C , 200 atm. Low temperature gives a better yield but the rate is too slow; high temperature is fast but gives a poor yield.
- C13.9** Zinc coating **keeps out air and water**; even when scratched, zinc is **more reactive** and corrodes first (**sacrificial protection**).
- C13.10** (a) $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$; (b) $\text{CaO} + \text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2$.

Exam-style question C13

- (a) tube A only [1]

- (b) B: boiling removes dissolved oxygen and the oil keeps air out [1]; C: calcium chloride removes water (no water) [1] [2]
- (c) oxygen (air) [1]; water [1] [2]
- (d) any two: painting, oiling/greasing, plastic coating, galvanising, sacrificial protection [2]
- (e) zinc is more reactive than iron [1]; zinc corrodes in preference to the iron (sacrificial protection) [1] [2]

C14 Organic Chemistry

- C14.1** (a) ethane; (b) propene; (c) methanol; (d) ethanoic acid.
- C14.2** (a) C_nH_{2n+2} ; (b) C_nH_{2n} ; C_7H_{16} (heptane).
- C14.3** A family of compounds with the **same general formula and functional group**; **similar chemical properties**, gradual trend in physical properties, differ by CH_2 .
- C14.4** **Fractional distillation**; e.g. **petrol** (car fuel), **diesel** (lorries), **bitumen** (roads), **paraffin** (jet fuel).
- C14.5** Makes **shorter, more useful alkanes (petrol)** and **alkenes** needed to make **plastics**.
- C14.6** $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$.
- C14.7** Add **bromine water**: **ethene decolourises it** (orange to colourless); ethane does not.
- C14.8** **Hydration of ethene**: steam, phosphoric acid catalyst, about 300 °C, 60 atm. **Fermentation of glucose**: yeast, 25 to 35 °C, no air.
- C14.9** **Ethyl ethanoate** (ester) and **water**; used as a **flavouring or perfume**.
- C14.10** Addition: one product only; condensation also gives **water**. Plastics **do not rot**, so they cause **pollution** and fill landfill sites.

Exam-style question C14

- (a) fractional distillation [1]
- (b) breaking down long-chain alkanes into shorter molecules [1]; to make more petrol / smaller useful alkanes [1]; and alkenes for plastics [1] [3]
- (c) $H_2C=CH_2$: two carbons joined by a double bond, each with two H atoms [1]
- (d) orange-brown to colourless [1]; addition reaction [1] [2]
- (e) addition polymerisation [1]; not biodegradable [1]; remains in the environment / fills landfill / harms wildlife [1] [3]

P1 Measurement and Density

- P1.1** (a) **2500 m**; (b) **0.45 kg**; (c) $3.2 \times 1\,000\,000 = 3\,200\,000\text{ cm}^3$.
- P1.2** A **micrometer screw gauge**.
- P1.3** Period = $32 \div 20 = 1.6\text{ s}$.
- P1.4** The **human reaction-time error** is fixed (about 0.2 s); spread over 20 swings it is a **much smaller fraction** of the total.
- P1.5** $V = 68 - 50 = 18\text{ cm}^3$; $\rho = 45 \div 18 = 2.5\text{ g/cm}^3$.
- P1.6** $m = \rho V = 13\,600 \times 0.002 = 27.2\text{ kg}$.
- P1.7** Floats in water: $\rho_{\text{wood}} < 1000\text{ kg/m}^3$. Sinks in kerosene: $\rho_{\text{wood}} > \rho_{\text{kerosene}}$. So **kerosene < wood < water**.
- P1.8** (a) **2**; (b) **3** (or 4 if the zero is significant); (c) **3**.
- P1.9** **0.037**; **6.85**.
- P1.10** Mass an empty beaker; pour in 50 cm^3 (measuring cylinder); mass again; **subtract**.

Exam-style question P1

- (a) balance [1]
- (b) partly fill cylinder and record volume V_1 [1]; lower the rock in so it is completely submerged and record V_2 [1]; volume = $V_2 - V_1$ [1] [3]
- (c) density = mass $\div$ volume [1]; $= 156 \div 20 = 7.8\text{ g/cm}^3$ [1] [2]

- (d) its density (7.8 g/cm^3) is greater than that of water (1 g/cm^3) [1]

P2 Motion

- P2.1 $90 \div 1.5 = 60 \text{ km/h}$; $60 \div 3.6 = 16.7 \text{ m/s}$.
- P2.2 Speed is a **scalar** (no direction); velocity is a **vector** (has direction).
- P2.3 $(25 - 5) \div 8 = 2.5 \text{ m/s}^2$.
- P2.4 $6 \times 20 = 120 \text{ m}$.
- P2.5 (a) **At rest**; (b) **constant speed** (no acceleration).
- P2.6 $\frac{1}{2} \times 6 \times 12 + 4 \times 12 = 36 + 48 = 84 \text{ m}$.
- P2.7 $v = g t = 10 \times 3 = 30 \text{ m/s}$.
- P2.8 Average speed = $\frac{1}{2}(0 + 20) = 10 \text{ m/s}$; $h = 10 \times 2 = 20 \text{ m}$.
- P2.9 As speed increases, **air resistance increases** until it **equals the weight**; resultant force is zero, so there is no more acceleration.
- P2.10 Large area increases air resistance above the weight; the resultant force acts upward until a new, **lower terminal velocity** is reached.

Exam-style question P2

- (a) $a = (v - u) \div t$ [1]; $= 15 \div 5 = 3 \text{ m/s}^2$ [1] [2]
- (b) constant speed of 15 m/s [1]
- (c) area under graph: $\frac{1}{2} \times 5 \times 15 = 37.5$ [1]; $10 \times 15 = 150$ [1]; $\frac{1}{2} \times 5 \times 15 = 37.5$; total = 225 m [1] [3]
- (d) total time = 20 s [1]; $225 \div 20 = 11.25 \text{ m/s}$ [1] [2]
- (e) air resistance increases with speed [1]; until it equals the weight, so resultant force is zero [1] [2]

P3 Mass, Weight, Forces and Moments

- P3.1 $W = mg = 65 \times 10 = 650 \text{ N}$.
- P3.2 Mass is in **kg**, constant everywhere; weight is in **N**, depends on gravity and is measured with a **spring balance**.
- P3.3 Extension = **4.0 cm**; with 3 N : $4.0 \times 3 \div 2 = 6.0 \text{ cm}$; length = **16.0 cm**.
- P3.4 Beyond this load, **extension is no longer proportional** to load and the spring will not return to its original length.
- P3.5 $a = F \div m = 60 \div 15 = 4 \text{ m/s}^2$.
- P3.6 Adv: **brakes grip**, can **walk**. Disadv: **wears moving parts**, **wastes energy as heat**.
- P3.7 $25 \times 0.40 = 10 \text{ N m}$.
- P3.8 $4 \times 0.50 = 5 \times d$; $d = 0.40 \text{ m}$.
- P3.9 The vertical line through the **centre of mass remains within the base** for a bigger tilt, so it needs a larger tilt to topple.
- P3.10 Suspend from a pin at three points; draw plumb-line verticals; the **intersection** is the centre of mass.

Exam-style question P3

- (a) force $\times$ perpendicular distance from the pivot (turning effect) [1]
- (b) distance = $25 \text{ cm} = 0.25 \text{ m}$ [1]; $2.0 \times 0.25 = 0.50 \text{ N m}$ [1] [2]
- (c) distance 0.30 m [1]; $3.0 \times 0.30 = 0.90 \text{ N m}$ [1] [2]
- (d) no [1]; anticlockwise moment (0.90) is greater than clockwise (0.50) [1] [2]
- (e) $0.90 = 2.0 \times d$ [1]; $d = 0.45 \text{ m}$ (the 95 cm mark) [1] [2]

P4 Work, Energy and Power

- P4.1 $W = Fd = 80 \times 6.0 = 480 \text{ J}$.
- P4.2 (a) chemical $\rightarrow$ electrical $\rightarrow$ light (+ heat); (b) p.e. $\rightarrow$ k.e.; (c) k.e. (wind) $\rightarrow$ electrical.

P4.3 $\frac{1}{2} \times 0.50 \times 8.0^2 = 16 \text{ J}$.

P4.4 $mgh = 60 \times 10 \times 15 = 9000 \text{ J}$.

P4.5 $E = mgh = 200 \times 10 \times 12 = 24\,000 \text{ J}$; $P = 24\,000 \div 40 = 600 \text{ W}$.

P4.6 $350 \div 500 = 0.70 = 70\%$.

P4.7 Some energy is **wasted as heat** (and sound) because of **friction** and resistance, spreading to the surroundings.

P4.8 Energy **cannot be created or destroyed**, only **transformed** from one form to another.

P4.9 They **do not run out** and **do not release CO₂** (less global warming).

P4.10 $E = Pt = 1000 \times 7200 = 7.2 \times 10^6 \text{ J}$.

Exam-style question P4

- (a) k.e. = $\frac{1}{2}mv^2$ [1]; $= \frac{1}{2} \times 0.20 \times 144 = 14.4 \text{ J}$ [1] [2]
- (b) zero [1]
- (c) p.e. gained = k.e. lost = 14.4 J [1]; $mgh = 14.4$ [1]; $h = 14.4 \div (0.20 \times 10) = 7.2 \text{ m}$ [1] [3]
- (d) kinetic energy changes to gravitational potential energy [1]
- (e) air resistance does work against the stone [1]; some k.e. is transferred to heat [1] [2]

P5 Waves, Light and Sound

P5.1 (a) distance between two successive crests; (b) number of waves passing a point per second (Hz).

P5.2 $v = f\lambda = 20 \times 2.5 = 50 \text{ m/s}$.

P5.3 Transverse: **light** (water ripples); longitudinal: **sound**.

P5.4 Both **decrease**; the frequency is **unchanged**.

P5.5 **35°**; **70°**.

P5.6 $n = \sin 45^\circ \div \sin 28^\circ = 0.707 \div 0.469 = 1.5$.

P5.7 Light **bends away from the normal** on leaving the water, so it seems to come from a **shallower point**.

P5.8 Travel at **$3 \times 10^8 \text{ m/s}$ in a vacuum**; **transverse**; carry energy.

P5.9 (a) **infra-red**; (b) **gamma rays**; (c) **microwaves**.

P5.10 $d = vt = 330 \times 3.0 = 990 \text{ m}$.

Exam-style question P5

- (a) the change in direction (and speed) of light as it passes from one medium into another [1]
- (b) $n = \sin i \div \sin r$ [1]; $= \sin 60^\circ \div \sin 35^\circ$ [1]; $= 0.866 \div 0.574 = 1.5$ [1] [3]
- (c) bends away from the normal [1]; emerges parallel to the incident ray [1] [2]
- (d) light is transverse, sound is longitudinal [1]; light travels through a vacuum, sound does not / light is much faster [1] [2]
- (e) $\lambda = v \div f$ [1]; $= 330 \div 660 = 0.50 \text{ m}$ [1] [2]

P6 Thermal Physics

P6.1 Particles **vibrate more** and move **slightly further apart**.

P6.2 **Very weak forces** between particles, so they move apart more easily.

P6.3 Two metals expand by **different amounts**; the one that expands more is on the **outside of the curve**, so the strip **bends**.

P6.4 **100 °C** (boiling point of pure water) and **0 °C** (melting point of pure ice).

P6.5 A **big change in reading** for a **small change** in temperature; use a **narrower tube** or **larger bulb**.

P6.6 It can measure **very high temperatures** and responds **quickly** because of its small junction.

P6.7 The energy is used to **break the bonds between particles**, not to speed them up.

P6.8 Evaporation: **surface only**, **any temperature**. Boiling: **throughout**, at the **boiling point**, with bubbles.

P6.9 **Vacuum** stops conduction and convection; **silvered surfaces** reflect radiation; stopper reduces convection/evaporation.

P6.10 Metal is a **good conductor**; plastic is an **insulator**, so the handle stays cool.

Exam-style question P6

- (a) conduction [1]
- (b) water at the bottom is heated and expands [1]; becomes less dense and rises [1]; cooler denser water sinks, forming a convection current [1] [3]
- (c) vacuum prevents conduction and convection [1]; silvered surfaces reflect infra-red radiation [1]; stopper reduces convection / conduction to air [1] [3]
- (d) energy supplied is used to overcome the forces between particles / change state [1]; not to raise the kinetic energy of particles [1] [2]
- (e) dull black surfaces are better absorbers of infra-red radiation [1]

P7 Static Electricity

P7.1 **Electrons** move from the cloth to the rod; the rod becomes **negative**.

P7.2 **Like charges repel; unlike charges attract.**

P7.3 Induced charge of the **opposite sign** is nearest the comb; the **attraction is stronger** than the repulsion.

P7.4 Electrons are attracted to the cap; the rod and leaf become **positive (same sign) and repel**, so the **leaf rises**.

P7.5 **Positive**; it attracts electrons to the cap, reducing the charge on the leaf.

P7.6 Otherwise the **charge flows through the holder to earth**.

P7.7 A coulomb is the amount of charge passing a point when **a current of 1 A flows for 1 s**.

P7.8 The **pointed metal rod** gives lightning a **low-resistance path to earth**, so the charge bypasses the building.

P7.9 Charge separates in the cloud by friction; the large **p.d.** makes air **conduct** and a **spark** passes.

P7.10 Useful: **photocopier / paint spraying**; dangerous: **sparks igniting fuel**, lightning.

Exam-style question P7

- (a) electrons transferred from the cloth to the rod by friction [1]; rod gains electrons so is negative [1] [2]
- (b) positive [1]
- (c) leaf rises [1]; electrons are repelled to the rod and leaf [1]; leaf and rod have the same charge so repel [1] [3]
- (d) leaf falls (the charges redistribute) [1]
- (e) earth the aircraft and fuel hose / connect with a conducting cable [1]

P8 Current Electricity

P8.1 $Q = It = 2.5 \times 4.0 = 10 \text{ C}$.

P8.2 $I = 240 \div 120 = 2.0 \text{ A}$.

P8.3 Conventional current: **+ to -**; electron flow: **- to +**.

P8.4 e.m.f.: energy **supplied** per coulomb **by the source**; p.d.: energy **converted** per coulomb **in a component**.

P8.5 $R = 12 \div 0.50 = 24 \Omega$.

P8.6 $V = IR = 15 \times 0.40 = 6.0 \text{ V}$.

P8.7 **16 Ω** .

P8.8 The filament **heats up**; **resistance increases**, so I rises less than V.

P8.9 Connect **in parallel** across the resistor.

P8.10 **Length** and **cross-sectional area** (also material and temperature).

Exam-style question P8

- (a) ammeter in series with the resistor [1]; voltmeter in parallel with the resistor [1] [2]
- (b) $R = V \div I$ [1]; $= 5.0 \div 0.25 = 20 \Omega$ [1] [2]

- (c) straight line through the origin [1]; resistance is constant / V is proportional to I [1] [2]
- (d) doubling length doubles R [1]; halving area doubles R again: $4 \times 20 = 80 \Omega$ [1] [2]
- (e) $Q = It$ [1]; $= 0.25 \times 30 = 7.5 \text{ C}$ [1] [2]

P9 Electric Circuits

- P9.1** (a) **ammeter**; (b) **lamp**; (c) **diode**.
- P9.2** It **melts and breaks the circuit** if the current is too high.
- P9.3** $15 + 25 + 10 = 50 \Omega$.
- P9.4** $(12 \times 4) \div 16 = 3 \Omega$.
- P9.5** $R = 5 \Omega$; $I = 6 \div 5 = 1.2 \text{ A}$.
- P9.6** $I = 9 \div 9 = 1 \text{ A}$; $V = 1 \times 3 = 3 \text{ V}$.
- P9.7** Each gets **full voltage** and can work **independently**.
- P9.8** $3 - 1.2 = 1.8 \text{ A}$.
- P9.9** It **decreases**.
- P9.10** Raising its resistance **reduces the current** through the lamp.

Exam-style question P9

- (a) $R = (30 \times 60) \div 90$ [1]; $= 20 \Omega$ [1] [2]
- (b) $20 + 20 = 40 \Omega$ [1]
- (c) $I = V \div R$ [1]; $= 12 \div 40 = 0.30 \text{ A}$ [1] [2]
- (d) p.d. across $20 \Omega = 0.30 \times 20 = 6.0 \text{ V}$ [1]; parallel p.d. $= 12 - 6.0 = 6.0 \text{ V}$ [1] [2]
- (e) $I = V \div R = 6.0 \div 60$ [1]; $= 0.10 \text{ A}$ [1] [2]

P10 Practical Electricity and Safety

- P10.1** Live: **brown**; neutral: **blue**; earth: **green/yellow**.
- P10.2** So the appliance is **disconnected from the live supply** when the fuse blows.
- P10.3** $I = 1500 \div 230 = 6.5 \text{ A}$; use **13 A**.
- P10.4** $0.060 \times 5 = 0.30 \text{ kWh} = 0.30 \times 3.6 \times 10^6 = 1.08 \times 10^6 \text{ J}$.
- P10.5** $E = IVt = 3.0 \times 12 \times 10 = 360 \text{ J}$.
- P10.6** If live touches the casing, a **large current flows to earth** and **blows the fuse**.
- P10.7** **Full voltage** on each lamp; lamps work **independently**.
- P10.8** Current excites **mercury vapour**, giving UV; the **phosphor coating** converts it to visible light.
- P10.9** (a) **shock**; (b) **shock** (water conducts).
- P10.10** An appliance with an **insulating case** so no earth is needed.

Exam-style question P10

- (a) $I = P \div V$ [1]; $= 2300 \div 230 = 10 \text{ A}$ [1] [2]
- (b) brown (live) [1]
- (c) the normal current (10 A) is larger than 3 A, so the fuse would blow [1]
- (d) $E = Pt = 2300 \times 240$ [1]; $= 552\,000 \text{ J}$ [1] [2]
- (e) large current flows through earth wire to earth [1]; fuse blows [1]; the case is no longer live [1] [3]

P11 Magnetism

- P11.1** Like poles **repel**; unlike poles **attract**.
- P11.2** **Nickel, steel, cobalt** (iron-containing).
- P11.3** A magnet **attracts** both a magnet and unmagnetised iron, but it **repels** only another magnet.
- P11.4** Place a compass near N pole, mark ends of needle, move it so the tail is at the previous head, repeat and **join the dots**; arrows $N \rightarrow S$.

P11.5 Iron: **electromagnet core**; steel: **permanent magnet**.

P11.6 A **new N and S pole** appear; each piece is a complete magnet.

P11.7 Magnetised: domains **aligned**; unmagnetised: **random**.

P11.8 **Hammering, heating, or decreasing a.c. in a coil**.

P11.9 A magnetic material becomes a **temporary magnet** by being near a magnet.

P11.10 It **magnetises and demagnetises easily**.

Exam-style question P11

- (a) the steel nail [1]
- (b) stroke the nail in one direction with one pole of the magnet [1]; repeat many times, lifting the magnet away at the end of each stroke [1] [2]
- (c) domains were randomly arranged [1]; now they line up in the same direction [1] [2]
- (d) it repels the north pole of a magnet / one pole of a suspended magnet [1]
- (e) heat it / hammer it / place in a coil carrying decreasing a.c. [1]

P12 Digital Electronics and Logic Gates

P12.1 Analogue: **continuous**, any value; digital: only **two states (high/low)**.

P12.2 0.

P12.3 (a) **both inputs 1**; (b) **both inputs 0**.

P12.4 AND 0; OR 1; NAND 1; NOR 0.

P12.5 The output is **inverted (NOT)**.

P12.6 A **NOT** gate.

P12.7 Same as **NOR**: 1 only for input 00.

P12.8 A light sensor with a **NOT gate** (output 1 when dark) feeding an **AND gate** with the switch.

P12.9 Less affected by **noise**; **easily stored and processed**.

P12.10 (0 OR 1) = 1; NOT 0 = 1; **Q = 1**.

Exam-style question P12

- (a) NAND [1]
- (b) 1, 1, 1, 0 (all four correct [3]; three correct [2]; two correct [1]) [3]
- (c) 0 [1]
- (d) analogue varies continuously (any value) [1]; digital has only two values (on/off, 1/0) [1] [2]
- (e) e.g. burglar alarm, automatic light, safety interlock [1]

P13 Electromagnetic Effects

P13.1 More **turns**, larger **current**, **soft iron core**.

P13.2 It can be **switched off** / its strength is controllable.

P13.3 The needle **deflects while moving**, then **returns to zero**.

P13.4 **Faster** movement; **more turns** (or stronger magnet).

P13.5 To **connect the rotating coil** to the external circuit without twisting the wires.

P13.6 Reverse the **current** or reverse the **field**.

P13.7 It **reverses the current** every half turn so the force keeps the coil turning the same way.

P13.8 $230 \times 50 \div 1000 = 11.5 \text{ V}$.

P13.9 $12 \times 3 = 36 \text{ W}$; $I = 36 \div 240 = 0.15 \text{ A}$.

P13.10 **Lower current** means **less heating (I^2R) loss** in cables.

Exam-style question P13

- (a) step-down [1]

- (b) $V_s = V_p \times N_s \div N_p$ [1]; $= 240 \times 100 \div 400 = 60 \text{ V}$ [1] [2]
- (c) power out $= 60 \times 2.0 = 120 \text{ W}$ [1]; power in = power out [1]; $I_p = 120 \div 240 = 0.50 \text{ A}$ [1] [3]
- (d) d.c. gives a constant magnetic field [1]; no changing field means no induced e.m.f. in the secondary [1] [2]
- (e) high voltage means low current [1]; less energy lost as heat in the cables [1] [2]

P14 Atomic and Nuclear Physics

P14.1 Protons **13**; neutrons $27 - 13 = 14$; nucleons **27**.

P14.2 Atoms with the **same number of protons but different numbers of neutrons**, e.g. carbon-12 and carbon-14.

P14.3 Radon gas from rocks, cosmic rays.

P14.4 (a) alpha; (b) gamma; (c) beta.

P14.5 $A = 222$; $Z = 86$: $^{222}_{86}\text{Rn}$.

P14.6 $Z = 28$ ($^{60}_{28}\text{Ni}$).

P14.7 $(\frac{1}{2})^3 = 1/8$.

P14.8 $640 \rightarrow 320 \rightarrow 160 \rightarrow 80$: 3 half-lives; half-life $= 15 \div 3 = 5$ minutes.

P14.9 Handle with **tongs**; store in **lead-lined boxes**; limit **exposure time**.

P14.10 They are **very penetrating** and **kill bacteria** even through packaging.

Exam-style question P14

- (a) a helium nucleus (2 protons and 2 neutrons) [1]
- (b) alpha particles are absorbed by paper [1]; they have a very low penetrating power / are highly ionising [1] [2]
- (c) $340 - 20$ [1]; $= 320$ counts/min [1] [2]
- (d) $12 \text{ min} = 3$ half-lives [1]; $480 \rightarrow 240 \rightarrow 120 \rightarrow 60$ [1]; 60 counts/min [1] [3]
- (e) store in a lead-lined container [1]

P15 Light-Emitting Diodes (LEDs)

P15.1 p-type and n-type.

P15.2 n-type: **free electrons**; p-type: **holes**.

P15.3 Electrons and holes **combine at the junction**, releasing **energy as light**.

P15.4 **Forward biased**: anode to the positive terminal.

P15.5 To **limit the current** and protect the LED.

P15.6 More **efficient, longer life**.

P15.7 **Red, green, blue**.

P15.8 All three LEDs at **full brightness**.

P15.9 Reverse bias: very **high resistance, no current**.

P15.10 The **semiconductor material** (energy released).

Exam-style question P15

- (a) p-n junction [1]
- (b) electrons and holes combine [1]; energy released as light [1] [2]
- (c) to limit the current so the LED is not damaged [1]
- (d) no light [1]; LED is reverse-biased and does not conduct [1] [2]
- (e) pixels each contain red, green and blue LEDs [1]; the brightness of each is varied to mix colours [1] [2]

Glossary

This glossary has two parts. **Part 1** lists the **command words** from the syllabus (Appendix 7) with their meanings. **Part 2** lists key science terms in alphabetical order.

Part 1: Command words

Command word	Meaning
Calculate	a numerical answer is required; show the working.
Deduce	like predict, but with a supporting statement (a law, principle or reasoning).
Define	give a formal statement, or an equivalent paraphrase, of the term.
Describe	state in words the main points; use diagrams where appropriate and mention visual observations.
Determine	obtain a quantity by calculation from measured or known values.
Discuss	give a critical account of the points involved.
Estimate	give a reasoned order-of-magnitude statement or calculation.
Explain	give reasons; refer to theory.
Find	a general term meaning calculate, measure or determine.
Identify	use given data to find patterns or trends, or locate a feature; give examples.
Investigate	plan the experiment yourself, then carry it out.
List	give a number of points, each usually one word, without elaboration.
Measure	obtain the quantity directly from an instrument.
Outline	be brief; give the essentials only.
Perform	carry out an experiment so as to recall the procedure and interpret the data.
Predict	make a logical connection between pieces of information; give a concise answer with no supporting statement.
Sketch	a graph or diagram that is qualitatively correct; take care over shape and proportion.
State	give a concise answer with little or no supporting argument.
Suggest	apply your knowledge to a new situation, or give one of several possible answers.
What is meant by	give a definition and a relevant comment about its significance.

Part 2: Key terms

A

Absolute zero: the lowest possible temperature, 0 K (−273 °C).

Acceleration: the rate of change of velocity, in m/s^2 .

Acid: a substance that produces H^+ ions in water; a proton donor.

Alkali: a soluble base; produces OH^- ions in water.

Alkane: a saturated hydrocarbon with the general formula $\text{C}_n\text{H}_{2n+2}$.

Alkene: an unsaturated hydrocarbon containing a $\text{C}=\text{C}$ bond, general formula C_nH_{2n} .

Allotropes: different forms of the same element in the same physical state, such as diamond and graphite.

Alloy: a mixture of a metal with other elements, usually harder than the pure metal.

Alpha particle: a helium nucleus (2 protons, 2 neutrons) emitted by a radioactive nucleus.

Amplitude: the maximum displacement of a wave from its rest position.

Anode: the positive electrode in electrolysis, where oxidation occurs.

Atom: the smallest particle of an element that keeps its chemical properties.

Atomic (proton) number: the number of protons in the nucleus of an atom.

B

Background radiation: the low level of ionising radiation always present around us.

Base: a substance that neutralises an acid to form a salt and water.

Beta particle: a fast electron emitted from a nucleus.

Boiling point: the temperature at which a liquid boils; energy is absorbed without a temperature rise.

C

Catalyst: a substance that speeds up a reaction and is not used up.

Cathode: the negative electrode in electrolysis, where reduction occurs.

Centre of mass: the point where the whole weight of a body appears to act.

Compound: a substance of two or more elements chemically combined in a fixed ratio.

Conduction: transfer of thermal energy through a material by particle vibration or free electrons.

Convection: transfer of thermal energy in a fluid by moving currents of hot and cold fluid.

Core (concept): an idea or definition that carries marks and must be learned exactly; shown in **bold** in this guide.

Covalent bond: a bond formed when two atoms share a pair of electrons.

Cracking: the breaking of long-chain alkanes into shorter alkanes and alkenes.

Current: the rate of flow of charge, in amperes.

D

Density: the mass per unit volume of a substance.

Diffraction: the spreading of waves as they pass through a gap or round an obstacle.

Displacement method: finding the volume of an irregular object by the volume of liquid it pushes aside.

Distillation: separating a liquid from a mixture by evaporating and condensing it.

E

E.m.f.: the energy supplied by a source to each coulomb of charge driven round a circuit.

Echo: the reflection of sound.

Efficiency: useful energy output divided by total energy input.

Electrolysis: the breaking down of an ionic compound, molten or in solution, by electricity.

Electrolyte: a liquid or solution that conducts electricity because it contains ions.

Electromagnetic induction: the production of an e.m.f. in a conductor when the magnetic field through it changes.

Electron: a negatively charged particle that orbits the nucleus.

Element: a substance made of only one kind of atom.

Endothermic: a reaction that takes in heat energy from its surroundings.

Evaporation: the escape of the faster particles from the surface of a liquid at any temperature.

Exothermic: a reaction that gives out heat energy to its surroundings.

F

Fermentation: the breakdown of sugar by yeast to form ethanol and carbon dioxide.

Frequency: the number of complete waves passing a point each second, in hertz.

Friction: a force that opposes the motion between surfaces in contact.

Fuse: a safety device with a thin wire that melts when the current is too large.

G

Gamma ray: a high-frequency electromagnetic wave emitted from a nucleus.

Group: a vertical column of the Periodic Table; elements have the same number of outer electrons.

H

Half-life: the time taken for half of the radioactive nuclei in a sample to decay.

Homologous series: a family of organic compounds with the same functional group and general formula.

Hydrocarbon: a compound containing only hydrogen and carbon.

I

Inertia: the property of a mass that resists a change in its motion.

Ion: an atom or group of atoms with an electric charge.

Ionic bond: the electrostatic attraction between oppositely charged ions.

Isotopes: atoms of the same element with different numbers of neutrons.

K

Kinetic energy: the energy of a moving object, $\frac{1}{2}mv^2$.

L

Limiting reactant: the reactant that is completely used up first, so it limits the amount of product.

Longitudinal wave: a wave whose vibrations are parallel to the direction of travel, such as sound.

M

Mass: the amount of matter in a body, in kilograms.

Melting point: the temperature at which a solid melts.

Mixture: two or more substances not chemically combined, which can be separated physically.

Mole: the amount of substance containing 6.02×10^{23} particles.

Molecule: a group of atoms joined by covalent bonds.

Moment: the turning effect of a force: force $\times$ perpendicular distance from the pivot.

N

Neutralisation: the reaction of an acid with a base to form a salt and water.

Neutron: an uncharged particle in the nucleus.

Nucleon number: the total number of protons and neutrons in a nucleus.

O

Ohmic conductor: a conductor with constant resistance, so that current is proportional to p.d.

Oxidation: the gain of oxygen or the loss of electrons.

P

Period: a horizontal row of the Periodic Table; or the time for one complete wave or oscillation.

pH: a number from 0 to 14 that shows how acidic or alkaline a solution is.

Polymer: a very large molecule made from many repeating monomer units.

Potential difference: the energy converted per coulomb of charge passing through a component.

Potential energy: the stored energy of a body due to its position or condition, such as mgh.

Power: the rate of doing work, or of transferring energy, in watts.

Precipitate: an insoluble solid formed when two solutions react.

Proton: a positively charged particle in the nucleus.

R

Radiation (heat): transfer of thermal energy by infrared waves; it needs no medium.

Reactivity series: a list of metals in order of how readily they react.

Reduction: the loss of oxygen or the gain of electrons.

Refraction: the change in direction of a wave when its speed changes at a boundary.

Refractive index: $n = \sin i \div \sin r$ for light entering a medium from air.

Relative atomic mass: the average mass of an atom of an element compared with 1/12 of the mass of a carbon-12 atom.

Resistance: the opposition to current; $R = V \div I$, in ohms.

S

Salt: an ionic compound formed when an acid has its hydrogen replaced by a metal or ammonium.

Saturated: containing only single carbon–carbon bonds.

Scalar: a quantity with size only, such as speed or mass.

Semiconductor: a material that conducts better than an insulator but worse than a metal, such as silicon.

T

Terminal velocity: the constant speed reached when air resistance equals the weight.

Thermal expansion: the increase in size of a substance when it is heated.

Transformer: a device that changes an alternating voltage using two coils on an iron core.

Transverse wave: a wave whose vibrations are at right angles to the direction of travel, such as light.

U

Unsaturated: containing at least one carbon–carbon double bond.

V

Vector: a quantity with both size and direction, such as velocity or force.

Velocity: speed in a stated direction.

W

Wavelength: the distance between two successive identical points on a wave.

Weight: the force of gravity on a mass, in newtons: $W = mg$.

Work done: energy transferred when a force moves an object: $W = Fd$, in joules.

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EGCSE Physical Science (6888) study guide. The notes and questions are original and aligned to the ECESWA syllabus.