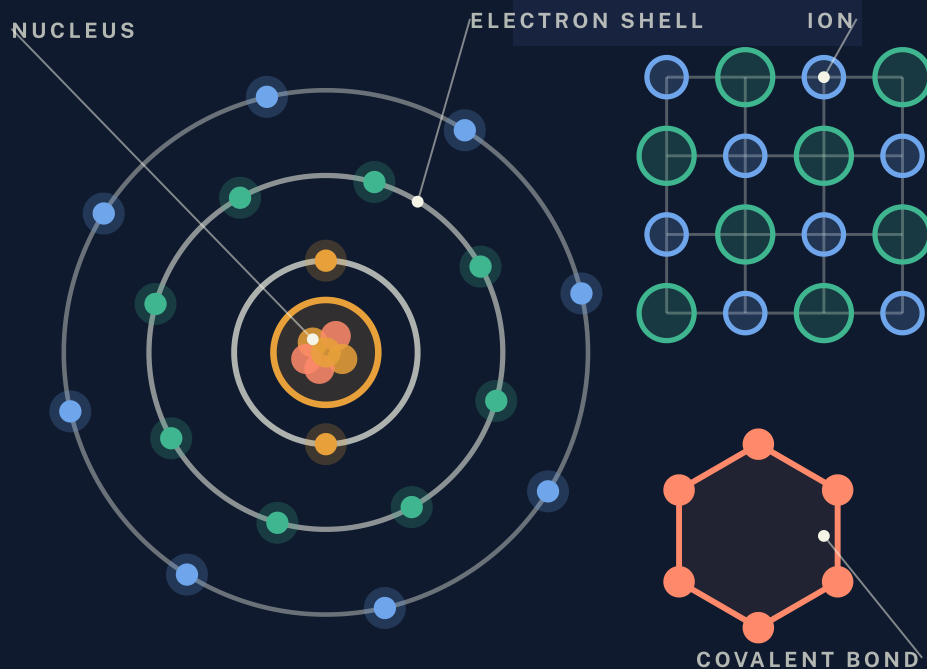


AQA GCSE CHEMISTRY (8462) · PAPER 1

Chemistry Paper 1

Atoms, bonding, moles, reactions and energy

Nine topics on two pages each: learn it, then use it. Exam questions marked in red pen, the graphs and calculations the paper really asks for, and a practice paper to finish.

**9**TOPICS, EACH ON TWO
PAGES**72**

KEY WORDS TO OWN

4

REQUIRED PRACTICALS

73MARKS IN THE PRACTICE
PAPER

[Start here](#)

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Two pages a topic

Learn it: sixty seconds of the topic, the facts with a circle to colour, key words, and a Spot it question on a sticky note.

Use it: a diagram or table, an exam question answered and marked in red pen, how it could be asked, a box to write from memory, and a quick-fire quiz.

Four steps, every time

Predict how much you'll remember. **Recall** with the page covered. **Check** in another colour and fill the circles. **Repair** the weakest part, then come back in two days.

Where it comes from

The facts follow AQA's specification (8462, version 1.1). The exam advice comes from AQA's own Paper 1 papers, mark schemes and examiners' reports (November 2021, June 2022, June 2023), plus AQA's command words list. No AQA question or mark scheme is reproduced: AQA's published marking points are used as sources and paraphrased, and every question here was written for this guide.

HT and Chemistry only

A red **HT** marks content the specification gives to Higher tier students only. A green **Chemistry only** marks content that is in GCSE Chemistry but not in Combined Science: Trilogy.

A four-week plan

Week 1: topics 1 to 3. **Week 2:** topics 4 to 6. **Week 3:** topics 7 to 9. **Week 4:** equations, maths, graphs and practicals (pages 22 to 26), then the practice paper (pages 29 to 32). Come back to each topic two days later and again a week later. The tracker is on page 33.

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Know the exam

Paper 1 on one page

Paper 1	
Topics	1 to 5: Atomic structure and the periodic table; Bonding, structure and the properties of matter; Quantitative chemistry; Chemical changes; Energy changes
Exam	Written, 1 hour 45 minutes
Marks	100, which is 50% of the GCSE
Tiers	Foundation and Higher
Questions	Multiple choice, structured, closed short answer and open response

That is just over a minute a mark. Bring a ruler and a scientific calculator. Write in black ink, and use pencil only for drawing and graphs. Show your working.

What the paper looks like

The Higher papers had nine questions in November 2021, eight in June 2022 and ten in June 2023. The demand rises through the paper: standard demand questions aim at grades 4 to 5, standard to high at 6 to 7, and high demand at 8 to 9, and each question gets harder as it goes on.

At least 20% of the marks test maths, and a lot test practical skills: plotting, reading graphs, variables, controls, uncertainty. About 60 marks need you to **use** what you know (AO2 and AO3), not just recall it (AO1, about 40).

Higher questions 1 to 3 in 2023, and 1 and 2 in 2022, were also set on the Foundation paper. Foundation papers have more multiple choice and short answers.

Paper 2 can draw on the ideas in topics 1 to 3 here, so atoms, bonding and moles are worth knowing twice.

What the question word asks for

Word	AQA's meaning, shortened	What it looks like
Give · Name · Write	A short answer. No explanation or description.	"Hydrogen."
Describe	Recall facts, events or a process accurately.	First this, then this, finally this.
Explain	Make it clear, or state the reasons.	Point, because, so.
Compare	Similarities and or differences, not just one thing.	A does this, whereas B does that.
Calculate	Use the numbers in the question to work out the answer.	Formula, numbers with units, answer with unit.
Suggest	Apply what you know to a new situation.	Link a fact you know to the new context.
Evaluate	Use the information given and your own knowledge to weigh evidence for and against, then reach a judgement.	For, against, so overall.
Justify	Use evidence from the information supplied to support an answer.	Quote a figure, then say what it shows.
Determine · Identify	Use given data to obtain an answer. Name or otherwise characterise.	Read it off the graph or table, then show how.
Predict · Estimate	A plausible outcome. An approximate value.	Use the pattern, or round the numbers first.
Plot · Complete · Label · Draw	Mark data on a graph. Fill in a table or diagram. Name the parts.	Crosses, a ruler, a smooth line.
Plan · Design	Write a method. Set out how something will be done.	Variable, measurement, controls, steps, repeats.

Four marks or more: open response

These are worth four to six marks. Some are marked from a list of points. Others are marked by **levels**: two marks a level, and the examiner picks the level that best fits your whole answer. Level 3 wants relevant points, in detail, linked into a clear account, and for an evaluation **at least one judgement**. A statement that contradicts a correct one can stop you getting full marks, and in a list answer a wrong item can cancel a right one. Plan for twenty seconds first.

Practise: a worked six-mark answer is on page 28.

Sources: AQA command words list; AQA, Our exams explained (GCSE science from summer 2018); AQA 8462 specification, papers and mark schemes (2021 to 2023). Check your own papers.

1 Part one · Atomic structure and the periodic table

Atoms and isotopes

Learn it

In sixty seconds

Every substance is made of atoms. An atom has a tiny nucleus of protons and neutrons, with electrons in shells around it. The atomic number is the number of protons. The mass number is protons plus neutrons. Isotopes are atoms of the same element with different numbers of neutrons. The model of the atom changed as new evidence arrived, from the plum pudding to the nuclear model.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Elements** are made of one type of atom. A **compound** is elements chemically combined in fixed proportions, and only a chemical reaction separates it. A **mixture** isn't chemically combined.
- Physical separation: filtration, crystallisation, simple and fractional distillation, chromatography. No new substances are made.
- Before the electron was found, atoms were thought to be tiny spheres that couldn't be divided. The **plum pudding model** was a ball of positive charge with negative electrons embedded in it.
- The alpha particle scattering experiment showed an atom's mass is concentrated at the centre, in a charged nucleus. The **nuclear model** replaced the plum pudding, and Bohr added electrons orbiting at specific distances.
- Later work gave the **proton**, and Chadwick's evidence showed **neutrons**, about 20 years after the nucleus was accepted. Other scientists check new evidence (**peer review**), which takes time.
- **Relative charges:** proton +1, neutron 0, electron -1. **Relative masses:** proton 1, neutron 1, electron very small. An atom has equal numbers of protons and electrons, so it has no overall charge.
- An atom's radius is about 0.1 nm (1×10^{-10} m). The nucleus is less than 1/10 000 of that, and almost all the mass is in the nucleus.
- **Atomic number** = number of protons. **Mass number** = protons + neutrons, so neutrons = mass number - atomic number. An **ion** has gained or lost electrons: the protons don't change.
- **Isotopes** are atoms of the same element with the same number of protons but different numbers of neutrons. Electrons aren't part of the definition.
- Electrons fill the lowest shell first: 2, then 8, then 8 up to calcium. Sodium is 2,8,1. **Relative atomic mass** is an average that takes account of how abundant each isotope is.

Key words

Element a substance made of one type of atom. ☐

Compound two or more elements chemically combined. ☐

Mixture substances not chemically combined. ☐

Isotope atoms of the same element with the same number of protons and different numbers of neutrons. ☐

Atomic number the number of protons in an atom. ☐

Mass number the number of protons plus neutrons. ☐

Relative atomic mass the average mass of the atoms of an element, allowing for isotopes. ☐

Electronic structure how an atom's electrons are arranged in shells. ☐

Working out an ion. Protons never change. Na^+ (atomic number 11) has lost one electron, so it has 10. Cl^- (atomic number 17) has gained one, so it has 18. Relative atomic mass isn't always a whole number, because it averages the isotopes.

The definition of an isotope was "not well known" in 2021: atoms of the same element, same protons, different neutrons. "Elements" in the plural, or a different relative atomic mass, contradicted it. In 2023 the plum pudding is a ball of positive charge, not "energy".

Spot it Which pair are isotopes?

Atom X has 17 protons and 18 neutrons. Atom Y has 17 protons and 20 neutrons. Atom Z has 18 protons and 22 neutrons. Which statement is correct?

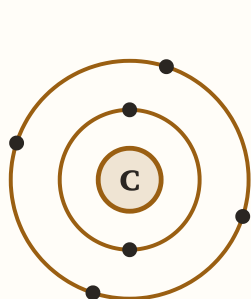
- (A) X and Z are isotopes because their mass numbers are close.
- (B) X and Y are isotopes: same protons, different neutrons.
- (C) X and Y are isotopes because their relative atomic masses differ.
- (D) Y and Z are isotopes because both have over 18 neutrons.

Cover this, choose, then read

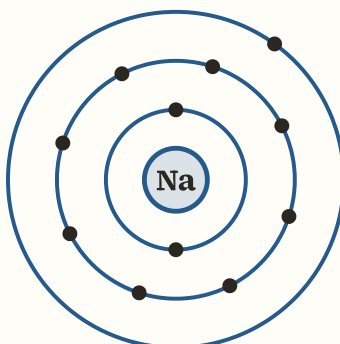
B. Isotopes are atoms of the same element, so the same number of protons (here 17) and different numbers of neutrons. A different relative atomic mass was a wrong answer in 2021. Z has 18 protons, so it is a different element.

1 Part one · Atomic structure and the periodic table

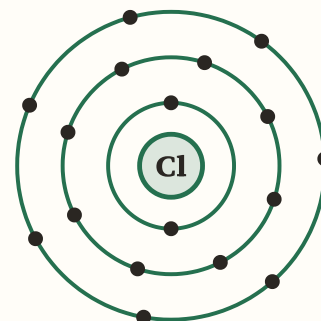
Atoms and isotopes

*Use it**Atoms as you'd draw them in an exam: fill the shells from the inside*

carbon 2,4



sodium 2,8,1



chlorine 2,8,7

The three particles

Particle	Relative charge	Relative mass	Where
Proton	+1	1	in the nucleus
Neutron	0	1	in the nucleus
Electron	-1	very small	in shells around the nucleus

Two isotopes of chlorine: chlorine-35 has 17 protons and 18 neutrons, chlorine-37 has 17 protons and 20 neutrons. Same element, different mass number.

Chlorine has two isotopes: 75% is chlorine-35 and 25% is chlorine-37. Calculate the relative atomic mass of chlorine to one decimal place.

[3 marks]

$$(35 \times 75) + (37 \times 25) = 2625 + 925 = 3550 \checkmark$$

$$3550 \div 100 \checkmark$$

$$= 35.5 \checkmark$$

3/3

1 for multiplying each mass by its percentage. 2 for dividing by 100, not by 72 (the sum of the mass numbers) or by 2 (the number of isotopes), both seen in 2022 and 2023. 3 for 35.5. The answer must sit between 35 and 37: a quick check that catches slips.

It could be asked as

- Describe how the nuclear model replaced the plum pudding model, and why.
- State the numbers of protons, neutrons and electrons in an atom or ion.
- Define an isotope, or calculate a relative atomic mass from percentage abundances.
- Draw the electronic structure of one of the first 20 elements.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33

- 1.1** How many neutrons are in an atom of sodium-23, atomic number 11?
-
- 1.3** What did the alpha particle scattering experiment show about the mass of an atom?
-

- 1.2** Give the electronic structure of chlorine, atomic number 17.
-
- 1.4** How many electrons does a magnesium ion Mg^{2+} have? (atomic number 12)
-

2 Part one · Atomic structure and the periodic table

The periodic table

Learn it

In sixty seconds

The elements are arranged by atomic number, with elements of similar properties in columns called groups. Elements in a group have the same number of outer electrons, which gives them similar reactions. Group 1, the alkali metals, get more reactive down the group. Group 7, the halogens, get less reactive down the group. Group 0, the noble gases, are unreactive. Metals are on the left, non-metals on the right.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- Elements are in order of **atomic number**. The table is **periodic** because similar properties come back at regular intervals. A column is a **group**, a row is a **period**.
- **Mendeleev** left gaps for elements not yet found, and sometimes changed the order. The elements he predicted turned up with the properties he said, which supported his table. Isotopes later explained the odd orders.
- Elements that react to form positive ions are **metals**: most elements, to the left and towards the bottom. **Non-metals** don't, and are towards the right and top.
- The group number is the number of **outer electrons**. The same outer electrons give a group similar chemical properties.
- **Group 0, the noble gases**, are unreactive because their atoms have a stable arrangement of electrons: eight in the outer shell, except helium with two. Boiling points rise down the group.
- **Group 1, the alkali metals**, have one outer electron. With water they make an alkaline metal hydroxide and hydrogen: $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$.
- Down Group 1 reactivity **increases**: lithium fizzes steadily, sodium fizzes faster and melts, potassium melts, moves quickly and burns with a lilac flame. The outer electron is further away and more shielded, so it's lost more easily.
- **Group 7, the halogens**, are non-metals with seven outer electrons, as molecules of two atoms: Cl_2 , Br_2 , I_2 . Down the group melting and boiling points rise and reactivity **decreases**.
- Halogens form **ionic** compounds with metals (sodium chloride) and **covalent** compounds with non-metals (hydrogen chloride).
- A more reactive halogen **displaces** a less reactive one from a solution of its salt: chlorine + potassium bromide → potassium chloride + bromine.

Key words

- Group** a column of the periodic table: the elements have similar properties. ☐
- Period** a row of the periodic table. ☐
- Outer electrons** the electrons in the highest occupied shell. ☐
- Alkali metal** an element in Group 1. ☐
- Halogen** an element in Group 7. ☐
- Noble gas** an element in Group 0. ☐
- Displacement** a more reactive element taking the place of a less reactive one in a compound. ☐
- Periodic** properties repeating at regular intervals. ☐

Chemistry only **Transition metals** (such as chromium, manganese, iron, cobalt, nickel and copper) have higher melting points and densities than Group 1, are harder and stronger, and are much less reactive. Many form ions with different charges and coloured compounds, and are useful as catalysts. When you compare them with Group 1, give **physical** properties for both (melting point, density, hardness): reactivity and colour didn't score in 2022.

Reactivity down Group 1 needs the outer electron named: weaker attraction between the nucleus and the outer electron, not "the electrons" in general. Some students wrote "less shielded" and lost the mark. And the noble gases don't all have eight outer electrons: helium has two.

Spot it The brown solution

A student bubbles chlorine through potassium iodide solution and the colourless solution turns brown. What happened?

- (A) Iodine is more reactive than chlorine, so it displaced chlorine.
- (B) Potassium chloride is brown, so it formed in the solution.
- (C) Chlorine is more reactive than iodine, so it displaced iodine.
- (D) The chlorine dissolved in the solution and turned it brown.

Cover this, choose, then read

C. A more reactive halogen displaces a less reactive one, and reactivity falls down Group 7. Chlorine displaces iodine, and iodine in solution is brown. Potassium chloride is colourless, and dissolving chlorine alone isn't the reaction.

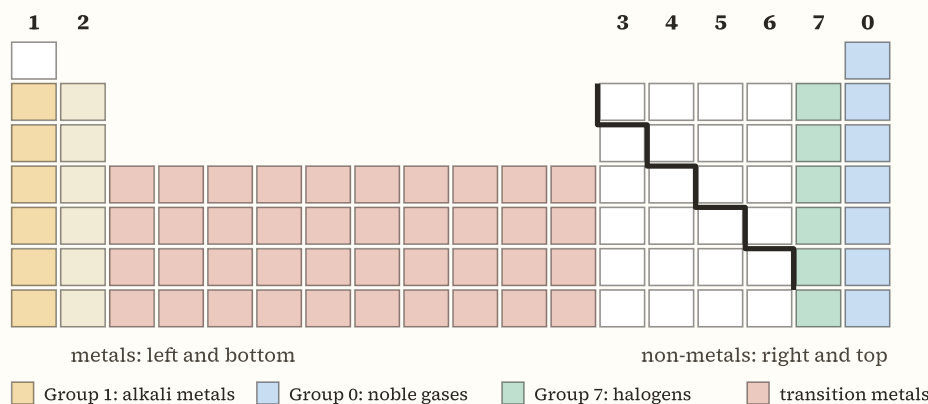
2

Part one · Atomic structure and the periodic table

The periodic table

Use it

The periodic table the way the exam prints it: the groups that matter are coloured



	Group 1: alkali metals	Group 7: halogens	Group 0: noble gases
Outer electrons	1	7	8 (helium 2)
Going down	more reactive	less reactive, higher melting and boiling points	boiling points rise
Typical reaction	with water: hydroxide and hydrogen	displace less reactive halogens	unreactive

Explain why potassium reacts more vigorously with water than lithium does.

[3 marks]

A potassium atom has more shells than a lithium atom, so its outer electron is further from the nucleus ✓. The outer electron is also more shielded ✓. The attraction between the nucleus and the outer electron is weaker, so potassium loses it more easily ✓.

3/3

1 further away, or more shells. 2 more shielded. 3 weaker attraction between the nucleus and the **outer** electron, so it is lost more easily. Reactivity here is about losing an electron: say so, and don't link it to melting point.

It could be asked as

- Explain why Group 1 metals become more reactive down the group.
- Describe what you'd see when sodium or potassium reacts with water.
- Predict a property of an element from its position in a group, or explain a halogen displacement.
- Describe how Mendeleev's table was built, and how his predictions supported it.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33

2.1 Why are the noble gases unreactive?

2.2 Name the products of sodium reacting with water.

2.3 How does the reactivity of the halogens change down Group 7?

2.4 Chlorine is bubbled into sodium bromide solution. What is displaced?

3 Ionic and metallic bonding

Learn it

In sixty seconds

Atoms bond to get a stable outer shell. In ionic bonding a metal atom gives electrons to a non-metal atom, making oppositely charged ions that attract each other strongly in a giant lattice. Ionic compounds have high melting points and only conduct when molten or dissolved. In a metal the outer electrons are delocalised, so metals conduct and can be bent and shaped.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- There are three types of strong chemical bond: **ionic**, **covalent** and **metallic**.
- In **ionic bonding** electrons are transferred from a metal atom to a non-metal atom. The metal atom loses electrons and becomes a positive ion, the non-metal atom gains them and becomes a negative ion. Each ion has the electronic structure of a noble gas.
- The group number gives the charge: Group 1 makes 1+, Group 2 makes 2+, Group 6 makes 2-, Group 7 makes 1-.
- Sodium chloride: Na (2,8,1) loses one electron to become Na⁺ (2,8), and Cl (2,8,7) gains it to become Cl⁻ (2,8,8). Magnesium oxide is Mg²⁺ and O²⁻. Sodium oxide is Na₂O.
- An ionic compound is a **giant structure**, a lattice of ions held together by strong **electrostatic forces of attraction** between oppositely charged ions, in all directions.
- So ionic compounds have **high melting and boiling points**: a lot of energy is needed to overcome the strong forces between the ions.
- Solid ionic compounds **don't conduct**: the ions are held in fixed positions. When **molten or dissolved** the ions are free to move and carry the charge.
- In **metallic bonding** the metal atoms lose their outer electrons into a sea of **delocalised electrons**. The strong electrostatic attraction between the positive ions and the delocalised electrons holds the metal together.
- Metals have high melting and boiling points, conduct electricity and heat because the delocalised electrons carry charge and energy, and are **malleable** because layers of atoms can slide over each other.
- An **alloy** is a mixture of metals, or a metal with another element. The different sized atoms distort the layers, so they slide less easily and the alloy is harder than the pure metal. Examples: steel, brass, bronze.

Key words

Ion an atom or group of atoms with an electric charge.	☐
Ionic bonding electrostatic attraction between oppositely charged ions.	☐
Giant lattice a regular, repeating arrangement of ions.	☐
Electrostatic force the attraction between opposite charges.	☐
Delocalised electrons electrons that aren't fixed to one atom, so they can move.	☐
Metallic bonding attraction between positive metal ions and delocalised electrons.	☐
Malleable able to be bent or hammered into shape.	☐
Alloy a mixture of a metal with other elements, usually harder.	☐

Every model has limits. A dot and cross diagram shows the transfer of electrons but not the lattice. A 3D model shows the lattice but not the electrons, and the gaps between the ions aren't real. To draw an ionic compound, you only need the **outer** electrons: atoms before, then the ions after, with their charges.

Drawing the ions: atoms before, ions after, outer electrons only, right charges and ratio. Don't mix ionic and covalent drawings, or write "shared" after a transfer. For a melting point, intermolecular forces or covalent bonds in an ionic compound earn nothing.

Spot it Molten or solid?

Why can molten sodium chloride conduct electricity but solid sodium chloride can't?

- (A) When molten, the ions can move and carry charge.
- (B) When molten, the electrons are free to move through it.
- (C) The solid has no ions, so nothing can carry the charge.
- (D) Melting breaks the covalent bonds, which frees electrons.

Cover this, choose, then read

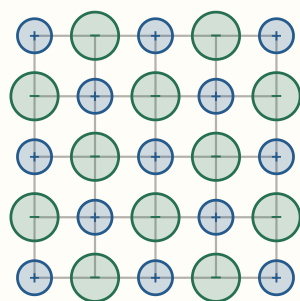
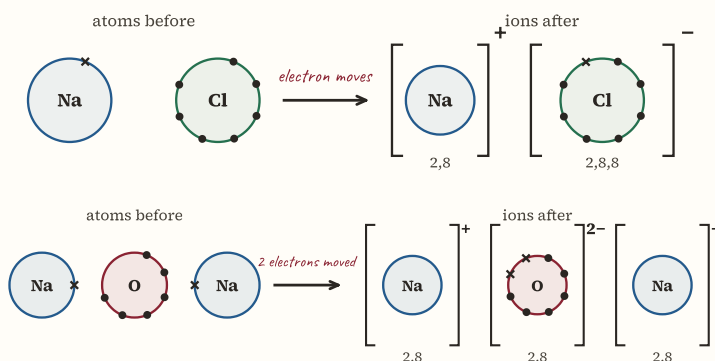
A. Solid sodium chloride is a lattice of ions held in fixed positions, so there is no current. Melting frees the ions. The electrons stay with their ions, and there are no covalent bonds to break.

3 Part two · Bonding, structure and properties

Ionic and metallic bonding

Use it

Sodium chloride: outer electrons only, then the lattice it makes



part of a giant ionic lattice

	Ionic compound	Metal
Held together by	attraction between + and - ions	attraction between + ions and delocalised electrons
Melting point	high	high
Conducts when solid?	no	yes
Conducts when molten?	yes	yes
Bends without breaking?	no, it's brittle	yes, layers slide

Explain why calcium oxide has a high melting point.

[3 marks]

Calcium oxide is a giant structure, a lattice of Ca^{2+} ions and O^{2-} ions ✓. There are strong electrostatic forces of attraction between the oppositely charged ions ✓. A lot of energy is needed to overcome these forces ✓.

3/3

1 giant structure of ions. 2 strong attraction between oppositely charged ions. 3 a lot of energy to overcome it. Don't mention covalent bonds or intermolecular forces here: students did in 2021 and the mark went. "More energy" needs something to be more than.

It could be asked as

- Draw the formation of an ionic compound from its atoms, with the charges.
- Explain why an ionic compound conducts when molten but not when solid.
- Describe metallic bonding and explain why metals conduct and can be shaped.
- Explain why an alloy is harder than a pure metal.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33

3.1 What is the charge on a Group 2 ion?

3.2 Give the formula of sodium oxide.

3.3 Why can a metal be bent without breaking?

3.4 Why is an alloy harder than a pure metal?

4 Covalent bonding and giant structures

Learn it

In sixty seconds

A covalent bond is a shared pair of electrons between non-metal atoms. Simple molecules, such as water and methane, have strong bonds inside but weak forces between the molecules, so their melting and boiling points are low. Giant covalent structures, such as diamond and graphite, have huge numbers of atoms bonded together, so their melting points are very high. Carbon also forms graphene and fullerenes, and nanoparticles behave differently from bulk materials.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- A **covalent bond** is a shared pair of electrons between two atoms, usually non-metals. Examples are H_2 , Cl_2 , O_2 , N_2 , HCl , H_2O , NH_3 and CH_4 .
- **Simple molecules** have strong covalent bonds inside but weak **intermolecular forces** between molecules. Melting or boiling overcomes the intermolecular forces, not the covalent bonds.
- The bigger the molecule, the stronger the intermolecular forces, so the higher the melting and boiling points. Simple molecules don't conduct electricity: they have no overall charge.
- **Polymers** are very large molecules with strong covalent bonds inside. The forces between polymer molecules are relatively strong, so they're solids at room temperature.
- Solid, liquid and gas have the state symbols (s), (l), (g) and (aq). Below its melting point a substance is a solid, above its boiling point a gas, and in between a liquid. The energy to change state depends on the forces between particles.
- **Giant covalent structures** have very high melting points: all the atoms are joined by strong covalent bonds, which take a lot of energy to break. Examples: diamond, graphite, silicon dioxide.
- **Diamond**: each carbon bonds to four others. It's very hard, melts at a very high temperature, and doesn't conduct: no free electrons.
- **Graphite**: each carbon bonds to three others in layers of hexagons. One electron per atom is delocalised, so graphite conducts. Weak forces between the layers let them slide, so it's soft and slippery.
- **Graphene** is a single layer of graphite: strong, and a good conductor. **Fullerenes** are hollow molecules such as C_{60} and nanotubes, used for drug delivery, catalysts, lubricants and strengthening.
- **Chemistry only** **Nanoparticles** are 1 to 100 nm across, smaller than fine (PM2.5) and coarse (PM10) particles. Sides ten times smaller give a surface area to volume ratio ten times bigger, so they differ from the bulk material. Uses: sun creams, catalysts.

Key words

- Covalent bond** a shared pair of electrons between two atoms. ☐
- Intermolecular force** a weak force between separate molecules. ☐
- Polymer** a very large molecule made of many repeating units. ☐
- Giant covalent structure** a huge network of atoms joined by covalent bonds. ☐
- Graphene** a single layer of graphite. ☐
- Fullerene** a hollow molecule of carbon atoms, such as C_{60} . ☐
- Nanoparticle** a particle between 1 and 100 nanometres across. ☐
- Surface area to volume ratio** how much surface a particle has for its size. ☐

Drawing a covalent molecule. Outer shells only. Keep the atoms in place and put a shared pair between each bonded pair (a line is one pair). In methane the carbon's four outer electrons pair with one from each hydrogen. Don't add an extra electron or draw ions: both were seen in 2023.

A polymer isn't a giant structure: in 2023 the full answer compared molecule size, so intermolecular forces, so energy, so melting point. Diamond has no intermolecular forces: writing them with covalent bonds cancelled the mark in 2022. Atoms, molecules and ions aren't interchangeable.

Spot it Two black solids

Why does graphite conduct electricity when diamond doesn't?

- (A) Graphite contains ions that carry the current.
- (B) Graphite is softer, so its atoms move more easily.
- (C) Graphite has covalent bonds but diamond has ionic bonds.
- (D) Graphite has one delocalised electron per carbon atom.

Cover this, choose, then read

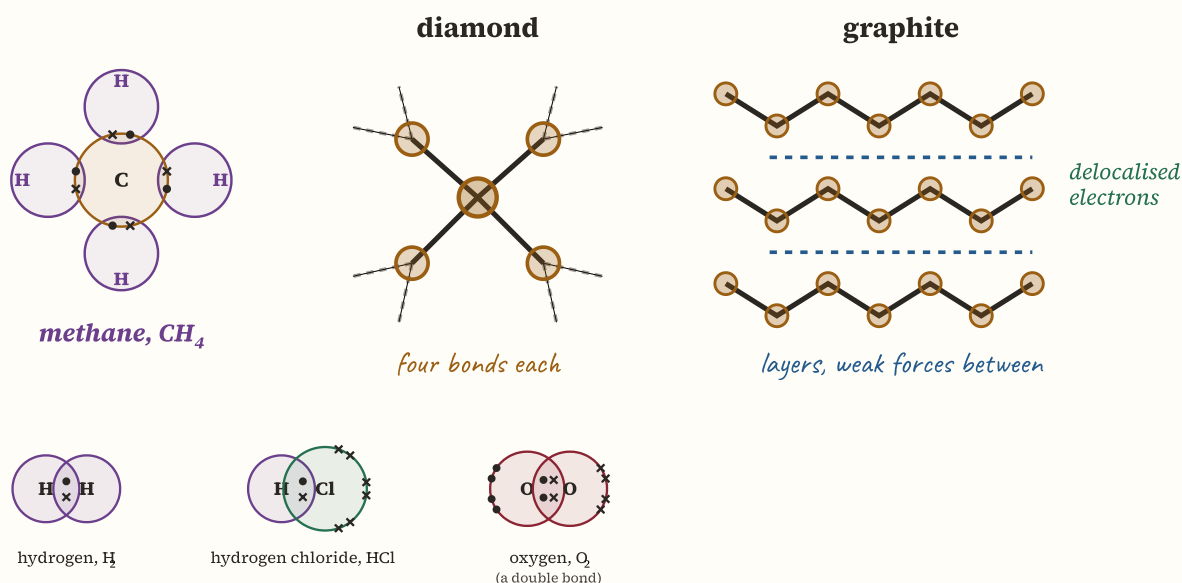
D. Each carbon atom in graphite makes three bonds and leaves one electron free to move, and it is those electrons that carry the current. Diamond uses all four outer electrons in bonds. Neither contains ions, and both have covalent bonds.

4 Covalent bonding and giant structures

Part two · Bonding, structure and properties

Use it

Covalent bonding in methane, and the carbon structures you must know



Structure	Example	Held together by	Melting point	Conducts?
Simple molecules	water, methane	strong bonds inside, weak forces between	low	no
Giant covalent	diamond, silicon dioxide	covalent bonds throughout	very high	no (graphite: yes)
Giant ionic	sodium chloride	ion to ion attraction	high	when molten or dissolved

Explain why graphite has a much higher melting point than ethane, C₂H₆.

[4 marks]

Graphite is a giant covalent structure, with strong bonds between all its atoms ✓. A lot of energy is needed to break them ✓. Ethane is a simple molecule, so only a little energy is needed to melt it ✓. But the covalent bonds in ethane are weak ✗.

3/4

3 out of 4. The last sentence cost the mark: the covalent bonds inside ethane are strong, and they stay intact when it melts. What is overcome are the weak intermolecular forces between the molecules. Full marks: "...so only the weak forces between ethane molecules need to be overcome."

It could be asked as

- Draw a covalent molecule, such as methane or water, showing the outer electrons.
- Explain why simple molecular substances have low boiling points.
- Explain, using structure, why diamond is hard and graphite conducts and is soft.
- Give uses of fullerenes or nanoparticles and say why their properties differ.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33**4.1** What is a covalent bond?**4.2** What is overcome when water boils?**4.3** What name is given to a single layer of graphite?**4.4** How many covalent bonds does each carbon atom make in diamond?

5

Part three · Quantitative chemistry

Mass and moles

Learn it

In sixty seconds

No atoms are lost or made in a reaction, so mass is conserved and equations must balance. The relative formula mass is the sum of the relative atomic masses of the atoms in the formula. A mass that seems to change usually involves a gas. At Higher tier, the amount in moles is mass divided by relative formula mass, and one mole is 6.02×10^{23} particles. Chemistry only: percentage yield and atom economy.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- The **law of conservation of mass**: no atoms are lost or made in a reaction, so the mass of the products equals the mass of the reactants. That's why symbol equations must be **balanced**. A large number before a formula multiplies every atom in it.
- The **relative formula mass** (M_r) of a compound is the sum of the relative atomic masses of its atoms, as shown in the formula. For CaCO_3 : $40 + 12 + (3 \times 16) = 100$.
- **Percentage by mass** of an element in a compound = $(A_r \times \text{number of atoms of that element} \div M_r) \times 100$.
- Mass can appear to change when a gas isn't counted. A metal heated in air gains mass as it combines with oxygen. A metal carbonate heated in an open tube loses mass because carbon dioxide escapes.
- Every measurement has some **uncertainty**. The range of results about the mean measures it: results of 12.3, 12.6 and 13.2 (mean 12.7) are at most 0.5 from the mean, so the uncertainty is ± 0.5 .
- **Concentration** can be mass per volume: g/dm^3 . Mass of solute = concentration $\times$ volume (in dm^3). $1 \text{ dm}^3 = 1000 \text{ cm}^3$, so divide cm^3 by 1000.
- **HT** **Moles**: amount (mol) = mass (g) $\div M_r$. One mole of any substance contains 6.02×10^{23} particles, the Avogadro constant, and its mass in grams equals its M_r .
- **HT** An equation is read in moles: in $\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$, one mole of magnesium reacts with two moles of acid. Use the ratio to find masses, or to balance an equation from the masses.
- **HT** The **limiting reactant** is the one used up first. It limits the amount of product made.
- **Chemistry only** **Percentage yield** = actual mass $\div$ maximum theoretical mass $\times 100$. It's below 100% if a reaction is reversible, product is lost on separating, or reactants react differently. **Atom economy** = M_r of the desired product $\div$ sum of the M_r of all reactants $\times 100$. **HT** Concentrations in mol/dm^3 and the 24 dm^3 molar gas volume at room temperature and pressure belong to Chemistry Higher tier.

Key words

- Conservation of mass** no atoms are lost or made, so mass doesn't change. ☐
- Relative formula mass** the sum of the relative atomic masses in a formula. ☐
- Mole** the unit for amount of substance. ☐
- Avogadro constant** 6.02×10^{23} particles in one mole. ☐
- Limiting reactant** the reactant that runs out first. ☐
- Concentration** the amount of solute in a given volume of solution. ☐
- Percentage yield** actual yield as a percentage of the maximum possible. ☐
- Atom economy** the percentage of the reactants' mass that ends up as the desired product. ☐

Units first. Volumes in cm^3 must be turned into dm^3 before you use a concentration or a number of moles. Use 3 significant figures if the data are given to 3. If the question gives you the data to use, use that: bringing in extra relative formula masses cost marks in 2023.

The slips were small ones. In 2021, students didn't multiply the M_r of hydrogen by the 3 in front of it, or left the carbon out of the reactants' total, or divided by 112 for iron instead of 56. In 2023, volumes weren't changed to dm^3 before dividing, and marks went.

Spot it The heavier magnesium

A student heats magnesium in an open crucible. The solid ends up heavier than the magnesium. Why?

- (A) Atoms are made when the magnesium is heated.
- (B) The magnesium has joined with oxygen from the air.
- (C) The magnesium atoms have gained neutrons.
- (D) Heating makes the magnesium denser, so it weighs more.

Cover this, choose, then read

B. No atoms are made or lost. The oxygen came from the air, and the gas wasn't weighed at the start. Heating doesn't change the number of neutrons in an atom, and density isn't mass.

5

Part three · Quantitative chemistry

Mass and moles

Use it

Mass is conserved: add up the M_r on each side

	CaCO_3	$\rightarrow \text{CaO}$	$+ \text{CO}_2$
Ar used	Ca 40, C 12, O 16	Ca 40, O 16	C 12, O 16
M_r	$40 + 12 + (3 \times 16) = 100$	$40 + 16 = 56$	$12 + (2 \times 16) = 44$
Check	100	$56 + 44 = 100$ ✓	

Why does it seem to lose mass?

In an open tube	In a sealed container
CaCO_3 loses 44 of every 100 g of mass: the carbon dioxide gas escapes into the air.	The mass stays the same: nothing can escape. The balance reads 100 g before and after.

Percentage of calcium in calcium carbonate: $40 \div 100 \times 100 = 40\%$.**HT Calculate the mass of magnesium oxide made when 4.8 g of magnesium burns completely in oxygen. $2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$. (A_r : Mg 24, O 16)** [4 marks]moles of Mg = $4.8 \div 24 = 0.2$ mol ✓

2 mol of Mg make 2 mol of MgO, so 0.2 mol of MgO ✓

 M_r of MgO = $24 + 16 = 40$ ✓mass = $0.2 \times 40 = 8.0$ g ✓

4/4

1 moles from mass $\div A_r$. 2 the mole ratio from the equation. 3 the M_r of the product. 4 mass = moles $\times M_r$. A check: the oxide must weigh more than the magnesium, because it gained oxygen. 8.0 g is more than 4.8 g.

It could be asked as

- Calculate a relative formula mass, or the percentage by mass of an element.
- Explain a change in mass when a gas is involved.
- Calculate the mass of a solute from its concentration and volume.
- **HT** Calculate moles from a mass, or a mass of product from a mass of reactant, using the equation.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33**5.1** Calculate the M_r of H_2SO_4 . (A_r : H 1, S 32, O 16)**5.2** Why does a metal carbonate lose mass when it's heated in an open tube?**5.3** **HT** How many moles are in 36 g of water? (M_r 18)**5.4** **Chemistry only** A reaction makes 8 g of a product. The maximum possible was 10 g. What is the percentage yield?

6

Part four · Chemical changes

Reactivity of metals

Learn it

In sixty seconds

Metals react by forming positive ions, and the reactivity series puts them in order of how easily they do it. A more reactive metal displaces a less reactive one from a compound. Metals less reactive than carbon are extracted by heating their oxides with carbon, which is reduction. Metals more reactive than carbon are extracted by electrolysis. Oxidation is gaining oxygen and reduction is losing it.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- When metals react, their atoms form **positive ions**. The reactivity of a metal is its tendency to do that: the more reactive the metal, the more easily its atoms lose electrons.
- The **reactivity series** comes from reactions with water and dilute acid: potassium, sodium, lithium, calcium, magnesium, then zinc, iron and copper. Carbon and hydrogen are often included for comparison. Aluminium sits between magnesium and carbon.
- Metals react with oxygen to form **metal oxides**. The more reactive the metal, the more vigorous the reaction.
- Potassium, sodium, lithium and calcium react with cold water to give a metal hydroxide and hydrogen. Magnesium, zinc and iron react with dilute acid to give a salt and hydrogen. Copper reacts with neither. Faster bubbling means a more reactive metal. These reactions are at room temperature.
- A more reactive metal **displaces** a less reactive metal from its compound. Iron + copper sulfate → iron sulfate + copper: the blue colour fades and brown copper forms on the iron.
- To put metals in order from results: a metal that displaces another is more reactive than it, and a metal that doesn't isn't.
- Unreactive metals such as gold are found in the Earth as the metal itself. Most metals are found as compounds, so a chemical reaction is needed to extract them. An **ore** contains enough metal to be worth extracting.
- **Oxidation** is gaining oxygen. **Reduction** is losing oxygen. A metal less reactive than carbon is extracted by reduction with carbon: iron oxide + carbon → iron + carbon dioxide. The iron oxide is reduced and the carbon is oxidised.
- Metals more reactive than carbon, such as aluminium, can't be reduced by carbon. They are extracted by **electrolysis**, which costs a lot of energy (see page 18).
- **HT** **In terms of electrons**, oxidation is loss of electrons and reduction is gain of electrons. $\text{Fe} + \text{Cu}^{2+} \rightarrow \text{Fe}^{2+} + \text{Cu}$: iron atoms lose electrons (oxidised) and copper ions gain them (reduced).

Key words

- Reactivity series** metals in order of how easily they form positive ions. ☐
- Displacement** a more reactive metal taking the place of a less reactive one in a compound. ☐
- Metal oxide** a compound of a metal with oxygen. ☐
- Ore** rock containing enough metal to make it worth extracting. ☐
- Oxidation** gaining oxygen. ☐
- Reduction** losing oxygen. ☐
- Positive ion** an atom that has lost electrons. ☐
- Ionic equation** an equation showing only the ions that change. ☐

Comparing reactivity by experiment. Add the same mass of each metal to the same volume of the same solution, such as copper sulfate, and measure the **temperature change**. Keep the volume, the concentration and the mass of metal the same: write volume or mass, never "amount". The bigger the temperature change, the more reactive the metal.

Say which metal displaces which: "it displaces it" earned nothing in 2022 when the examiner couldn't tell which "it" was meant. And reactivity isn't about melting or boiling point: in 2021 many students linked them, and it's about how easily an atom loses electrons.

Spot it Which will react?

Which of these mixtures will show a chemical reaction?

- (A) Copper added to zinc sulfate solution.
- (B) Silver added to copper sulfate solution.
- (C) Zinc added to copper sulfate solution.
- (D) Iron added to magnesium sulfate solution.

Cover this, choose, then read

C. Zinc is more reactive than copper, so it displaces copper. In each other mixture the metal added is less reactive than the metal in the solution: copper below zinc, silver below copper, iron below magnesium.

6 Reactivity of metals

Part four · Chemical changes

Use it**The reactivity series, and which metals displace which**most reactive $\longrightarrow$ least reactive

K	Na	Li	Ca	Mg	Al	C	Zn	Fe	H	Cu	Ag	Au
potassium	sodium	lithium	calcium	magnesium	aluminium	carbon	zinc	iron	hydrogen	copper	silver	gold
extracted by electrolysis						extracted with carbon				found as the metal		

Metal added to the solution	copper sulfate	iron sulfate	zinc sulfate	magnesium sulfate
magnesium	reacts	reacts	reacts	n/a
zinc	reacts	reacts	n/a	no reaction
iron	reacts	n/a	no reaction	no reaction
copper	n/a	no reaction	no reaction	no reaction

Read down a column: copper sulfate reacts with everything above copper, so copper is the least reactive of the four.

Explain, using the reactivity series, why carbon can be used to extract iron from iron oxide but not aluminium from aluminium oxide. [3 marks]

Carbon is more reactive than iron ✓, so it can remove the oxygen from iron oxide: the iron oxide is reduced ✓.
Aluminium is more reactive than carbon, so carbon can't remove the oxygen from aluminium oxide ✓.

3/3

1 carbon is more reactive than iron. 2 so it takes the oxygen: reduction of the iron oxide. 3 aluminium is more reactive than carbon, so it doesn't work. Name the metals each time rather than writing "it".

It could be asked as

- Put metals in order of reactivity from experimental results.
- Describe what you'd see when a metal is added to a salt solution of another metal.
- Explain which method is used to extract a metal from its ore, using its position.
- Identify what is oxidised and what is reduced in a reaction.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33**6.1** Name the products when magnesium reacts with dilute hydrochloric acid.**6.2** In terms of oxygen, what is reduction?**6.3** Why is gold found in the ground as the metal itself?**6.4** **HT** In $\text{Fe} + \text{Cu}^{2+} \rightarrow \text{Fe}^{2+} + \text{Cu}$, what happens to the iron?

7 Acids, bases and salts

Part four · Chemical changes

Learn it**In sixty seconds**

Acids make hydrogen ions in water and alkalis make hydroxide ions. The pH scale runs from 0 to 14. Acids are neutralised by bases, alkalis and metal carbonates to make a salt and water, and carbon dioxide too for a carbonate. The salt depends on the acid and the metal. To make a pure dry soluble salt, add excess insoluble solid to warm acid, filter, then crystallise. Strong acids are fully ionised and weak acids only partly.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- **Acid + metal → salt + hydrogen.** The salt depends on the acid: hydrochloric acid makes chlorides, nitric acid nitrates, sulfuric acid sulfates.
- **Acid + base or alkali → salt + water. Acid + metal carbonate → salt + water + carbon dioxide.** Bases include metal oxides and hydroxides. An **alkali** is a soluble base.
- Acids produce **hydrogen ions** (H^+) in solution; alkalis contain **hydroxide ions** (OH^-). pH runs from 0 to 14: below 7 acidic, 7 neutral, above 7 alkaline. Measure it with universal indicator or a pH probe.
- **Neutralisation:** $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. The hydrogen ions and hydroxide ions react to make water.
- **Required practical 1**, making a pure dry salt from an insoluble oxide or carbonate: warm the dilute acid, add the solid until no more reacts, filter off the excess, heat the filtrate to evaporate some water, leave it to crystallise, then filter and dry the crystals.
- Why: heating **speeds up** the reaction. The solid is in **excess** so all the acid reacts and the leftover is easy to filter off. Heat the filtrate in a water bath or with an electric heater until crystals start to form, not to dryness.
- **Chemistry only** **Titration** finds the volumes of strong acid and strong alkali that react: pipette for the alkali, burette for the acid, indicator, white tile. Add acid drop by drop near the end-point, and repeat until results agree.
- **HT** A **strong acid** is fully ionised in water (hydrochloric, nitric, sulfuric). A **weak acid** is only partly ionised (ethanoic, citric, carbonic). **Dilute** and **concentrated** are about the amount in the volume. **Strong** and **weak** are about ionisation.
- **HT** Each pH unit down means ten times the hydrogen ions: pH 2 has 100 times those of pH 4. A stronger or a more concentrated acid has a lower pH.
- **Chemistry only** **HT** In a titration, moles = concentration (mol/dm^3) × volume (dm^3), then use the ratio from the equation.

Key words

- Acid** a substance that makes hydrogen ions in water. ☐
- Alkali** a soluble base that makes hydroxide ions in water. ☐
- Base** a substance that neutralises an acid. ☐
- Neutralisation** an acid and a base reacting to make a salt and water. ☐
- Salt** a compound formed when an acid's hydrogen is replaced by a metal. ☐
- pH** a scale from 0 to 14 for how acidic or alkaline a solution is. ☐
- Strong acid** an acid that is fully ionised in water. ☐
- Titration** finding the volumes of two solutions that react exactly. ☐

Not every practical is an investigation.

Making a salt is a method to follow, so don't write about independent, dependent and control variables: some students did in 2023. **Chemistry only** Titration indicators: phenolphthalein goes from pink in alkali to colourless in acid, methyl orange from yellow to red. Say "colourless", not "clear".

Know why, not just what. AQA credited "so all the acid reacts" in 2021 but wanted "the excess solid is easy to filter off" in 2022: give both. Heating the acid speeds the reaction. It's water that evaporates, to the point crystals form, not to dryness. A weak acid is partially ionised: a pH answer wasn't accepted.

Spot it Solid left at the bottom

Magnesium oxide is added to warm sulfuric acid until some solid stays at the bottom of the beaker. What does that show?

- (A) All the acid has reacted: the magnesium oxide is in excess.
- (B) The magnesium oxide is dissolving slowly because it is cold.
- (C) The reaction has not started yet.
- (D) The solid that stays is a salt that has formed.

Cover this, choose, then read

A. Solid that stays means the magnesium oxide has no acid left to react with. That is the point of adding excess. The salt, magnesium sulfate, is soluble, so it is in the solution, not at the bottom.

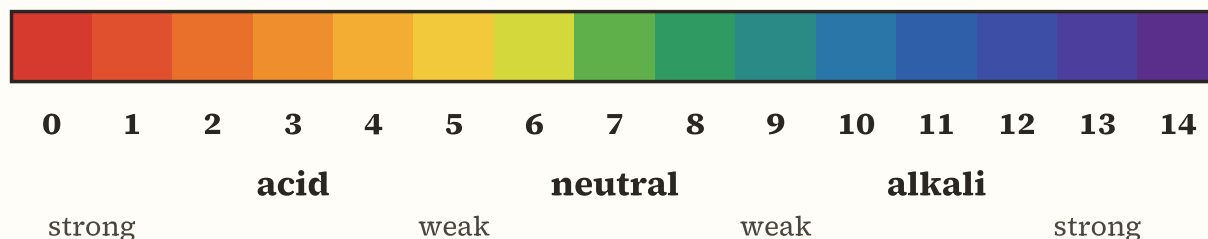
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Part four · Chemical changes

Acids, bases and salts

Use it

The pH scale, and how to make a soluble salt from an insoluble solid



1 • Warm and add

Warm the dilute acid. Add the solid until no more reacts and some stays at the bottom.



2 • Filter

Filter off the excess solid. The filtrate is a solution of the salt.



3 • Crystallise

Heat the filtrate until crystals start to form, leave it to cool, then filter and dry.

Acid	Salt it makes	Example
hydrochloric	a chloride	zinc oxide + hydrochloric acid → zinc chloride + water
nitric	a nitrate	copper oxide + nitric acid → copper nitrate + water
sulfuric	a sulfate	magnesium + sulfuric acid → magnesium sulfate + hydrogen

Describe how to make a pure, dry sample of copper sulfate crystals from copper oxide and sulfuric acid.

[4 marks]

Warm dilute sulfuric acid ✓. Add copper oxide a bit at a time until some stays at the bottom, so it's in excess ✓.

Filter to remove the excess copper oxide ✓. Heat the filtrate until crystals start to form, then leave it to cool and crystallise ✓.

4/4

1 acid warmed. 2 excess solid. 3 filter off the excess. 4 heat to the point of crystallisation, then cool: not to dryness. A fifth point would be to filter and dry the crystals. Use a water bath or an electric heater, not a Bunsen burner, which heats to dryness.

It could be asked as

- Name the salt made from a given acid and base, and write the equation.
- Describe how to make a pure dry sample of a soluble salt, and say why each step is done.
- Explain the difference between strong and weak acids, or dilute and concentrated.
- Describe how to carry out a titration.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33

7.1 Name the salt made from zinc oxide and sulfuric acid.

7.2 Which ion makes a solution alkaline?

7.3 **Chemistry only** Give an indicator and its colour change when acid is added to alkali.

7.4 **HT** How many times more hydrogen ions are in pH 2 than in pH 4?

8 Electrolysis

Part four · Chemical changes

Learn it

In sixty seconds

Electrolysis uses electricity to break down an ionic compound that is molten or dissolved. Positive ions go to the cathode and negative ions to the anode. Molten compounds give the metal at the cathode and the non-metal at the anode. In a solution, the cathode gives hydrogen unless the metal is less reactive than hydrogen, and the anode gives oxygen unless a halide ion is present. Aluminium is made by electrolysis of molten aluminium oxide in cryolite.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- In **electrolysis** an electric current is passed through an **electrolyte**, an ionic compound that is molten or in solution, so its ions are free to move. The compound is decomposed. It uses electricity to cause a chemical reaction.
- **Positive ions** move to the negative electrode, the **cathode**. **Negative ions** move to the positive electrode, the **anode**. Opposites attract.
- **Molten ionic compounds** give the metal at the cathode and the non-metal at the anode: molten lead bromide gives lead and bromine. Keep the products apart, or they react and re-form the compound.
- Metals more reactive than carbon are extracted by electrolysis of their molten compounds, which costs a lot of energy.
- **Aluminium:** aluminium oxide dissolves in molten **cryolite**, which lowers the melting temperature. Aluminium forms at the cathode, oxygen at the carbon anodes, which burn away as carbon dioxide and are replaced.
- In an **aqueous solution** water also gives H^+ and OH^- ions. At the cathode, **hydrogen** forms if the metal is more reactive than hydrogen, otherwise the metal. At the anode, **oxygen** forms unless a halide ion is present, then the halogen.
- Copper sulfate solution gives copper at the cathode and oxygen at the anode, and the blue colour fades as copper ions are discharged. Sodium chloride solution gives hydrogen and chlorine, leaving sodium hydroxide.
- **Required practical 3:** electrolyse aqueous solutions with inert electrodes and identify the products. Hydrogen pops with a lighted splint, oxygen relights a glowing splint, chlorine bleaches damp litmus paper.
- **HT** At the cathode ions **gain electrons**: reduction. At the anode ions **lose electrons**: oxidation.
- **HT** Half equations: $Na^+ + e^- \rightarrow Na$ and $Al^{3+} + 3e^- \rightarrow Al$ at the cathode; $2Cl^- \rightarrow Cl_2 + 2e^-$ and $4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ at the anode.

Key words

Electrolysis breaking down an ionic compound with electricity.	☐
Electrolyte the molten or dissolved ionic compound that conducts.	☐
Electrode a rod that carries the current into or out of the electrolyte.	☐
Cathode the negative electrode, where positive ions arrive.	☐
Anode the positive electrode, where negative ions arrive.	☐
Inert electrode an electrode, such as graphite, that doesn't react.	☐
Cryolite a compound that lowers the melting point of aluminium oxide.	☐
Half equation an equation for what happens at one electrode.	☐

Electrolysis and cells are opposites.

Electrolysis uses electricity to make a reaction happen. A cell uses a reaction to make electricity. Very few students saw that in 2021. Ions are **discharged** at the electrodes, not “separated”, and ions carry the current through a solution: electrons don't.

In sodium chloride solution there are four ions: Na^+ , Cl^- , H^+ and OH^- , not “oxygen ions”. Write chloride, not “chlorine ions”, and don't swap the electrodes: the cathode is negative and the anode is positive. The blue colour fades because copper ions are removed, and copper itself doesn't dissolve.

Spot it Salt water

Aqueous sodium chloride is electrolysed with inert electrodes. Which products form?

- (A) Sodium at the cathode and chlorine at the anode.
- (B) Hydrogen at the anode and chlorine at the cathode.
- (C) Sodium at the anode and oxygen at the cathode.
- (D) Hydrogen at the cathode and chlorine at the anode.

Cover this, choose, then read

D. Sodium is more reactive than hydrogen, so hydrogen is made at the negative electrode. Chloride is a halide ion, so chlorine is made at the positive electrode. Positive ions go to the cathode, never the anode.

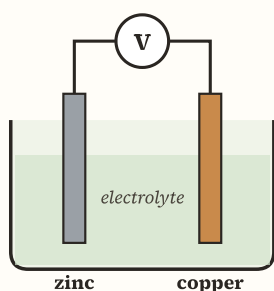
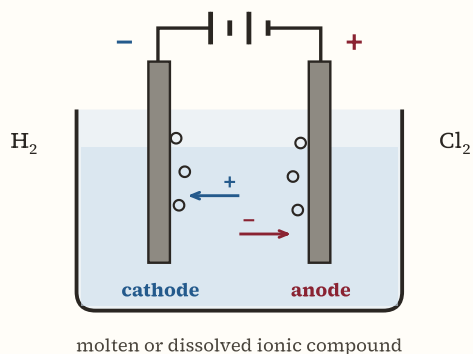
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Part four · Chemical changes

Electrolysis

Use it

An electrolysis cell, and what to expect at each electrode



Electrolyte	Cathode (-)	Anode (+)
molten lead bromide	lead	bromine
aqueous copper sulfate	copper	oxygen
aqueous sodium chloride	hydrogen	chlorine
aqueous sodium sulfate	hydrogen	oxygen
molten aluminium oxide in cryolite	aluminium	oxygen

A chemical cell is the opposite. Two different metals dip into an electrolyte and the reaction makes electricity. The bigger the difference in reactivity, the bigger the voltage. Draw both metals, the electrolyte and a complete circuit: in 2022 students drew an electrolysis cell by mistake.

Predict the product at each electrode when aqueous potassium bromide is electrolysed using inert electrodes. Explain each answer.

[4 marks]

At the cathode, hydrogen is made ✓, because potassium is more reactive than hydrogen, so hydrogen ions are discharged rather than potassium ions ✓. At the anode, bromine is made ✓, because the solution contains a halide ion ✓.

4/4

1 hydrogen at the cathode. 2 the reason: the metal is more reactive than hydrogen. 3 bromine at the anode. 4 the reason: a halide ion is present. Without the bromide, the anode would give oxygen from the hydroxide ions in the water.

It could be asked as

- Predict the products of electrolysis of a molten compound or an aqueous solution.
- Explain why an ionic compound must be molten or dissolved.
- Describe how aluminium is extracted, including why cryolite is used.
- **HT** Write a half equation for a reaction at an electrode.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33

8.1 Why must the ionic compound be molten or dissolved for electrolysis?

8.3 Why is cryolite added when aluminium is extracted?

8.2 What is made at the cathode when molten lead bromide is electrolysed?

8.4 **HT** Write the half equation for hydrogen forming at the cathode.

9 Energy changes

Part five · Energy changes

Learn it**In sixty seconds**

In an exothermic reaction energy is transferred to the surroundings and the temperature rises. In an endothermic reaction energy is taken in and the temperature falls. A reaction profile shows the energy of the reactants and products, and the activation energy. At Higher tier, breaking bonds takes in energy, making bonds releases it, and the difference is the energy change. Chemistry only: cells and fuel cells.

Facts to know

Try it, then colour the circle: ● knew it ● shaky ○ missed

- Energy is conserved in a reaction. It is transferred between the chemicals and their surroundings.
- **Exothermic** reactions transfer energy to the surroundings, so the temperature of the surroundings **rises**. Examples: combustion, oxidation and neutralisation. Uses: hand warmers and self-heating cans.
- **Endothermic** reactions take in energy from the surroundings, so the temperature **falls**. Examples: thermal decomposition, and citric acid with sodium hydrogencarbonate. Use: sports injury packs.
- **Required practical 4:** investigate temperature changes when solutions react. Use a polystyrene cup with a lid to reduce heat loss, record the **highest or lowest** temperature reached, and keep the volumes and concentrations the same.
- A **reaction profile** plots energy against the progress of the reaction. The **activation energy** is the minimum energy colliding particles need to react: the gap from the reactants up to the peak.
- In an exothermic profile the products are lower than the reactants. In an endothermic profile they are higher. The overall energy change is the gap between the two levels.
- Drawing one: use a ruler, label reactants and products, draw an arrow for the activation energy (reactants to the peak), an arrow for the overall energy change, and dotted lines for the levels.
- **HT** Energy must be supplied to **break bonds**, and energy is released when **bonds form**. The overall energy change is energy to break bonds minus energy released making bonds.
- **HT** Exothermic: more energy is released making the new bonds than is needed to break the old ones. Endothermic: more energy is needed to break bonds than is released making them.
- **Chemistry only** **Cells and batteries** use chemical reactions to make electricity. Two different metals in an electrolyte make a simple cell. A bigger difference in reactivity gives a bigger voltage. A **fuel cell** is supplied with hydrogen and oxygen, and the hydrogen is oxidised to make water.

Key words

- Exothermic** a reaction that transfers energy to the surroundings. ☐
- Endothermic** a reaction that takes in energy from the surroundings. ☐
- Activation energy** the minimum energy particles need to react. ☐
- Reaction profile** a diagram of the energy changes in a reaction. ☐
- Bond energy** the energy needed to break one mole of a particular bond. ☐
- Cell** two metals and an electrolyte that make electricity. ☐
- Battery** two or more cells connected together. ☐
- Fuel cell** a cell supplied with a fuel such as hydrogen and with oxygen. ☐

From the practical. The step students most often missed was recording the **highest** temperature reached. Quote a temperature change in °C: g/°C was seen for a gradient, but “C°” is never right. Plot points in pencil, annotate your graph when you read a gradient, and give the uncertainty as the biggest distance of any result from the mean.

The activation energy isn't the peak: it's the gap from the reactants up to the peak, drawn as an arrow with a ruler. Finish the profile with the products' energy level, and label it. In 2023 some wrote that energy is needed in both steps, or only mentioned making bonds, or said an exothermic reaction loses matter. It loses energy to the surroundings.

Spot it The cold pack

A student mixes two solutions and the temperature falls from 21 °C to 16 °C. What type of reaction is this?

- (A) Exothermic, because the temperature changed.
- (B) Endothermic, because energy was taken in.
- (C) Exothermic, because energy was released.
- (D) Endothermic, because energy was given out.

Cover this, choose, then read

B. A falling temperature means the mixture is taking in energy from its surroundings. Exothermic reactions make the temperature rise. A change on its own isn't enough: the direction matters.

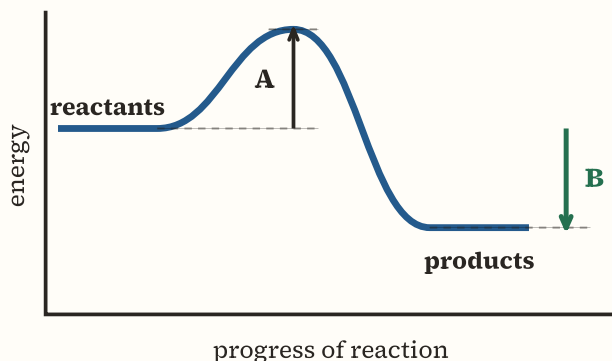
9 Energy changes

Part five · Energy changes

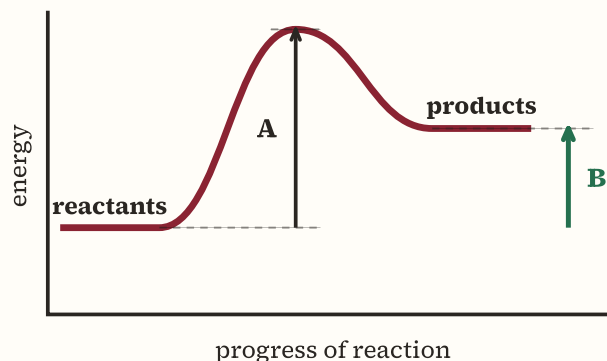
Use it

Reaction profiles, and the bond energy sum for Higher tier

exothermic: products lower



endothermic: products higher



A activation energy, reactants up to the peak · B overall energy change, between the two levels

HT $\text{N}=\text{N} + 3 \text{H}-\text{H} \rightarrow 2 \text{NH}_3$, with bond energies in kJ per mole

	Bonds broken	Bonds made	Energy change
Working	$945 + (3 \times 436) = 2253$	$6 \times 391 = 2346$	$2253 - 2346$
Answer	2253 kJ in	2346 kJ out	-93 kJ per mole: exothermic

HT Nitrogen reacts with hydrogen: $\text{N}=\text{N} + 3 \text{H}-\text{H} \rightarrow 2 \text{NH}_3$, which has 6 N-H bonds. The bond energies are N=N 945, H-H 436 and N-H 391 kJ/mol. Calculate the energy change and say whether the reaction is exothermic or endothermic.

[3 marks]

energy to break the bonds = $945 + (3 \times 436) = 2253 \text{ kJ}$ ✓
 energy released making the bonds = $6 \times 391 = 2346 \text{ kJ}$ ✓
 energy change = $2253 - 2346 = -93 \text{ kJ/mol}$, so the reaction is exothermic ✓

3/3

1 add the bonds broken, counting every H-H bond. 2 add the bonds made: ammonia has three N-H bonds, and there are two molecules. 3 subtract, and use the sign. A 2023 question on a different molecule showed the same slips: adding all the energies together, or counting one bond too few. The negative sign means energy is released overall.

It could be asked as

- Classify a reaction as exothermic or endothermic from a temperature change.
- Draw and label a reaction profile, including the activation energy.
- Describe the practical on temperature changes, and say what to measure.
- **HT** Calculate the energy change of a reaction from bond energies, and explain it in terms of bonds.

Cover both pages and write your sixty seconds from memory

predict ___ / 10 got ___ / 10

Quick-fire. Answers are on page 33

9.1 Is the neutralisation of an acid by an alkali exothermic or endothermic?

9.3 What unit goes with a temperature change?

9.2 What is activation energy?

9.4 **HT** More energy is released making bonds than is needed to break them. Is the reaction exothermic or endothermic?

Skills

Ions, formulae and equations

AQA expects formulae and balanced equations for every reaction in the specification. In 2021 few could write the products of potassium and water.

Ions to know

Charge	The common ions
1+	hydrogen H^+ · lithium Li^+ · sodium Na^+ · potassium K^+ · silver Ag^+ · ammonium NH_4^+
2+	magnesium Mg^{2+} · calcium Ca^{2+} · barium Ba^{2+} · zinc Zn^{2+} · copper(II) Cu^{2+} · iron(II) Fe^{2+} · lead Pb^{2+}
3+	aluminium Al^{3+} · iron(III) Fe^{3+}
1-	chloride Cl^- · bromide Br^- · iodide I^- · hydroxide OH^- · nitrate NO_3^-
2-	oxide O^{2-} · sulfate SO_4^{2-} · carbonate CO_3^{2-}

A formula from its ions: swap the numbers so the charges cancel, then simplify

Compound	Ions	Formula
magnesium chloride	Mg^{2+} and Cl^-	MgCl_2
aluminium nitrate	Al^{3+} and NO_3^-	$\text{Al}(\text{NO}_3)_3$
sodium sulfate	Na^+ and SO_4^{2-}	Na_2SO_4
calcium hydroxide	Ca^{2+} and OH^-	$\text{Ca}(\text{OH})_2$
iron(III) oxide	Fe^{3+} and O^{2-}	Fe_2O_3

Brackets for a group of atoms: $\text{Ca}(\text{OH})_2$. To balance, change the big numbers in front, never the small numbers inside a formula.

Groups 1 and 7

In words	Balanced equation
sodium + water → sodium hydroxide + hydrogen	$2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2$
lithium + oxygen → lithium oxide	$4\text{Li} + \text{O}_2 \rightarrow 2\text{Li}_2\text{O}$
sodium + chlorine → sodium chloride	$2\text{Na} + \text{Cl}_2 \rightarrow 2\text{NaCl}$
chlorine + potassium bromide → potassium chloride + bromine	$\text{Cl}_2 + 2\text{KBr} \rightarrow 2\text{KCl} + \text{Br}_2$

Metals

In words	Balanced equation
magnesium + oxygen → magnesium oxide	$2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$
calcium + water → calcium hydroxide + hydrogen	$\text{Ca} + 2\text{H}_2\text{O} \rightarrow \text{Ca}(\text{OH})_2 + \text{H}_2$
magnesium + hydrochloric acid → magnesium chloride + hydrogen	$\text{Mg} + 2\text{HCl} \rightarrow \text{MgCl}_2 + \text{H}_2$
iron + copper sulfate → iron sulfate + copper	$\text{Fe} + \text{CuSO}_4 \rightarrow \text{FeSO}_4 + \text{Cu}$
iron oxide + carbon → iron + carbon dioxide	$2\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Fe} + 3\text{CO}_2$

Acids

In words	Balanced equation
hydrochloric acid + sodium hydroxide → sodium chloride + water	$\text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{H}_2\text{O}$
sulfuric acid + copper oxide → copper sulfate + water	$\text{H}_2\text{SO}_4 + \text{CuO} \rightarrow \text{CuSO}_4 + \text{H}_2\text{O}$
hydrochloric acid + zinc carbonate → zinc chloride + water + carbon dioxide	$2\text{HCl} + \text{ZnCO}_3 \rightarrow \text{ZnCl}_2 + \text{H}_2\text{O} + \text{CO}_2$
neutralisation, as ions	$\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$

Electrolysis

In words	Balanced equation
molten lead bromide → lead + bromine	$\text{PbBr}_2 \rightarrow \text{Pb} + \text{Br}_2$
aluminium oxide → aluminium + oxygen	$2\text{Al}_2\text{O}_3 \rightarrow 4\text{Al} + 3\text{O}_2$
sodium chloride solution → hydrogen + chlorine + sodium hydroxide	$2\text{NaCl} + 2\text{H}_2\text{O} \rightarrow \text{H}_2 + \text{Cl}_2 + 2\text{NaOH}$

Energy

In words	Balanced equation
calcium carbonate → calcium oxide + carbon dioxide (thermal decomposition)	$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$
methane + oxygen → carbon dioxide + water (combustion)	$\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}$
hydrogen + oxygen → water (fuel cell)	$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$

HT Ionic and half equations

What is happening	Equation
A metal displaces a metal ion	$\text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu}$
A halogen displaces a halide ion	$\text{Cl}_2 + 2\text{Br}^- \rightarrow 2\text{Cl}^- + \text{Br}_2$
Cathode, metal ions gain electrons	$\text{Na}^+ + \text{e}^- \rightarrow \text{Na}$
Cathode, aluminium	$\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al}$
Cathode, hydrogen	$2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$
Anode, chloride or bromide loses electrons	$2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$
Anode, hydroxide loses electrons	$4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$

Include state symbols if asked: (s), (l), (g), (aq).

Skills

The maths you need

Set every calculation out the same way: write the formula, put the numbers in with their units, calculate, then write the unit. Check it's sensible. Examiners give marks for each step, so show them all. At least a fifth of the marks on Chemistry papers test maths.

Relative formula mass

Calcium hydroxide, $\text{Ca}(\text{OH})_2$. A_r : Ca 40, O 16, H 1.
 $M_r = 40 + 2 \times (16 + 1)$

$$= 74$$

The 2 outside the bracket multiplies everything inside it. Write each step.

Percentage by mass

The percentage of magnesium in magnesium oxide, MgO .
 A_r of Mg $\div$ M_r of $\text{MgO} \times 100 = 24 \div 40 \times 100$

$$= 60\%$$

Use the A_r for the number of atoms of that element in the formula.

Relative atomic mass

Boron is 20% boron-10 and 80% boron-11.
 $(10 \times 20 + 11 \times 80) \div 100 = 1080 \div 100$

$$= 10.8$$

Divide by 100, not by the number of isotopes or the sum of the mass numbers. It must sit between 10 and 11.

Concentration in g/dm^3

4.0 g of sodium hydroxide is in 250 cm^3 of solution.
 $250 \text{ cm}^3 = 0.25 \text{ dm}^3$, so concentration = mass $\div$ volume =
 $4.0 \div 0.25$

$$= 16 \text{ g/dm}^3$$

Change cm^3 to dm^3 by dividing by 1000 before you divide.

Moles from a mass HT

How many moles are in 5.3 g of sodium carbonate,
 Na_2CO_3 ? $M_r = 106$.
 moles = mass $\div$ $M_r = 5.3 \div 106$

$$= 0.05 \text{ mol}$$

Mass divided by M_r ; grams per mole. Check the answer is a sensible size.

Significant figures

A titration calculation gives $0.00252 \div 0.0214 = 0.117757\dots$
 mol/dm^3 on the calculator. The data were to 3 significant figures.

Keep every digit until the last step, then round once:
 $0.1177\dots$ to 3 s.f.

$$= 0.118 \text{ mol/dm}^3$$

Count from the first non-zero digit. AQA allows a correctly rounded answer from a wrong calculation, as long as it uses all the data.

Yield and atom economy Chemistry only

A reaction should make 8.0 g and made 6.4 g: $6.4 \div 8.0 \times 100$. For $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$, the wanted CaO has M_r 56 and the reactant 100: $56 \div 100 \times 100$.

$$= 80\% \text{ yield} \cdot 56\% \text{ atom economy}$$

Yield is never above 100%. Atom economy uses the balanced equation and the M_r of **all** the reactants.

Surface area to volume Chemistry only

A cube of side 2 nm: surface area $6 \times 2^2 = 24 \text{ nm}^2$, volume
 $2^3 = 8 \text{ nm}^3$, so the ratio is $24 \div 8$. A cube of side 20 nm:
 $2400 \div 8000$.

$$= 3 : 1 \text{ and } 0.3 : 1$$

Ten times smaller on each side, so ten times bigger ratio. That is why nanoparticles behave differently.

Standard form

An atom's radius is $1 \times 10^{-10} \text{ m}$. A nucleus's is $1 \times 10^{-14} \text{ m}$.
 $10^{-10} \div 10^{-14} = 10^{-10 - (-14)}$

$$= 10^4 = 10\,000 \text{ times}$$

Subtract the powers. Use the $\times 10^x$ or EXP key on your calculator, not " $\times 10$ " typed by hand.

Gradient and uncertainty

Temperature rises of 7.2, 7.4 and 7.9 $^\circ\text{C}$ give a mean of 7.5 $^\circ\text{C}$. The furthest result is 0.4 from the mean.

A line goes from (0 g, 0 $^\circ\text{C}$) to (2.5 g, 20 $^\circ\text{C}$): gradient = $20 \div 2.5$

$$\pm 0.4 \text{ }^\circ\text{C} \cdot 8 \text{ }^\circ\text{C per g}$$

Uncertainty is the biggest distance from the mean (half the range is 0.35, not the same thing). Write the gradient's unit as y per x: $^\circ\text{C per g}$.

Skills

Moles, volumes and titrations

Every one of these is a Higher tier calculation, and some are Chemistry only. They were worth marks in each of the 2021, 2022 and 2023 papers. Use four moves: **write the balanced equation, turn what you know into moles, use the ratio, turn moles into what was asked for**. Show every move, because the marks are for the method too.

Reacting masses **HT**

$2\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Fe} + 3\text{CO}_2$. How much iron from 1.6 kg of iron oxide? A_r : Fe 56, O 16.

1.6 kg = 1600 g. M_r of Fe_2O_3 = 160, so $1600 \div 160 = 10$ mol.

Ratio Fe_2O_3 : Fe = 2 : 4, so 20 mol Fe. Mass = 20×56

$$= 1120 \text{ g (1.12 kg)}$$

Change kg to g first: AQA used kg in 2022 and 2023. Moles of what you know, then the ratio, then back to mass.

Gas volume from moles **Chemistry only HT**

$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$. What volume of carbon dioxide at room temperature and pressure from 25 g of CaCO_3 ?
moles CaCO_3 = $25 \div 100 = 0.25$, so 0.25 mol CO_2 . Volume = 0.25×24

$$= 6.0 \text{ dm}^3$$

One mole of any gas is 24 dm^3 at 20 °C and 1 atmosphere.

Gas volumes in a ratio **Chemistry only HT**

$\text{N}_2 + 3\text{H}_2 \rightarrow 2\text{NH}_3$. 30 cm^3 of nitrogen reacts completely.

Volumes of gases in an equation are in the same ratio as the moles: hydrogen 3×30 , ammonia 2×30

$$= 90 \text{ cm}^3 \text{ H}_2 \text{ and } 60 \text{ cm}^3 \text{ NH}_3$$

No need for 24 here. AQA's 2022 mark scheme allowed this method or the moles method.

Titration with a 1 : 2 ratio **Chemistry only HT**

$\text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$. 20.0 cm^3 of 0.0500 mol/dm^3 H_2SO_4 neutralises 25.0 cm^3 of NaOH solution.

moles H_2SO_4 = $0.0500 \times 20.0 \div 1000 = 0.00100$. Moles NaOH = $2 \times 0.00100 = 0.00200$. Concentration = $0.00200 \div (25.0 \div 1000)$

$$= 0.0800 \text{ mol/dm}^3$$

Volumes to dm^3 both times. The 2 comes from the equation, so write the equation first. Unit slips cost marks in 2023.

mol/dm³ to g/dm³ **Chemistry only HT**

Sodium hydroxide solution is 0.0800 mol/dm^3 . M_r of NaOH = 40.

g/dm^3 = $\text{mol/dm}^3 \times M_r$ = 0.0800×40

$$= 3.20 \text{ g/dm}^3$$

Go the other way by dividing by M_r : 4.0 g/dm^3 of NaOH is $4.0 \div 40 = 0.10 \text{ mol/dm}^3$.

Number of particles **HT**

How many atoms are in 3.0 g of carbon? A_r = 12. Avogadro constant 6.02×10^{23} .

moles = $3.0 \div 12 = 0.25$. Atoms = $0.25 \times 6.02 \times 10^{23} = 1.505 \times 10^{23}$

$$= 1.5 \times 10^{23} \text{ atoms}$$

Moles first from mass $\div A_r$, then $\times 6.02 \times 10^{23}$. AQA asked a similar particles question in 2022.

Limiting reactant **HT**

$2\text{Mg} + \text{O}_2 \rightarrow 2\text{MgO}$. 3.0 g of Mg and 3.0 g of O_2 . Which runs out, and how much MgO is made? (A_r : Mg 24, O 16)

Mg: $3.0 \div 24 = 0.125$ mol, which needs 0.0625 mol O_2 = 2.0 g. There is 3.0 g, so magnesium limits. $\text{MgO} = 0.125 \times 40$

$$= 5.0 \text{ g of MgO}$$

The reactant that runs out sets the amount of product.

Concentration units

2.0 g of sodium hydroxide (M_r 40) is dissolved to make 500 cm^3 of solution.

$500 \text{ cm}^3 = 0.5 \text{ dm}^3$. g/dm^3 = $2.0 \div 0.5 = 4.0$. mol/dm^3 = $4.0 \div 40$

$$= 4.0 \text{ g/dm}^3 = 0.10 \text{ mol/dm}^3$$

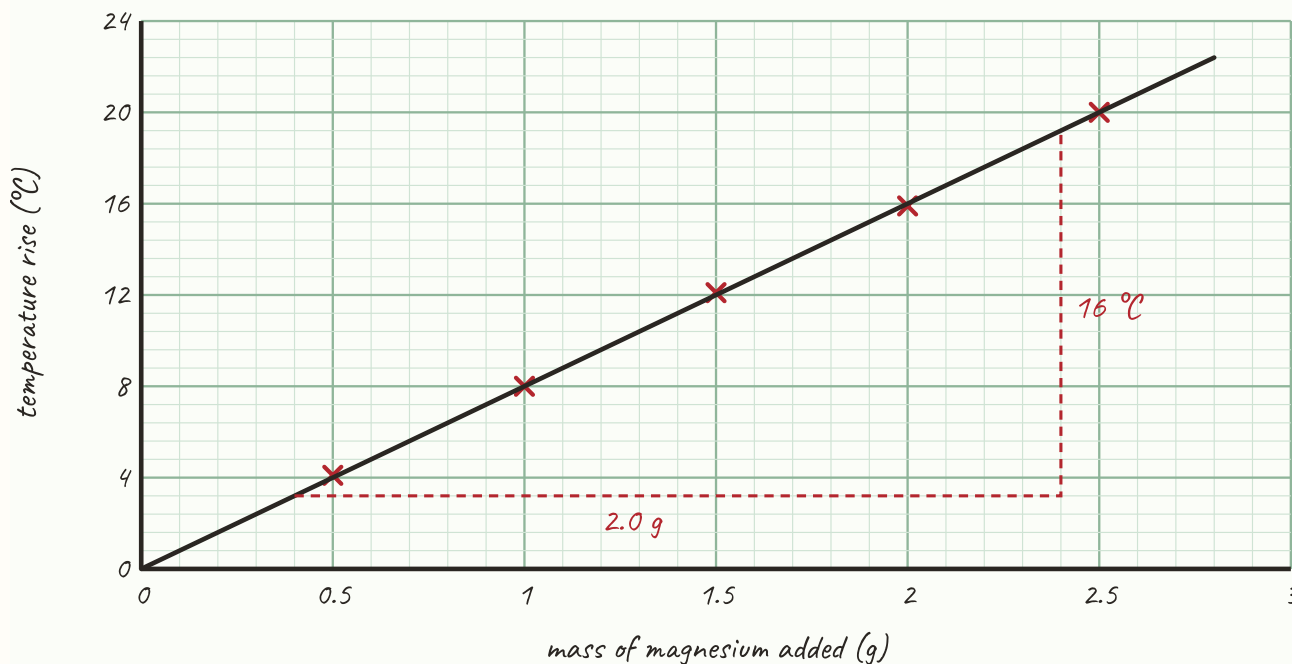
Two units for the same solution. Work out which one the question wants.

Skills

Graphs and data

Plotted the way an examiner wants it. The results are made up for practice. The red triangle gives the gradient: $16 \div 2.0 = 8 \text{ }^{\circ}\text{C per g}$.

Mass of magnesium (g)	0.5	1	1.5	2	2.5
Temperature rise ($^{\circ}\text{C}$)	4.1	8	12.1	15.9	20



Plotting

- Independent variable on the x-axis. Label both axes with the quantity and the unit.
- A scale that fills more than half the grid, in even steps. Not 3s, not 7s.
- Plot with a small cross, **in pencil**. An ink point can't be changed, and examiners won't give the benefit of the doubt.
- Draw one line of best fit with a ruler or a smooth curve, with points either side of it. Not dot to dot.
- Extrapolate by extending the line to the axis, and show it: a value read without marks on the graph earned nothing in 2022.

Reading and the gradient

Pick two points far apart on the **line**, not on the data. Annotate the graph, then divide the change in y by the change in x. The unit is y per x, so $^{\circ}\text{C per g}$ here. In 2022 many wrote $\text{g}/^{\circ}\text{C}$ and some wrote " $^{\circ}\text{C}$ ", which is never right.

Proportional

A straight line **through the origin** means the two variables are proportional: double one and the other doubles. "Positive correlation" and "linear" aren't enough. Students rarely mentioned the origin in 2021.

Uncertainty

Use the range of results about the mean: results of 12.3, 12.6 and 13.2 (mean 12.7) are at most 0.5 from it, so ± 0.5 . It isn't half of the whole range (0.45), a mistake in 2023. A scatter of points either side of the line is **random error**. A **systematic error** shifts every result the same way.

Describing a trend

Say what happens to one variable as the other changes, and quote numbers from both ends: "as the mass rises from 0.5 g to 2.5 g, the temperature rise increases from 4.1°C to 20.0°C ." A rise in temperature means energy is released: the reaction is exothermic. To improve accuracy, swap a measuring cylinder for a burette or gas syringe, which has a finer scale.

Skills

The four required practicals

Practical skills are marked on every paper, so expect to be asked how you'd run, plan or improve these. The aim is as the specification words it. The rest is what AQA's papers have asked about each one.

Practical	The aim	What gets asked
1 Making a salt	Prepare a pure, dry sample of a soluble salt from an insoluble oxide or carbonate. A Bunsen burner heats the dilute acid, and a water bath or electric heater evaporates the solution.	Why heat the acid: it speeds up the reaction. Why excess solid: all the acid reacts, and the excess is easy to filter off. A visible sign of excess: solid stays at the bottom. Evaporate water, not salt, to the point where crystals form, then cool. Not to dryness, so no direct Bunsen heating. It's a method, not an investigation.
2 Titration Chemistry only	Find the reacting volumes of a strong acid and a strong alkali by titration.	Pipette for the alkali, burette for the acid, indicator, white tile, swirl, drops near the end-point, repeat and take a mean of the concordant results (within 0.10 cm ³): a rough or odd titre is left out. Phenolphthalein: pink in alkali, colourless in acid (not "clear"); methyl orange: yellow to red. Any one indicator was accepted, but the colour change was often the wrong way round. HT Moles = concentration × volume in dm ³ , then the mole ratio. See page 24.
3 Electrolysis	Investigate what happens when aqueous solutions are electrolysed using inert electrodes. It should be an investigation that develops a hypothesis.	Write a hypothesis ("if the metal is more reactive than hydrogen, hydrogen forms at the cathode") and predict from the halide rule. To measure a gas, use a measuring cylinder or gas syringe, which has a scale. Gas tests: hydrogen pops, oxygen relights a glowing splint, chlorine bleaches damp litmus. To weigh the copper that plates out: wash, dry and weigh the negative electrode, and use the mass gain . A straight line through the origin of mass against current × time means proportional.
4 Temperature changes	Investigate the variables that affect temperature changes in reacting solutions, such as acid with a metal, carbonate or alkali.	The six-mark plan: measuring cylinder for the acid, polystyrene cup, starting temperature, mass on a balance, stir, record the highest temperature reached (or the lowest if it falls), repeat with other masses, same volume and concentration each time. Then plot, draw a line, use the gradient.

Words for a fair test

Word	Meaning	Example
Independent variable	The one thing you change.	mass of magnesium, concentration of acid
Dependent variable	What you measure.	temperature change, mass gain of an electrode
Control variable	Everything you keep the same.	volume and concentration of acid, mass of metal
Repeatable · reproducible	Same person gets similar results again · different people with different kit do.	Repeat three times and find a mean
Accurate · precise	Close to the true value · closely clustered.	A result can be precise but not accurate

Separating mixtures: choose the technique

Technique	Use it to separate	Example
Filtration	an insoluble solid from a liquid	sand from water; excess solid from a salt solution
Crystallisation	a soluble solid from its solution	salt crystals from salt solution
Simple distillation	the solvent from a solution	pure water from salt water
Fractional distillation	liquids with different boiling points	ethanol from water
Chromatography	coloured substances in a mixture	the dyes in an ink

Hazards. Name the hazard and one precaution: dilute acid or alkali irritates eyes (eye protection); hot solutions and dishes (heatproof mat, tongs); chlorine from electrolysis is toxic (small volumes, a ventilated space).

Say volume, mass or concentration, never "amount". A control variable spoiled by "the same amount" lost the mark in 2021. **Errors.** Random error makes results vary unpredictably, so take more measurements and use a mean. Systematic error shifts every result by the same amount. If one result is far from the rest, check for a measuring mistake before you ignore it.

Skills

What AQA's examiners saw students get wrong

These come from AQA's Reports on the Examination for the Higher paper (November 2021, June 2022, June 2023). They're paraphrased. The struck-through words are what students wrote. The green words are what earned the mark.

Isotopes. ~~Elements~~ in the plural, ~~a different relative atomic mass~~, or electrons in the definition. Atoms of the same element with the same number of protons and different numbers of neutrons.

Relative atomic mass. Dividing by ~~the sum of the mass numbers~~ (2022, 2023) or by ~~the number of isotopes~~ (2022). Divide by 100. The answer sits between the two isotope masses, to the decimal places asked.

The plum pudding. A ball of positive ~~energy~~, or electrons ~~outside~~ the ball. A ball of positive charge with electrons embedded in it.

Mendeleev. ~~He left gaps and predicted properties~~, with no result. He left gaps, gallium filled one, and its properties matched his prediction.

Group 1 and water. ~~A vigorous reaction, a colour change~~, the same observation twice. Fizzing. The metal moves and melts. Potassium melts and burns with a lilac flame.

Group 1 trends. ~~The attraction between the nucleus and the electrons, or less shielded~~. A weaker attraction between the nucleus and the **outer** electron, which is further away and more shielded.

Drawing an ionic compound. Drawing ~~covalent~~ structures, or ~~both~~, or electrons ~~in two places~~. Outer electrons only. Atoms before, ions after, right charges and ratio.

Ionic melting point. ~~Intermolecular forces or covalent bonds~~, or ignoring the giant structure. A lot of energy to overcome the strong attraction between ions in the giant structure.

Diamond and graphite. ~~Intermolecular forces in diamond. Gaps between the layers~~ for electricity to "slip through". Diamond has none. Graphite's current is delocalised electrons. Weak forces hold the layers.

Polymers. A ~~giant structure~~, and no mention of energy or melting point. Large molecules, stronger intermolecular forces, more energy, higher melting point.

Alloys. ~~Molecules, different shapes, rows~~, or alloys as ~~compounds~~. Different sized atoms distort the layers, so they can't slide.

Metals conduct. Electrons ~~throughout~~ the metal, or ~~bumping~~ into atoms. Delocalised electrons move through the metal in one direction.

Making a salt. Heating ~~helps the solid dissolve~~. Evaporating the ~~acid~~ or ~~salt~~. ~~Zinc~~ for zinc oxide. Heated ~~to dryness~~ on a Bunsen burner. Heating speeds the reaction. Solid stays at the bottom: excess. Water evaporates to the point crystals form, using a water bath or electric heater.

Group 1 and transition metals. One-sided answers, or ~~chemical~~ properties such as reactivity. Physical properties of both: Group 1 has lower melting points, lower density, and is softer.

Writing equations. Balancing by ~~inventing products~~. ~~Chloride~~ put into an ionic equation. Charges not balanced. Get each product's formula right first, then balance atoms and charge.

Comparing reactivity. ~~Temperature~~ not temperature change, or ~~the same amount~~. Temperature change. Same volume, concentration and mass.

Electrolysis. ~~Separating~~ a compound. A cell ~~using~~ electricity. Electrolysis decomposes a compound with electricity. A cell makes electricity.

Ions in solution. Electrons moving through the solution, ~~chlorine ions, oxygen ions~~. Ions carry the current. Chloride. H^+ , OH^- , Na^+ and Cl^- in salt water.

Products at electrodes. ~~Iodide~~ for iodine. ~~Nitrogen~~ at the anode. Oxygen at the anode when there is no halide ion.

Blue colour fading. ~~Copper is removed or copper dissolves~~. Blue copper ions are discharged at the cathode.

Electrode mass. The mass is ~~added to the electrode~~. Not washed and dried. Wash, dry, weigh the copper. Use the mass gain.

Proportional. ~~Positive correlation, linear~~. A straight line through the origin. Doubling one doubles the other.

Moles. Dividing iron by ~~442~~. Not changing ~~cm^2~~ to dm^3 . Divide by 56. Divide the volume in cm^3 by 1000.

Reaction profiles. Activation energy as ~~the peak~~, an ~~unfinished~~ profile, arrows drawn by hand. Reactants to the peak. Label the products. Use a ruler and dotted lines.

Exothermic. ~~Energy needed in both steps. Loses matter~~. More energy is released making bonds than is needed to break them.

Weak acids and pH. ~~A low pH~~ for weak. The acid is ~~partially ionising~~. A fall of 2 units ~~divides by 100~~. A weak acid is only partially ionised. A fall of 2 pH units means 100 times more hydrogen ions.

Skills

Two six-mark answers, marked

Plan for twenty seconds, then write in order. The red ticks show where the points are. Both answers were written for this guide to meet the top-level description.

Describe how to make pure, dry crystals of magnesium sulfate from magnesium carbonate and sulfuric acid. [6 marks]

Pour dilute sulfuric acid into a beaker and warm it ✓. Add magnesium carbonate a little at a time, stirring, until the fizzing stops and some solid stays at the bottom ✓. This means the magnesium carbonate is in excess and all the acid has reacted ✓. Filter the mixture to remove the excess magnesium carbonate ✓. Heat the filtrate in a water bath or with an electric heater until crystals start to form at the edge, then stop, so the water has evaporated but the salt hasn't dried out ✓. Leave it to cool so crystals form, then filter them off and pat them dry with filter paper ✓.

Level 3

Name the acid first: the salt depends on it. Then excess, filter, crystallise, in that order, with the reason for each. AQA's top level is a method that would give a valid outcome, with the key steps in a logical order. It isn't an investigation, so don't name variables.

A car maker is choosing between a hydrogen fuel cell and a rechargeable battery. Evaluate the two, using the data and your own knowledge. [6 marks]

Invented data	Hydrogen fuel cell car	Rechargeable battery car
Time to refuel or recharge	4 minutes	7 hours
Distance on one fill or charge	480 km	310 km
What leaves the car	water only	nothing
Cost of the car	£58 000	£39 000
Where the energy comes from	hydrogen, usually made using fossil fuels	the grid, which can use renewable energy

The fuel cell car refuels in 4 minutes and goes 480 km ✓, so it suits long journeys ✓. Its only emission is water ✓, but the hydrogen is usually made using fossil fuels, so it isn't necessarily clean ✓. The battery car costs £19 000 less ✓ and can use renewable electricity ✓, but it takes 7 hours to charge and goes less far ✓. **Overall** a fuel cell is better for someone who drives long distances, and a battery car for short trips and a lower price ✓.

Level 3

Both sides, then a judgement. Use the table and what you know: a fuel cell is supplied with hydrogen and oxygen, a rechargeable cell has its reaction reversed by a current. A Level 3 answer commits to a conclusion and says what it depends on. Don't quote the whole table back: use it.

The magnesium sulfate question at three levels

Level 1 (1 to 2 marks). "Add magnesium carbonate to the acid and heat it to get crystals." Some steps, but they wouldn't give a valid result and nothing links them.

Level 2 (3 to 4 marks). "Warm the acid, add the carbonate until it's in excess, filter, then evaporate the solution." Most steps, but it doesn't say how far to heat, or the plan isn't quite in order.

Level 3 (5 to 6 marks). The answer above: every key step in a logical order, giving a valid outcome.

Your turn

Cover the answers. Write one in six minutes, then mark yourself: did every sentence do something, and did the last one reach a judgement? Do the other one two days later.

Practice

Practice paper, part one

73 marks over four pages, about 77 minutes. Written for this guide, with invented data. Mark it on pages 33–34. HT marks Higher tier questions, and Chemistry only marks the ones that aren't in Combined Science.

1 Tick one box for each question. [1 mark each] *[4]***1.1** Which statement about isotopes is correct?

- | | |
|---|--|
| ☐ A They have different numbers of protons. | ☐ B They have different numbers of electrons. |
| ☐ C They have different numbers of neutrons. | ☐ D They have different atomic numbers. |

1.3 What is the formula of calcium nitrate?

- | | |
|---|---|
| ☐ A CaNO_3 | ☐ B Ca_2NO_3 |
| ☐ C $\text{Ca}(\text{NO}_3)_2$ | ☐ D $\text{Ca}(\text{NO}_3)$ |

1.2 Which halogen is a liquid at room temperature?

- | | |
|-------------------------------------|-------------------------------------|
| ☐ A fluorine | ☐ B chlorine |
| ☐ C bromine | ☐ D iodine |

1.4 Which substance conducts electricity when molten but not when solid?

- | | |
|--|---|
| ☐ A copper | ☐ B diamond |
| ☐ C sodium chloride | ☐ D poly(ethene) |

2.1 Chlorine has atomic number 17. A chlorine-37 atom has a mass number of 37. Give the number of protons, neutrons and electrons in the atom. *[3]*

2.2 Explain why fluorine is more reactive than chlorine. *[3]*

2.3 Iodine is added to potassium bromide solution. Explain why nothing happens. *[2]*

2.4 Balance the equation: $__ \text{Fe} + __ \text{Cl}_2 \rightarrow __ \text{FeCl}_3$ *[1]***3.1** Silicon dioxide melts at 1610°C . Explain why, in terms of its structure and bonding. *[3]*

3.2 Draw a dot and cross diagram to show the bonding in hydrogen chloride. Show the outer electrons only. *[2]*

Practice

Practice paper, part two

3.3 The table shows the melting points and boiling points of three substances. Give the state of each at 25 °C. [3]

Substance	Melting point (°C)	Boiling point (°C)
P	-101	-34
Q	801	1413
R	-7	59

--

3.4 **Chemistry only** Calculate the surface area to volume ratio of a cube with sides of 20 nm and of a cube with sides of 2 nm. Say how the ratio changes. [3]

4.1 Calculate the relative formula mass of ammonium sulfate, $(\text{NH}_4)_2\text{SO}_4$. (A_r : H 1, N 14, O 16, S 32) [2]

4.2 12.5 g of zinc carbonate, ZnCO_3 , was heated in an open tube. It made zinc oxide and carbon dioxide. The solid left weighed 8.1 g. Explain why the mass fell, and calculate the mass of gas that escaped. [3]

4.3 **HT** Calculate the number of moles in the mass of carbon dioxide that escaped. (M_r of CO_2 = 44) [2]

4.4 **HT** $2\text{Fe}_2\text{O}_3 + 3\text{C} \rightarrow 4\text{Fe} + 3\text{CO}_2$. Calculate the mass of iron, in kg, that can be made from 3.2 kg of iron oxide, Fe_2O_3 . (A_r : Fe 56, O 16) [4]

4.5 **Chemistry only** A student made 6.3 g of copper from a possible 9.0 g. Calculate the percentage yield. Give two reasons why a yield can be less than 100%. [4]

Practice

Practice paper, part three

- 5.1 Write a balanced symbol equation for magnesium reacting with sulfuric acid, H_2SO_4 . [2]

- 5.2 Zinc oxide can be reduced by carbon. Aluminium oxide can't. Explain why aluminium is extracted by electrolysis, and give one disadvantage of using electrolysis. [3]

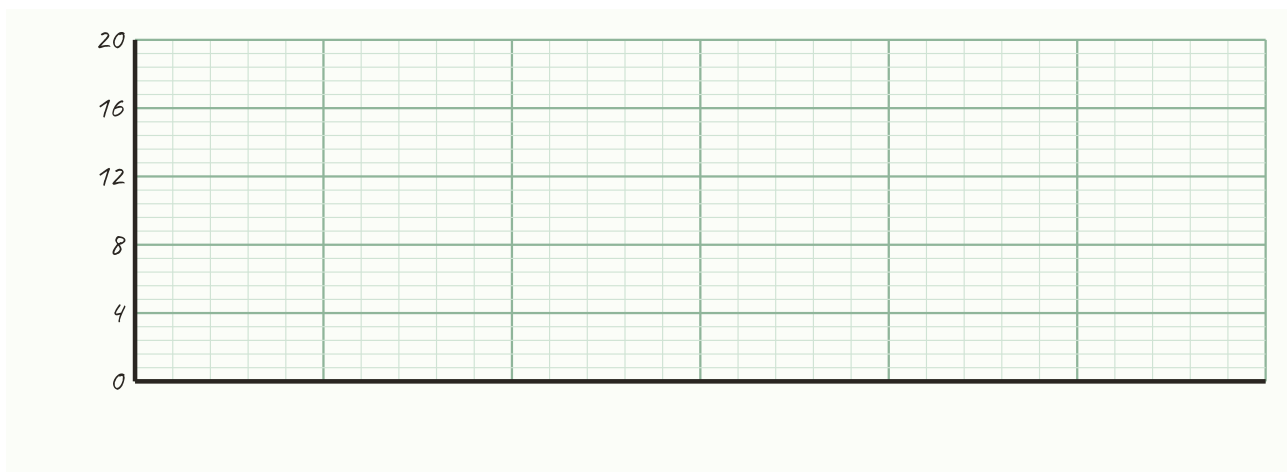
- 5.3 Aqueous copper(II) chloride is electrolysed with inert electrodes. Name the product at the cathode and at the anode.

HT Write the half equation for the reaction at the anode. [3]

- 5.4 **Chemistry only** **HT** 24.0 cm³ of 0.0250 mol/dm³ sulfuric acid neutralised 20.0 cm³ of potassium hydroxide solution. $\text{H}_2\text{SO}_4 + 2\text{KOH} \rightarrow \text{K}_2\text{SO}_4 + 2\text{H}_2\text{O}$. Calculate the concentration of the potassium hydroxide in mol/dm³. [3]

- 6.1 A student added different concentrations of hydrochloric acid to the same volume of sodium hydroxide solution and measured the temperature rise. Plot the results and draw a line of best fit. [3]

Concentration of acid (mol/dm ³)	0.5	1	1.5	2	2.5
Temperature rise (°C)	3.1	6.3	9.2	12.5	15.4



- 6.2 Calculate the gradient of your line. Give the unit. [3]

- 6.3 Three repeats with 1.5 mol/dm³ acid gave temperature rises of 8.9 °C, 9.2 °C and 9.8 °C. Calculate the mean and the uncertainty. [2]

--

Practice

Practice paper, part four

6.4 Draw a reaction profile for an endothermic reaction. Label the reactants, the products and the activation energy. [3]

6.5 **HT** $2\text{H}-\text{H} + \text{O}=\text{O} \rightarrow 2 \text{H}-\text{O}-\text{H}$. Bond energies in kJ/mol: H-H 436, O=O 498, O-H 464. Calculate the energy change for the reaction. (Water has two O-H bonds.) [3]

6.6 **Chemistry only** Draw a labelled diagram of a simple cell that uses zinc and copper. [3]

7 Compare the structures and the properties of diamond, graphite and methane. Explain the differences in terms of their bonding. [6]

Answers

Quick-fire answers

1 Atoms and isotopes

- 1.1** 12 (23 – 11).
1.2 2,8,7.
1.3 It's concentrated at the centre, in a charged nucleus, so the nuclear model replaced the plum pudding.
1.4 10.

4 Covalent and giant structures

- 4.1** A shared pair of electrons between two atoms.
4.2 The weak intermolecular forces between the molecules, not the covalent bonds.
4.3 Graphene.
4.4 Four.

7 Acids, bases and salts

- 7.1** Zinc sulfate.
7.2 The hydroxide ion, OH⁻.
7.3 Any acid-base indicator, such as phenolphthalein: pink to colourless.
7.4 100 times.

2 The periodic table

- 2.1** Their atoms have a stable arrangement of electrons (a full outer shell: eight, or two for helium).
2.2 Sodium hydroxide and hydrogen.
2.3 It decreases.
2.4 Bromine (the solution turns orange-brown), and sodium chloride forms.

5 Mass and moles

- 5.1** 98.
5.2 Carbon dioxide gas escapes.
5.3 2 mol.
5.4 80%.

8 Electrolysis

- 8.1** So its ions are free to move.
8.2 Lead.
8.3 It lowers the melting temperature, which saves energy.
8.4 $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$.

3 Ionic and metallic bonding

- 3.1** 2+.
3.2 Na₂O: two Na⁺ for every O²⁻.
3.3 The layers of atoms can slide over each other.
3.4 The different sized atoms distort the layers, so they can't slide as easily.

6 Reactivity of metals

- 6.1** Magnesium chloride and hydrogen.
6.2 Loss of oxygen.
6.3 It's very unreactive, so it doesn't combine with other substances.
6.4 It's oxidised: iron atoms lose electrons.

9 Energy changes

- 9.1** Exothermic.
9.2 The minimum energy that particles must have to react.
9.3 °C.
9.4 Exothermic.

Your tracker

Colour a circle when it's done. Return two days later, and a week later.

Topic	Learn it	Use it	Recall box	Quick-fire	2 days later	1 week later
1 Atoms and isotopes	☐	☐	☐	☐	☐	☐
2 The periodic table	☐	☐	☐	☐	☐	☐
3 Ionic and metallic bonding	☐	☐	☐	☐	☐	☐
4 Covalent and giant structures	☐	☐	☐	☐	☐	☐
5 Mass and moles	☐	☐	☐	☐	☐	☐
6 Reactivity of metals	☐	☐	☐	☐	☐	☐
7 Acids, bases and salts	☐	☐	☐	☐	☐	☐
8 Electrolysis	☐	☐	☐	☐	☐	☐
9 Energy changes	☐	☐	☐	☐	☐	☐

Lost marks? Go here

Question	Go to	Pages
1.1, 2.1 to 2.3	Topics 1 and 2	4–5, 6–7
1.3, 2.4, 5.1	Ions, formulae and equations	22
1.4, 3.1 to 3.4, 7	Topics 3 and 4, the maths page	8–9, 10–11, 23
4.1 to 4.3, 4.5	Topic 5, the maths page	12–13, 23
4.4, 5.4	Moles, volumes and titrations	24
5.2, 5.3	Topics 6 and 8	14–15, 18–19
6.1 to 6.3	Graphs and data, practical 4	25, 26
6.4 to 6.6	Topics 9 and 8	20–21, 18–19

Answers

Practice paper: marks and answers

1 1.1 C, different numbers of neutrons; 1.2 C, bromine; 1.3 C, $\text{Ca}(\text{NO}_3)_2$; 1.4 C, sodium chloride. [4]

2.1 17 protons [1]; $37 - 17 = 20$ neutrons [1]; 17 electrons [1].

2.2 A fluorine atom is smaller, so its outer shell is closer to the nucleus [1]; the attraction between the nucleus and an electron it gains is stronger [1]; so fluorine gains an electron more easily [1].

2.3 Iodine is less reactive than bromine [1], so it can't displace bromine from potassium bromide [1].

2.4 $2\text{Fe} + 3\text{Cl}_2 \rightarrow 2\text{FeCl}_3$. [1]

3.1 Silicon dioxide is a giant covalent structure [1]; the atoms are joined by strong covalent bonds [1]; a lot of energy is needed to break them [1].

3.2 A shared pair of electrons in the overlap between H and Cl [1]; six non-bonded electrons on the chlorine (three pairs), and no extra electron on the hydrogen [1].

3.3 P is a gas, Q is a solid, R is a liquid. [1 each] (P boils below 25°C , Q melts above 25°C , R melts below and boils above 25°C .)

3.4 20 nm cube: surface area $6 \times 20^2 = 2400 \text{ nm}^2$, volume $20^3 = 8000 \text{ nm}^3$, ratio $0.3 : 1$ [1]. 2 nm cube: $24 \div 8 = 3 : 1$ [1]. The ratio is ten times bigger when the sides are ten times smaller [1].

4.1 $2 \times (14 + 4) + 32 + (4 \times 16)$ [1] = 132 [1].

4.2 Carbon dioxide gas escapes into the air, so the solid is lighter [1]; $12.5 - 8.1$ [1] = 4.4 g [1].

4.3 moles = mass $\div M_r = 4.4 \div 44$ [1] = 0.1 mol [1].

4.4 **HT** M_r of $\text{Fe}_2\text{O}_3 = 160$, so $3200 \text{ g} \div 160 = 20 \text{ mol}$ [1]; ratio $2 : 4$, so 40 mol of iron [1]; mass = $40 \times 56 = 2240 \text{ g}$ [1]; = 2.24 kg [1].

4.5 $6.3 \div 9.0 \times 100$ [1] = 70% [1]. Any two of: the reaction may be reversible; some product is lost when it is separated; some reactants may react in other ways. [2]

5.1 $\text{Mg} + \text{H}_2\text{SO}_4 \rightarrow \text{MgSO}_4 + \text{H}_2$. [1 for the formulae of the products, 1 for balanced.]

5.2 Aluminium is more reactive than carbon [1], so carbon can't remove the oxygen from aluminium oxide [1]. Electrolysis needs a lot of energy (or is expensive) [1].

5.3 Cathode: copper [1]. Anode: chlorine [1]. **HT** $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$ [1].

5.4 **HT** moles $\text{H}_2\text{SO}_4 = 0.0250 \times 24.0 \div 1000 = 0.000600$ [1]; moles $\text{KOH} = 2 \times 0.000600 = 0.00120$ [1]; concentration = $0.00120 \div (20.0 \div 1000) = 0.0600 \text{ mol/dm}^3$ [1].

6.1 Axes labelled with units and a scale that fills more than half the grid [1]; points plotted as crosses, in pencil, allowing one slip [1]; a straight line of best fit through the origin and the points [1].

6.2 Two points taken from the line, far apart, and shown on the graph [1]; change in $y \div$ change in x [1]; about $6.2^\circ\text{C per mol/dm}^3$ (accept 5.8 to 6.6) [1].

6.3 Mean = $(8.9 + 9.2 + 9.8) \div 3 = 9.3^\circ\text{C}$ [1]; the furthest result is 0.5 from the mean, so the uncertainty is $\pm 0.5^\circ\text{C}$ [1].

6.4 Reactants lower than products [1]; the peak above the products, with an arrow for the activation energy from the reactants to the peak [1]; the products' level labelled [1].

6.5 **HT** Bonds broken: $(2 \times 436) + 498 = 1370 \text{ kJ}$ [1]. Bonds made: $4 \times 464 = 1856 \text{ kJ}$ [1]. Energy change = $1370 - 1856 = -486 \text{ kJ/mol}$ [1].

6.6 Two different metals, zinc and copper, as electrodes [1]; both dipping into an electrolyte, which is labelled [1]; connected by wires in a complete circuit, with a voltmeter allowed [1].

7 Level 3 (5 to 6): all three structures with their bonding, linked to properties. For example: diamond is a giant covalent structure, each carbon bonded to four others, so a lot of energy is needed to break the bonds, giving a very high melting point and hardness, and no free electrons, so no conduction; graphite is also giant covalent, each carbon bonded to three in layers, with a delocalised electron each, so it conducts, and weak forces between the layers let them slide; methane is a simple molecule with weak intermolecular forces, so a low boiling point and no conduction. Level 2 (3 to 4): two structures explained, or all three without the link to energy. Level 1 (1 to 2): properties listed with little explanation.

Mark with a different colour and add up. Your teacher may accept other correct wording.

More from Empower Educators

The Chemistry range

If this guide was useful, here is the rest of the Chemistry shelf. Everything shown is on the site now.



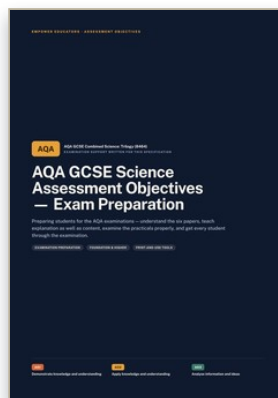
The Science playbook

The science department's playbook, with Chemistry inside it.



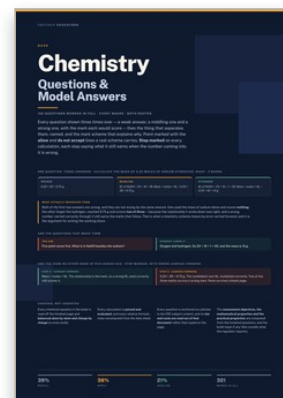
Schemes of work

Year 10 to Year 11. One sequence table a year, unit by unit and in teaching order.



Science exam board playbooks

The science department's books, one for each board, with Chemistry inside them.



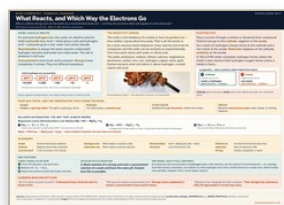
GCSE questions and answers

Exam-style questions, each answered three times: weak, middling and strong.



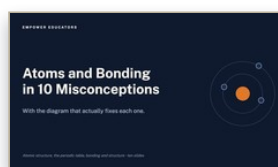
Knowledge organisers

Year 10 to Year 11. A4, printable, one per unit.



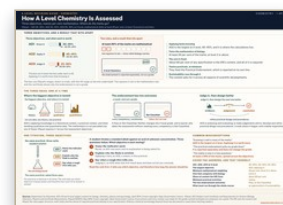
GCSE knowledge mats

One landscape sheet a topic, such as chemical changes and atomic structure.



GCSE PowerPoints

Atoms and bonding as an editable PowerPoint, with diagrams.



A Level revision guide

The core ideas beside a figure, worked examples and the misconceptions that cost marks.

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