Science 9–10

Chapter 11 — Chemical sciences B: chemical reactions

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Contents

Conservation of mass and the rearrangement of atoms — modelling reactions in closed and open systems

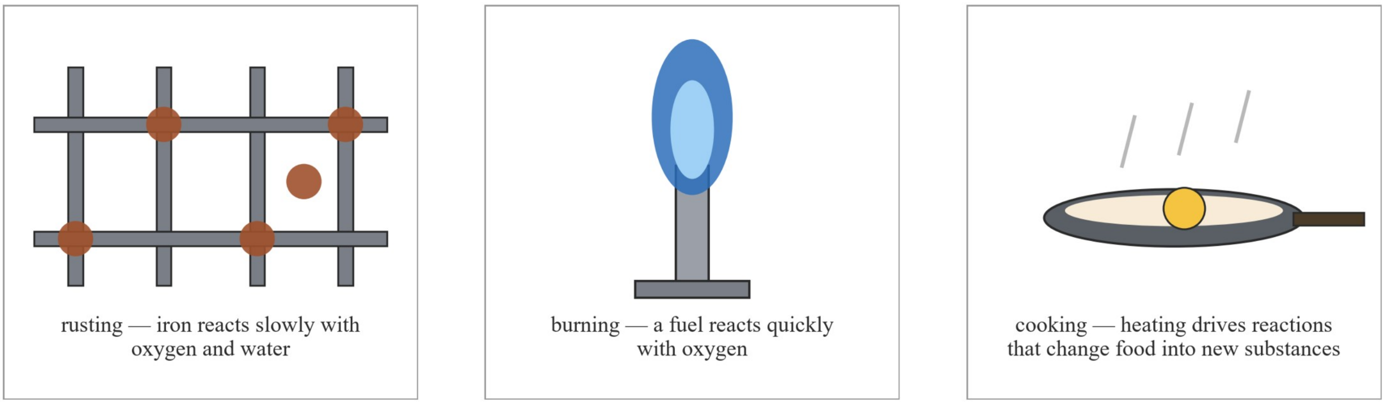
Chapter 11 — Chemical sciences B: chemical reactions (Science, Levels 9 and 10)

Subtopic 11A · VC2 Science Understanding — Chemical sciences

CD code: `VC2S10U08` † (split delivery: this subtopic is the accountable owner of the first clause — the Law of Conservation of Mass, the rearrangement of atoms, and representations; partner subtopic 11B delivers the second clause — word and balanced symbol equations) **Content description (verbatim):** “chemical reactions are described by the Law of Conservation of Mass and involve the rearrangement of atoms; they can be modelled using a range of representations, including word and simple balanced chemical equations” **This subtopic’s limb (TOC §4 clause split):** Law of Conservation of Mass, rearrangement of atoms, representations. The partner `11B` delivers the other limb: writing word and balanced symbol equations. Equations that appear here are given to you as models, never something you must balance. **Elaboration ids drawn on:** `VC2S10U08.E01` · `VC2S10U08.E02` · `VC2S10U08.E03` · `VC2S10U08.E05` · `VC2S10U08.E06` (id `VC2S10U08.E04` is drawn on by partner Subtopic 11B) **Achievement standard (extract served):** “They demonstrate the Law of Conservation of Mass in chemical reactions.” (Writing word and balanced chemical equations is served by Subtopic 11B.)

Theory

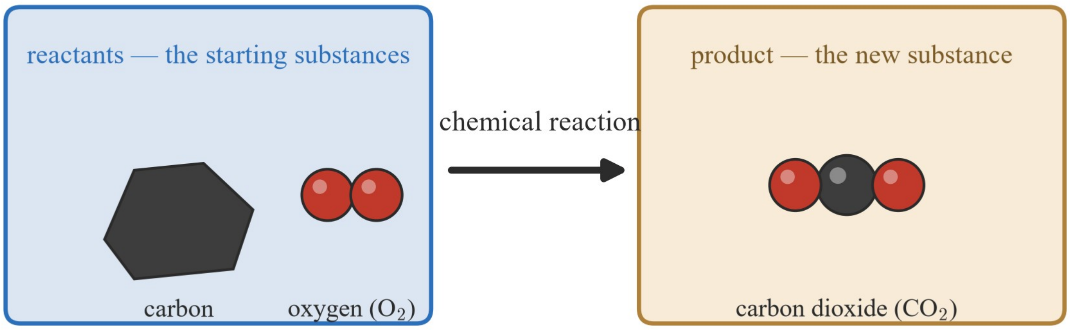
New substances are being made all around you. A gate left out in the weather slowly turns from grey metal to reddish-brown rust. A gas burner gives out heat and light while a blue flame burns. An egg in a hot pan sets into new substances with new properties. In each case the starting materials have not simply changed shape — they have changed into different substances. That is the signature of a **chemical reaction**: a change in which the starting substances are changed into new substances with different properties.



Three panels of everyday chemical reactions. The first shows a metal gate with patches of reddish-brown rust, labelled rusting, iron reacting slowly with oxygen and water. The second shows a blue gas flame on a burner, labelled burning, a fuel reacting quickly with oxygen. The third shows an egg cooking in a pan with steam rising, labelled cooking, heating drives reactions that change food into new substances.

Reactants and products. In this subtopic, a **reactant** is defined as a substance that is taken apart or used up during a chemical reaction, and a **product** is defined as a new substance made by the reaction. Chemists write reactions as a short story with an arrow: the reactants on the left, the products on the right, and the arrow read as “reacts to make”. When carbon burns in oxygen, the single product is carbon dioxide:

carbon + oxygen → carbon dioxide



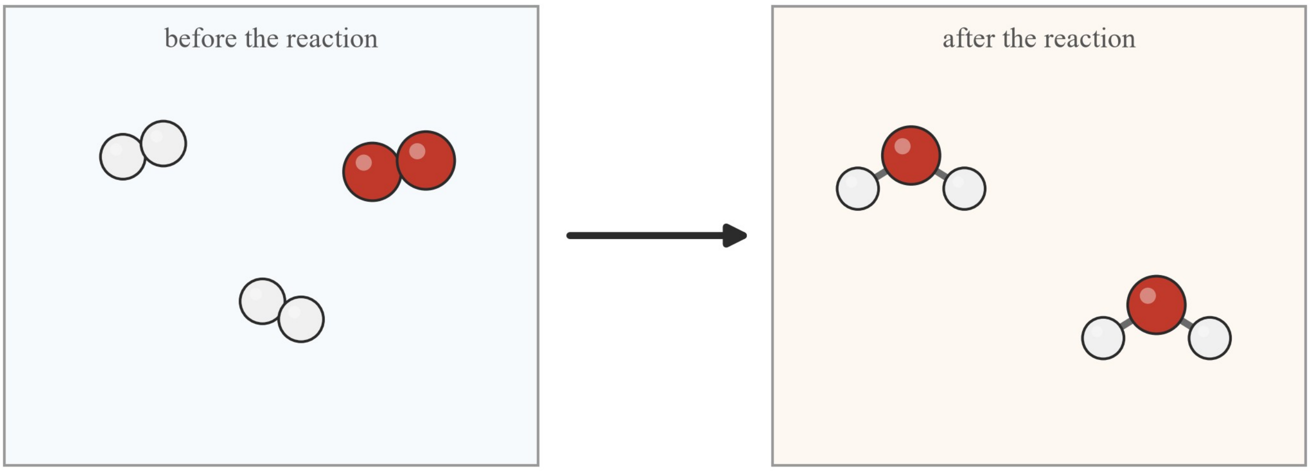
carbon + oxygen → carbon dioxide

A flow diagram of a chemical reaction. A blue box labelled reactants, the starting substances, contains a black lump labelled carbon and a pair of joined red spheres labelled oxygen, O2. An arrow labelled chemical reaction points to a cream box labelled product, the new substance, containing one black sphere joined between two red spheres, labelled carbon dioxide, CO2. Below, the word equation reads carbon + oxygen → carbon dioxide.

The reactants here are carbon and oxygen; the product is carbon dioxide. Notice that the product is a different substance from either reactant — a colourless gas made from a black solid and a colourless gas. Spotting the reactants and products is the first skill this subtopic builds.

A reaction rearranges atoms. Look closer, at the particle level, and every chemical reaction turns out to be the same kind of event: a chemical reaction rearranges atoms — the reactants are taken apart and their atoms rejoin in new combinations to form the products. Atoms are never created and never destroyed in a chemical reaction; they are only regrouped. The links that hold atoms together inside a molecule are called **bonds**, and a reaction means some bonds break while new bonds form. In this subtopic, a **molecule** is defined as a group of atoms joined together by bonds, acting as one particle.

bonds break; atoms rejoin in new combinations



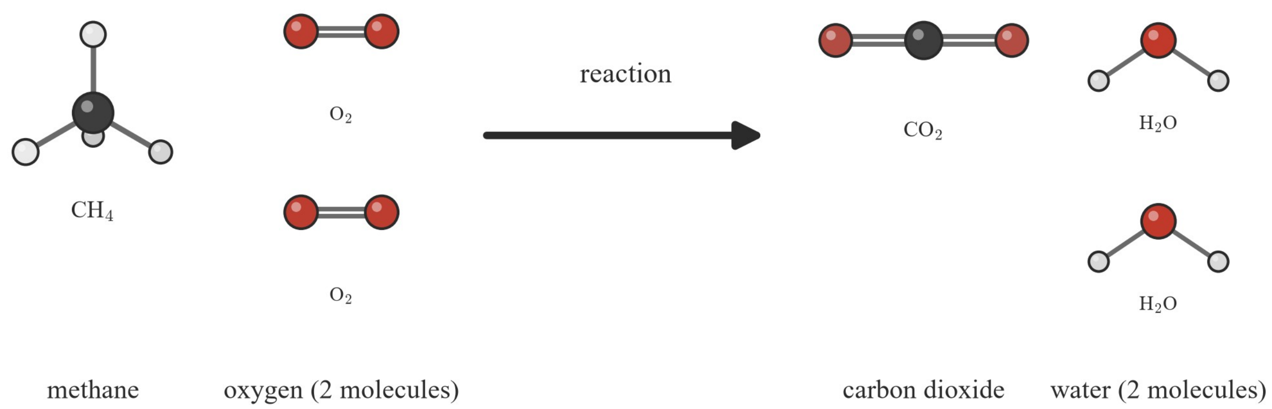
Every atom is still there — 4 hydrogen atoms and 2 oxygen atoms on each side — but they are joined in new groups.

Two panels of particle models. The left panel, before the reaction, contains two molecules of two pale hydrogen atoms joined together and one molecule of two red oxygen atoms joined together. The right panel, after the reaction, contains two water molecules, each one red oxygen atom joined to two pale hydrogen atoms at an angle. A label above reads bonds break; atoms rejoin in new combinations. The caption states that every atom is still there, 4 hydrogen atoms and 2 oxygen atoms on each side, but joined in new groups.

Count the atoms in that picture: before the reaction there are 4 hydrogen atoms and 2 oxygen atoms; after it there are still 4 hydrogen atoms and 2 oxygen atoms. The atoms are simply joined differently — in new groups. That is what "rearrangement" means, and it is the idea everything else in this subtopic rests on.

Models you can hold. Chemists use ball-and-stick models in which each ball is an atom and each stick is a bond, with one colour per element: hydrogen pale, carbon black, oxygen red. Burning methane (the main gas in natural gas) is shown below with these models. One methane molecule (1 carbon, 4 hydrogen) reacts with two oxygen molecules, and the atoms regroup into one carbon dioxide molecule and two water molecules.

Count the atoms: 1 carbon, 4 hydrogen and 4 oxygen on each side — nothing is lost, nothing is made.



Ball-and-stick models of methane burning. On the left, one methane molecule, a black carbon joined to four pale hydrogen atoms, and two oxygen molecules of two red atoms each. An arrow labelled reaction points right to one carbon dioxide molecule, a black carbon between two red oxygens, and two bent water molecules, each a red oxygen joined to two pale hydrogens. The caption reads: count the atoms, 1 carbon, 4 hydrogen and 4 oxygen on each side — nothing is lost, nothing is made.

Counting atoms checks the story. Because atoms are only rearranged, the number of atoms of each element must be the same on both sides of any true account of a reaction. The tally for methane burning confirms it:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

(given balanced — you will write and balance equations in Subtopic 11B)

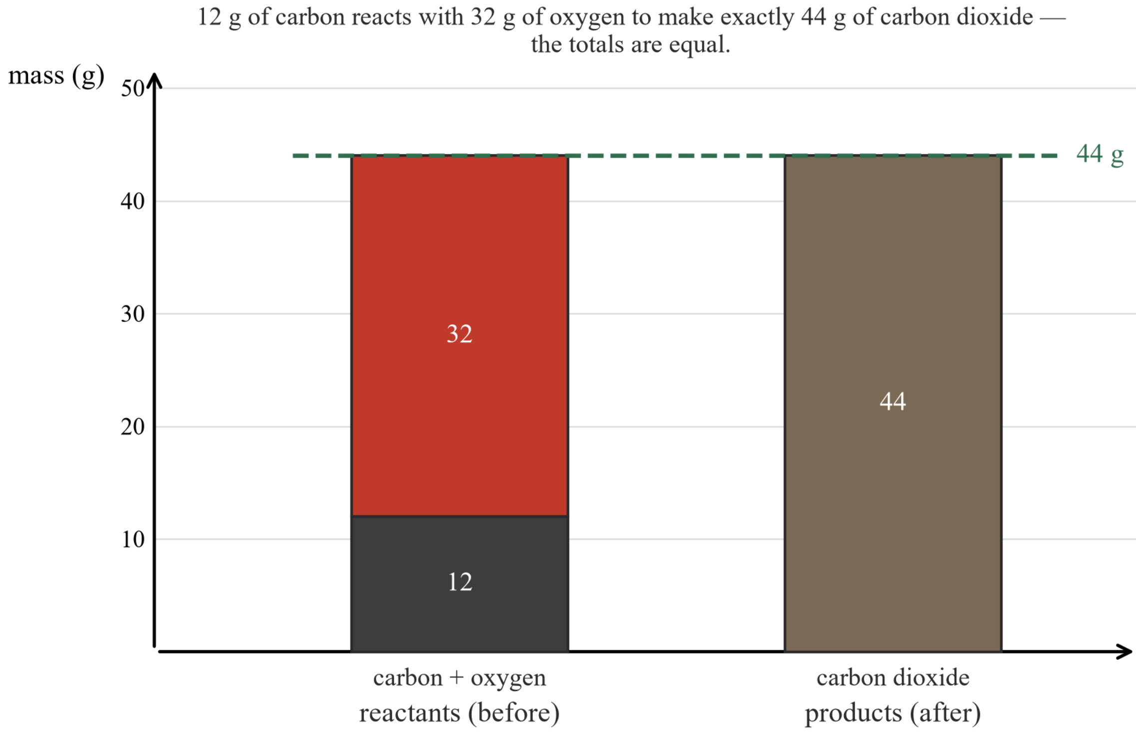
element	atoms on the left	atoms on the right
carbon (C)	1	1
hydrogen (H)	4	4
oxygen (O)	4	4
total	9	9

The totals match — the equation agrees with the Law of Conservation of Mass.

The symbol equation CH4 + 2O2 → CO2 + 2H2O above a three-column tally table. Rows for carbon, hydrogen and oxygen show atoms on the left 1, 4, 4 and atoms on the right 1, 4, 4, with equal totals of 9. A note states the equation is *given balanced and that writing and balancing equations is taught in Subtopic 11B, and the caption reads: the totals match — the equation agrees with the Law of Conservation of Mass.*

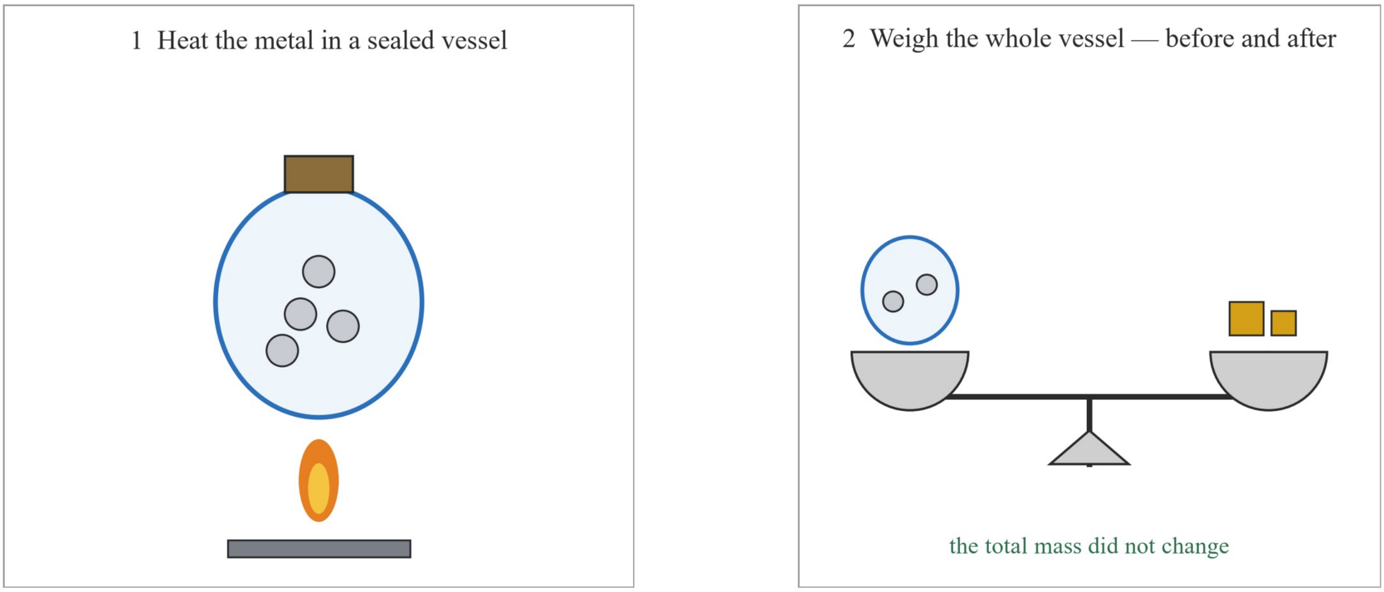
The symbol form of this equation ($CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$) is given to you here as a model of one representation. Writing and balancing symbol equations yourself is the work of Subtopic 11B; in this subtopic the point of the tally is only that atom counts match, which is exactly what the law of conservation of mass says we should see.

The Law of Conservation of Mass. Add up the masses now. If atoms are neither created nor destroyed, then the total mass going into a reaction must equal the total mass coming out. That claim is the **Law of Conservation of Mass**: in this subtopic, the law is defined as the rule that the total mass of the products of a chemical reaction equals the total mass of the reactants, because no atoms are created or destroyed. Burn 12 g of carbon in 32 g of oxygen and exactly 44 g of carbon dioxide is made — 12 + 32 = 44.



A bar chart comparing masses. The left stacked bar, labelled carbon + oxygen, reactants (before), shows a 12 g black segment beneath a 32 g red segment. The right bar, labelled carbon dioxide, products (after), is a single 44 g bar of the same total height, with a dashed green line at 44 g across both bars. The caption reads: 12 g of carbon reacts with 32 g of oxygen to make exactly 44 g of carbon dioxide — the totals are equal.

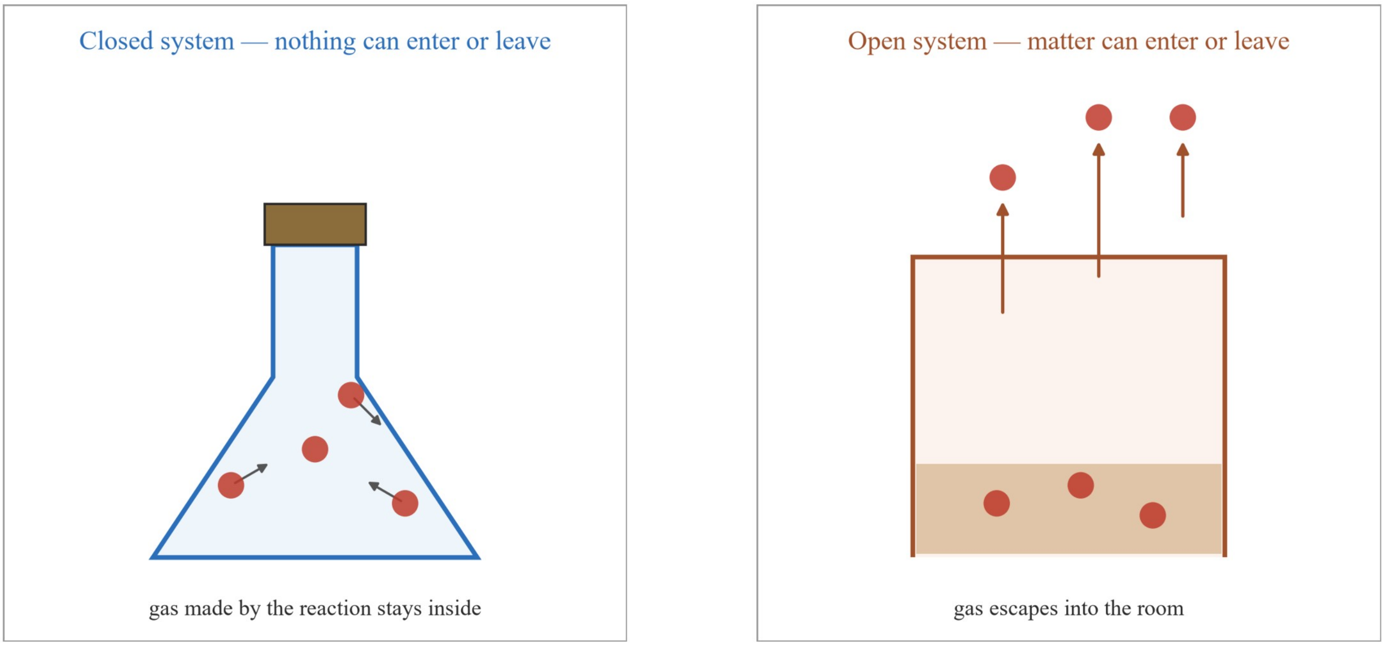
The law was established carefully in the late 1700s by the French chemist Antoine Lavoisier, who heated metals such as tin inside sealed vessels and weighed the whole vessel before and after. However much the metal changed, the total mass never did.



Lavoisier (late 1700s) heated tin in sealed vessels: the vessel and everything in it weighed the same after the reaction as before.

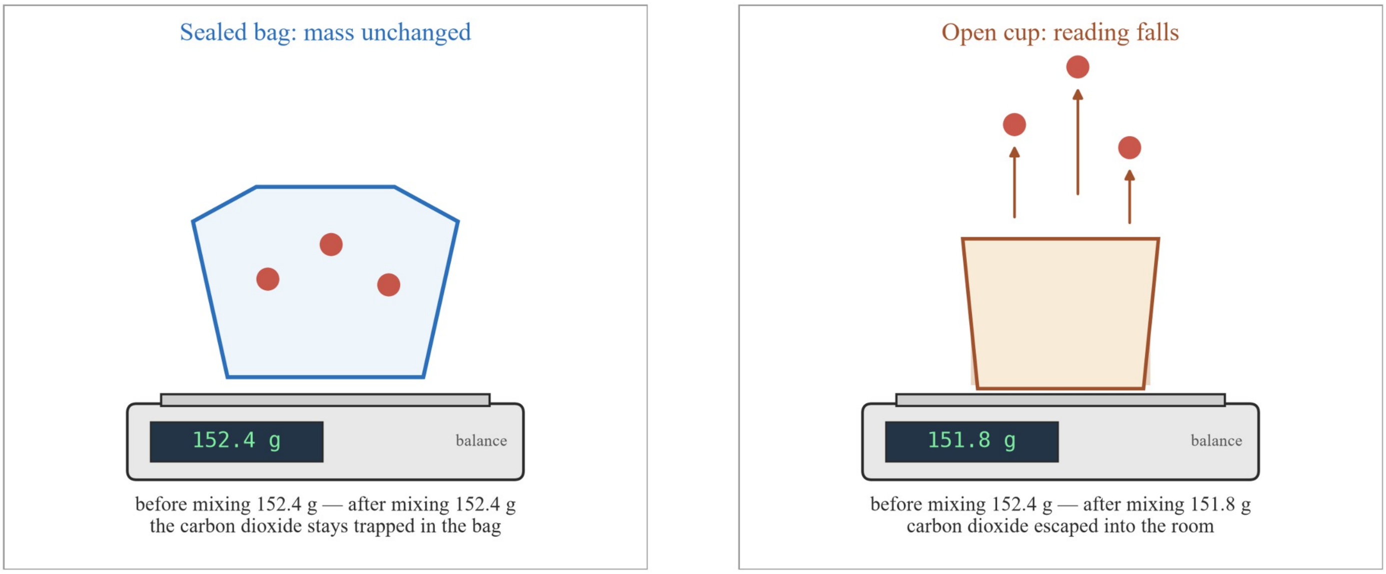
Two panels. The first shows a sealed glass vessel holding pieces of metal, heated by a flame, labelled heat the metal in a sealed vessel. The second shows the same sealed vessel on one pan of a beam balance with standard masses on the other pan, the beam level, labelled weigh the whole vessel, before and after, with the note the total mass did not change. A caption explains that Lavoisier, in the late 1700s, heated tin in sealed vessels and found the vessel and everything in it weighed the same after the reaction as before.

Closed and open systems. Whether you can *see* the law holding depends on whether matter can get in or out. In this subtopic, a **closed system** is defined as a setup in which no matter can enter or leave, and an **open system** is defined as a setup in which matter can enter or leave. A stoppered flask is closed; an open beaker on the bench is open, because gases can wander in and out of its top.



Two panels. The left shows a stoppered conical flask with red gas particles bouncing inside, labelled closed system, nothing can enter or leave, captioned gas made by the reaction stays inside. The right shows an open beaker of liquid with red gas particles rising out of the top on arrows, labelled open system, matter can enter or leave, captioned gas escapes into the room.

In a closed system the law shows itself plainly. Mix vinegar with sodium hydrogen carbonate (the white powder in many baking recipes) inside a sealed plastic bag on a balance, and the mixture fizzes as carbon dioxide gas forms — yet the reading never moves: 152.4 g before mixing and 152.4 g after. The gas is matter, and it is still inside the bag, so its mass is still on the balance. In the open cup, the same reaction gives a falling reading, 152.4 g becoming 151.8 g, because the carbon dioxide escapes into the room and takes its 0.6 g with it. The data for both setups are simulated data for practice.

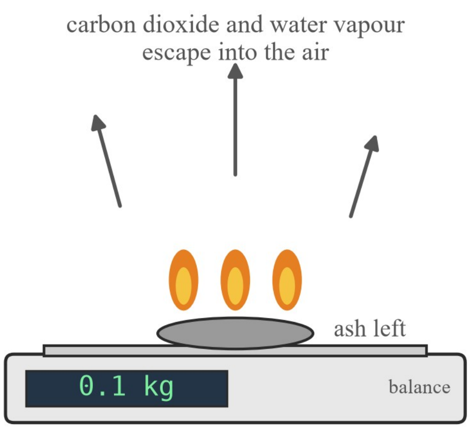


Simulated data for practice: vinegar mixed with sodium hydrogen carbonate.

Two panels, each showing a balance. The left panel shows a sealed bag of liquid and trapped red gas particles on the balance, reading 152.4 g, titled sealed bag, mass unchanged, captioned before mixing 152.4 g, after mixing 152.4 g, the carbon dioxide stays trapped in the bag. The right panel shows an open cup on a balance, reading 151.8 g, with red gas particles leaving on upward arrows, titled open cup, reading falls, captioned before mixing 152.4 g, after mixing 151.8 g, carbon dioxide escaped into the room. A footer states the readings are simulated data for practice, vinegar mixed with sodium hydrogen carbonate.

In an open system, mass can seem to fall. Burn a 2.0 kg log in air and only about 0.1 kg of ash is left. The missing mass has not vanished: the carbon and hydrogen in the wood react with oxygen to make carbon dioxide and water vapour, gases that drift away with most of the mass. Weigh the ash alone and the reading falls, but trap every gas as well and the total mass of products would again equal the total mass of reactants. The law holds; the open system was letting the evidence escape.

Burning wood in an open system

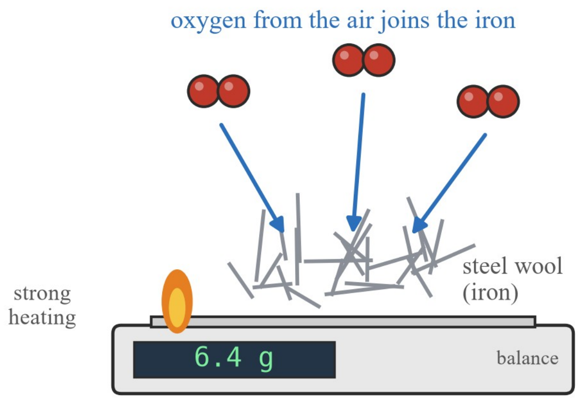


The log started at 2.0 kg. The ash left is only 0.1 kg — the rest of the mass left as gases (example values).

An open-system sketch of a log fire on a balance reading 0.1 kg. A small pile of grey ash sits on the balance pan with flames above it, and arrows carry gas particles up and away, labelled carbon dioxide and water vapour escape into *the air. The caption states the log started at 2.0 kg and the ash left is only 0.1 kg — the rest of the mass left as gases, using example values.*

In an open system, mass can also seem to rise. Heat steel wool (fine iron wire) on a balance in air and the reading *climbs*: 5.0 g of wool becomes 6.4 g of dark product. Nothing was added by hand — but the iron reacts with oxygen from the air, and oxygen atoms that were floating in the room end up bonded into the solid product, adding their mass to the pan. Once more the totals balance: 5.0 g of iron plus 1.4 g of joined oxygen gives 6.4 g of product. A falling reading, a rising reading and an unchanged reading all agree with the Law of Conservation of Mass once every particle of matter — including invisible gases — is counted.

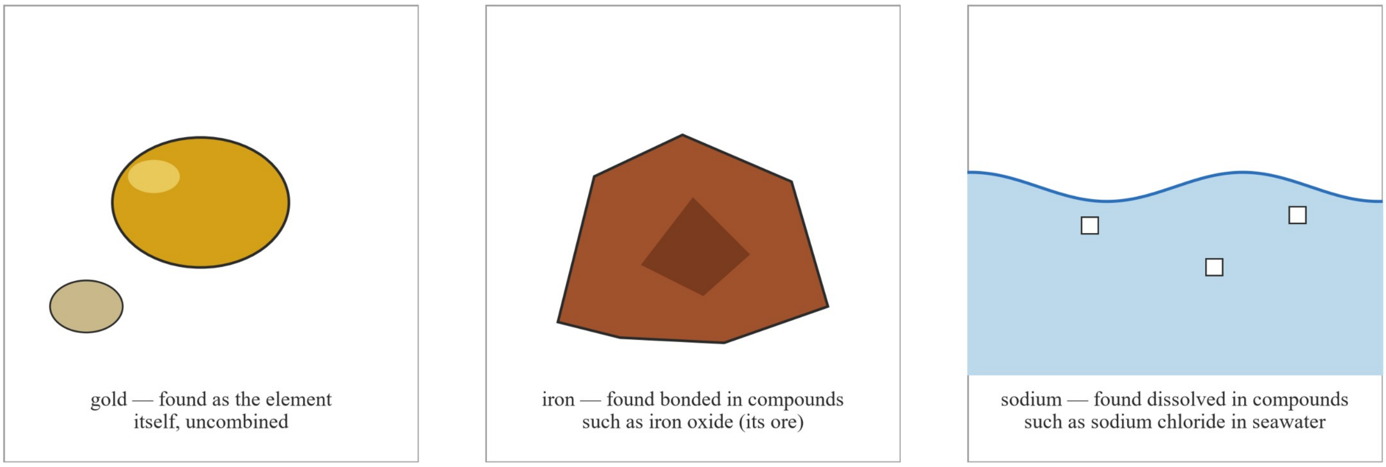
Heating steel wool in an open system



The wool started at 5.0 g. After heating in air the reading is 6.4 g — the extra mass is the oxygen that joined (example values).

An open-system sketch of steel wool on a balance reading 6.4 g. Grey tangled fibres of steel wool sit on the pan beside a flame labelled strong heating, and arrows bring red oxygen molecules down from the air into the wool, labelled oxygen from the air joins the iron. The caption states the wool started at 5.0 g and after heating in air the reading is 6.4 g — the extra mass is the oxygen that joined, using example values.

Why most elements are not found in their elemental state. An **element** is a substance made of only one kind of atom, and a **compound** is a substance in which atoms of different elements are bonded together in fixed combinations. Because most elements react easily with other elements — over minutes, years or millions of years — most are found in nature bonded into compounds, not sitting about as the pure element. Iron is dug from ore such as iron oxide, the product of iron's slow reaction with oxygen; sodium is found dissolved in seawater as compounds such as sodium chloride. Only a few unreactive elements, such as gold, are found in their elemental state, as nuggets and veins of the pure metal. Every ore and every dissolved salt is evidence of atoms rearranging in chemical reactions that happened long ago.

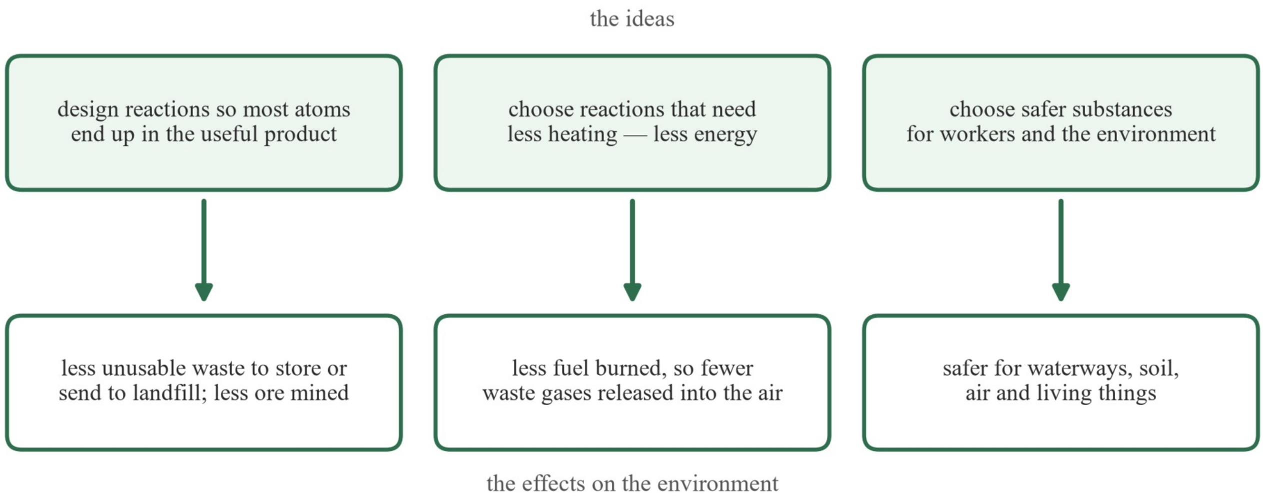


Most elements are reactive, so they are found bonded into compounds; only a few unreactive ones, like gold, are found as the element itself.

Three panels. The first shows a shiny gold nugget beside a pebble of dull host rock, captioned gold, found as the element itself, uncombined. The second shows a lump of reddish-brown iron ore with a darker patch, captioned iron, found bonded in compounds such as iron oxide, its ore. The third shows a cross-section of seawater with small white squares of dissolved salt, captioned sodium, found dissolved in compounds such as sodium chloride in seawater. A footer notes that most elements are reactive and so are found bonded into compounds, while only a few unreactive ones, like gold, are found as the element itself.

Green chemistry: designing reactions that waste less. Because atoms are conserved, every atom of reactant ends up somewhere — in the useful product, in a waste product, or released into the air or water. **Green chemistry** is the name for designing chemical processes so that they harm the environment as little as possible. In this subtopic the ideas are illustrated by three design choices: arrange the reaction so most atoms end up in the useful product, choose reactions that need less energy such as less heating, and choose safer substances for workers and the environment.

Green chemistry — designing reactions that waste less and harm less



Because atoms are conserved, every atom of reactant ends up somewhere — green chemistry aims to make that somewhere the useful product.

A three-column flow diagram. Each column shows a green idea box at the top, a downward arrow, and a white effect box below. Column one: design reactions so most atoms end up in the useful product, leading to less unusable waste to store or send to landfill, and less ore mined. Column two: choose reactions that need less heating, less energy, leading to less fuel burned and fewer waste gases released into the air. Column three: choose safer substances for workers and the environment, leading to safer waterways, soil, air and living things. The caption notes that because atoms are conserved, every atom of reactant ends up somewhere, and green chemistry aims to make that somewhere the useful product.

The effect on the environment follows directly. If most atoms finish in the useful product, less unusable waste goes to landfill and less ore has to be mined in the first place. If a process needs less heating, less fuel is burned and fewer waste gases reach the air. If the substances chosen are safer, waterways, soil and living things are less harmed. The Law of Conservation of Mass is what makes green chemistry possible as a science at all: you can track every atom and design the process so it finishes where you want it to.

Activities

Activity 1 — Spot the reactants and products (elaboration `VC2S10U08.E01`). Your teacher adds vinegar to sodium hydrogen carbonate in a beaker. Record three observations of the change — what the powder does, what the liquid does, and what forms above it — then list the reactants and the products you can name, given that the gas formed is carbon dioxide. Wear eye protection and follow Science ASSIST (ASTA) guidance for all practical work.

Activity 2 — Build the rearrangement (elaboration `VC2S10U08.E02`). Using a molecular model kit (or paper circles and sticks), build two hydrogen molecules and one oxygen molecule. Break the bonds, then rebuild the atoms into as many water molecules as you can. Draw a before-and-after box diagram like the one in the theory, count atoms of each element on both sides, and state what your counts show about the Law of Conservation of Mass.

Activity 3 — Closed against open (elaboration `VC2S10U08.E03`). Place a small cup of vinegar and a teaspoon of sodium hydrogen carbonate inside a sealable plastic bag on a digital balance, and record the mass. Tip the powder in without opening the bag, and record the mass again. Repeat with the same amounts in an open beaker. Relate both readings to the Law of Conservation of Mass. Wear eye protection and follow Science ASSIST (ASTA) guidance.

Activity 4 — A rising reading (elaboration `VC2S10U08.E03`). The table below is **simulated data for practice** from heating steel wool on a balance in air.

Time (s)	0	30	60	90	120
Balance reading (g)	5.0	5.7	6.1	6.4	6.4

Explain the trend in the reading using the rearrangement of atoms, identify the substance that joined the iron, and state what the unchanged reading after 90 s shows.

Activity 5 — Where is the element? (elaboration `VC2S10U08.E05`). Choose three elements — one from gold, one from iron, one from sodium or aluminium. For each, state whether it is found in nature in its elemental state or bonded in compounds, name one place it is found, and explain the pattern across your three using the idea of how easily each element reacts.

Activity 6 — A greener process (elaboration `VC2S10U08.E06`). A factory makes a useful solid by one of two routes. Route X: 100 kg of reactants gives 60 kg of product and 40 kg of unusable waste, and needs strong heating for 6 h. Route Y: 100 kg of reactants gives 90 kg of product and 10 kg of unusable waste, and needs gentle warming for 1 h. Explain, using the Law of Conservation of Mass, where the 40 kg in route X finishes, and describe two effects on the environment of switching from route X to route Y.

Worked examples

Example 1 — scaffolded

Magnesium ribbon burns in oxygen. A student burns 4.8 g of magnesium, and 3.2 g of oxygen from the air joins it. (a) Name the reactants and the product of this reaction. (b) Calculate the mass of the product made. (c) State the law that justifies your calculation.

Working	Comment
Reactants: magnesium and oxygen; product: magnesium oxide	The starting substances are used up; the white powder is the new substance.
mass of product = 4.8 g + 3.2 g	Every atom of both reactants ends up in the product.

Working	Comment
= **8.0 g** of magnesium oxide	Mass is conserved, so the product carries the mass of both reactants.
Law of Conservation of Mass	Total mass of products equals total mass of reactants.

Example 2 — scaffolded

The picture of methane burning shows one methane molecule and two oxygen molecules on the left, and one carbon dioxide molecule and two water molecules on the right. (a) Count the carbon, hydrogen and oxygen atoms on the left. (b) Count them on the right. (c) State what the comparison shows about atoms in a chemical reaction.

Working	Comment
Left: C = 1, H = 4, O = 2 × 2 = 4	One methane supplies 1 C and 4 H; each O_2 supplies 2 O.
Right: C = 1, H = 2 × 2 = 4, O = 2 + 2 = 4	Carbon dioxide supplies 1 C and 2 O; each water supplies 2 H and 1 O.
Every count matches	Atoms are rearranged, never created or destroyed.
So total mass is unchanged — the Law of Conservation of Mass	Same atoms in, same atoms out, so the same total mass.

Example 3 — unscaffolded

A student heats 5.0 g of steel wool in air on a balance and the reading rises to 6.4 g. She concludes the Law of Conservation of Mass must be wrong, because mass increased. Evaluate her conclusion, and calculate the mass of the substance that joined the iron.

The conclusion is wrong. The balance pan is an open system: oxygen from the air is a reactant that was never weighed at the start. The iron rearranges with that oxygen into a new solid that stays on the pan, so the reading rises by exactly the mass of oxygen that joined: 6.4 g − 5.0 g = **1.4 g**. Counting the oxygen, the total mass of reactants (5.0 g of iron + 1.4 g of oxygen) equals the total mass of product (6.4 g), exactly as the law requires.

Example 4 — unscaffolded

A 2.0 kg log burns completely in an open fire, leaving 0.1 kg of ash. (a) Explain where the other 1.9 kg of the log went. (b) A friend says this reaction destroys mass. Use the Law of Conservation of Mass to show why the fire is not destroying anything.

(a) The carbon and hydrogen in the log react with oxygen and end up in carbon dioxide and water vapour; those gases rise away with the 1.9 kg. The ash is only the small part of the log that cannot burn.
(b) The fire is an open system, so the gaseous products escape before they are weighed. If every gas were trapped and weighed together with the ash and the oxygen that joined, the total mass of products would equal the total mass of reactants. Mass that leaves a system is still mass; nothing has been destroyed.

Practice questions

Scaffolded questions

Question 1 *(elaboration `VC2S10U08.E01`)* Methane burns in oxygen to make carbon dioxide and water: methane + oxygen → carbon dioxide + water. (a) Name the two reactants. (b) Name the two products. (c) State what the arrow means.

Question 2 *(elaboration `VC2S10U08.E02`)* A diagram shows two hydrogen molecules and one oxygen molecule before a reaction, and two water molecules after it. (a) Count the hydrogen atoms before and after. (b) Count the oxygen atoms before and after. (c) State whether any atoms were created or destroyed, and how you know.

Question 3 State the Law of Conservation of Mass in your own words, and predict the total mass of products when a reaction in a closed system starts with 20 g of reactants.

Question 4 *(elaboration `VC2S10U08.E03`)* Vinegar and sodium hydrogen carbonate are mixed inside a sealed bag on a balance reading 152.4 g. Predict the reading after the reaction finishes, and explain your prediction.

Question 5 Burning 4.8 g of magnesium uses 3.2 g of oxygen. Calculate the mass of magnesium oxide produced, naming the law you used.

Question 6 *(elaboration `VC2S10U08.E05`)* Gold jewellery keeps its shine for centuries, while an iron gate rusts within a few years of being painted over and scratched. Explain what this contrast tells you about where each element is found in nature.

Unscaffolded questions

Question 7 *(elaboration `VC2S10U08.E03`)* In an open cup, the same vinegar and sodium hydrogen carbonate reaction gives a reading that falls from 152.4 g to 151.8 g. (a) Calculate the mass that left the cup. (b) Identify the substance that left, and the state it is in. (c) Explain why the fall does not break the Law of Conservation of Mass.

Question 8 *(elaboration `VC2S10U08.E03`)* Heating steel wool in air changes a balance reading from 5.0 g to 6.4 g. (a) Calculate the mass of oxygen that joined the iron. (b) Explain, in terms of atoms, why the reading rose in this open system.

Question 9 *(novel scenario)* A candle stands on a balance and is lit. The reading slowly falls. A student claims the observation proves mass is destroyed in chemical reactions. Evaluate the claim, and describe one change to the setup that would test your answer.

Question 10 *(elaboration `VC2S10U08.E02`, novel scenario)* Hydrogen burns in chlorine to make hydrogen chloride: one hydrogen molecule (two pale atoms) plus one chlorine molecule (two green atoms) gives two hydrogen chloride molecules (each a pale atom joined to a green atom). Describe the before-and-after particle picture, count the atoms of each element on both sides, and state what the counts show.

Question 11 *(elaboration `VC2S10U08.E05`)* Sodium is never found in nature as the element, and in the laboratory it is stored under oil to keep it away from air and water. (a) Explain both facts with one idea. (b) Name the compound in which sodium is commonly found dissolved in seawater.

Question 12 *(elaboration `VC2S10U08.E06`)* A chemist redesigns a process so that 95% of the reactant atoms finish in the useful product instead of 50%. (a) Use the Law of Conservation of Mass to explain what happens to the atoms that no longer become waste. (b) Describe two ways the environment benefits from the change.

Question 13 *(data interpretation)* The table below is **simulated data for practice** from an experiment like Lavoisier's: tin is heated in a sealed vessel, and the whole vessel is weighed.

	Mass of sealed vessel and contents (g)
Before heating	245.6
After heating and cooling	245.6

(a) Explain why the two readings are the same even though the tin changed.
(b) The vessel is then opened, air rushes in, and the reading becomes 246.1 g. Explain the rise.

Question 14 *(elaboration `VC2S10U08.E02`)* Burning 16 g of methane completely uses 64 g of oxygen. Without drawing any models, use the Law of Conservation of Mass to state the total mass of carbon dioxide and water produced together, with a reason.

Question 15 *(novel scenario)* A 11.2 g iron nail left outdoors for years gains a coating of rust, and the nail plus rust now has a mass of 16.0 g. (a) Calculate the mass of oxygen that joined the iron over those years. (b) Explain why the rusted nail is heavier even though no person added anything to it.

Question 16 *(elaboration `VC2S10U08.E03`)* Two students each run the vinegar and sodium hydrogen carbonate reaction with identical amounts. Student P works with a sealed flask; student Q with an open beaker. Predict and explain each final balance reading compared with the starting reading, and state which student's setup demonstrates the Law of Conservation of Mass directly.

Answers

Question 1 (a) methane and oxygen; (b) carbon dioxide and water; (c) “reacts to make” — the reactants change into the products. **Question 2** (a) 4 before, 4 after; (b) 2 before, 2 after; (c) none — the counts are equal on both sides. **Question 3** The total mass of the products equals the total mass of the reactants, because atoms are neither created nor destroyed; 20 g. **Question 4** 152.4 g; the carbon dioxide is trapped inside, so all of the product mass stays on the balance. **Question 5** 8.0 g; the Law of Conservation of Mass. **Question 6** Iron reacts easily, so it is found in nature bonded in compounds (and rusts); gold is unreactive, so it is found as the element itself. **Question 7** (a) 0.6 g; (b) carbon dioxide, a gas; (c) the mass left as a gas that escaped — it was not destroyed; in a closed system the total would be unchanged. **Question 8** (a) 1.4 g; (b) oxygen atoms from the air bonded into the solid product and added their mass to the pan. **Question 9** The claim is wrong — see solution; trap the gases (run the candle in a sealed container with a supply of oxygen) and the total mass is unchanged. **Question 10** See solution; 2 hydrogen and 2 chlorine atoms on each side; atoms are rearranged, not created or destroyed. **Question 11** (a) Sodium reacts very easily, so in nature it has all reacted into compounds, and in the lab it must be shielded from air and water; (b) sodium chloride. **Question 12** (a) They finish in the useful product instead of as waste — the atoms are conserved either way; (b) less waste to landfill, less ore mined, less energy and fewer waste gases (any two). **Question 13** (a) The vessel is a closed system: no matter entered or left; (b) opening let in air to replace the oxygen the tin had used — 0.5 g of oxygen. **Question 14** 80 g; all of the methane and oxygen mass must finish in the products. **Question 15** (a) 4.8 g; (b) oxygen from the air bonded into the rust and added its mass. **Question 16** P: unchanged; Q: falls; P’s sealed flask demonstrates the law directly — see solution.

Fully-worked solutions

Question 1 (a) The **reactants** are methane and oxygen — the starting substances used up. (b) The **products** are carbon dioxide and water — the new substances made. (c) The arrow means “reacts to make”: it separates the reactants (left) from the products (right).

Question 2 (a) Before: 2 molecules × 2 atoms = 4 hydrogen atoms; after: 2 water molecules × 2 hydrogen atoms = 4. (b) Before: 1 oxygen molecule × 2 atoms = 2 oxygen atoms; after: 2 water molecules × 1 oxygen atom = 2. (c) No atoms were created or destroyed, because the count of each element is the same on both sides. The atoms only rejoin in new groups.

Question 3 The Law of Conservation of Mass says the total mass of the products of a chemical reaction equals the total mass of the reactants, because the atoms are only rearranged. In a closed system nothing escapes, so 20 g of reactants gives **20 g** of products.

Question 4 The reading stays at **152.4 g**. The reaction makes carbon dioxide gas, but the sealed bag is a closed system: the gas, and its mass, remain inside the bag on the balance, so the total mass weighed is unchanged.

Question 5 mass of magnesium oxide = mass of magnesium + mass of oxygen = 4.8 g + 3.2 g = **8.0 g**, by the Law of Conservation of Mass: every atom of both reactants finishes in the product.

Question 6 Iron reacts easily with oxygen and water, which is why the gate rusts and why iron is found in nature bonded into compounds such as iron oxide, not as the metal itself. Gold stays shiny because it rarely reacts, which is why gold is found in its elemental state. How easily an element reacts decides where it is found.

Question 7 (a) 152.4 g − 151.8 g = **0.6 g** left the cup. (b) The substance is **carbon dioxide**, in the gaseous state. (c) The law counts all the matter. The 0.6 g of gas escaped into the room carrying its mass, so the open cup weighed less; the atoms were not destroyed. In a closed system the same reaction leaves the reading unchanged, as Activity 3 shows.

Question 8 (a) 6.4 g − 5.0 g = **1.4 g** of oxygen joined the iron. (b) The iron atoms bonded with oxygen atoms taken from the air. Those oxygen atoms were not on the pan at the start but are part of the solid product at the end, so the open system gained their mass and the reading rose.

Question 9 The claim is wrong. The candle wax reacts with oxygen to make carbon dioxide and water vapour, and both gases leave the open setup, carrying mass with them — exactly like the log fire in the theory. Mass that escapes is not mass destroyed. To test this, burn the candle inside a sealed container that also holds its own oxygen supply (a closed system) and weigh the whole container before and after: the reading will be unchanged.

Question 10 Before: one hydrogen molecule (2 pale atoms) and one chlorine molecule (2 green atoms). After: two hydrogen chloride molecules, each a pale atom bonded to a green atom. Counts: hydrogen 2 before and 2 after; chlorine 2 before and 2 after. The equal counts show the atoms were rearranged, not created or destroyed, so the reaction obeys the Law of Conservation of Mass.

Question 11 (a) One idea covers both: sodium is extremely reactive. In nature it has long since reacted with other elements, so it exists only bonded in compounds; in the laboratory the oil layer keeps air and water away so the sodium cannot react. (b) **Sodium chloride**, dissolved in seawater.

Question 12 (a) Atoms cannot vanish, so the atoms that were becoming waste now finish bonded into the useful product. The law says every reactant atom ends up somewhere; the redesign simply changes that "somewhere". (b) Less unusable waste means less material sent to landfill and less new ore mined to replace lost atoms; and processes redesigned this way usually need less energy, so less fuel is burned and fewer waste gases reach the air.

Question 13 (a) The sealed vessel is a closed system. The tin changed into a new substance by reacting with oxygen inside the vessel, but no matter crossed the seal, so the total mass weighed stayed 245.6 g — the Law of Conservation of Mass in action. (b) While sealed, the tin used 0.5 g of the oxygen inside, leaving the gas inside thinner than outside air. Opening the vessel let outside air rush in to fill that gap, adding the 0.5 g of oxygen now bonded into the tin: 245.6 g + 0.5 g = 246.1 g.

Question 14 Total mass of products = total mass of reactants = 16 g + 64 g = **80 g**. The carbon, hydrogen and oxygen atoms of the reactants all finish inside the carbon dioxide and water molecules, so those two products together must carry the whole 80 g.

Question 15 (a) 16.0 g − 11.2 g = **4.8 g** of oxygen joined the iron. (b) Rusting is the iron reacting with oxygen (and water) from the air. The oxygen atoms bond into the solid rust and stay on the nail, so the nail plus rust gains exactly the mass of oxygen that joined — the open system took matter in.

Question 16 Student P's sealed flask is a closed system: the carbon dioxide made stays inside, so the final reading equals the starting reading. Student Q's open beaker lets the carbon dioxide escape, so the final reading is lower than the starting reading. P's setup demonstrates the law directly, because all of the product mass is present to be weighed; Q's result agrees with the law too, once the escaped gas is accounted for.

Where this leads: the conservation-of-mass picture taught here is the starting point for quantitative chemistry in VCE Chemistry, where the mole and calculations with amounts of substance put numbers on these same ideas — reference-only for this book, as those calculations sit above this book's ceiling (TOC D9). Inside the book, this subtopic hands its ideas forward: Subtopic 11B writes and balances the word and symbol equations for the reactions modelled here, Subtopic 11C uses the conservation picture for synthesis, decomposition and displacement reactions, and Subtopic 11D builds on the rearrangement of atoms when it classifies reactions by their energy changes. The investigation skills practised in Activities 3 and 4 also feed into SIT-2, the full investigation report that follows this chapter.

Writing and balancing word and symbol equations

Chapter 11 — Chemical sciences B: chemical reactions (Science, Levels 9 and 10)

> **Subtopic 11B** · VC2 Science Understanding — Chemical sciences
>
> **CD code:** `VC2S10U08` (split delivery †; this subtopic is the partner, not the accountable owner) **Content description (verbatim):** "chemical reactions are described by the Law of Conservation of Mass and involve the rearrangement of atoms; they can be modelled using a range of representations, including word and simple balanced chemical equations" **This subtopic's limb (TOC §4 clause split):** word and balanced symbol equations. The accountable owner `11A` delivers the other limb: the Law of Conservation of Mass, the rearrangement of atoms, and representations of reactions in closed and open systems. **Elaboration ids drawn on:** `VC2S10U08.E04` (`VC2S10U08.E01`–`VC2S10U08.E03`, `VC2S10U08.E05` and `VC2S10U08.E06` are drawn on by Subtopic 11A.) **Achievement standard (extract served):** "write word and balanced chemical equations for these reactions." Subtopic 11B is assessed against the second clause — writing word and balanced chemical equations; the first clause ("They demonstrate the Law of Conservation of Mass in chemical reactions") is served by Subtopic 11A. **Maths interlock (D11):** `VC2M9M05` — coefficients are read as ratio terms and scaled up, re-using the ratio and scaling reasoning taught in Subtopic 4B.

Theory

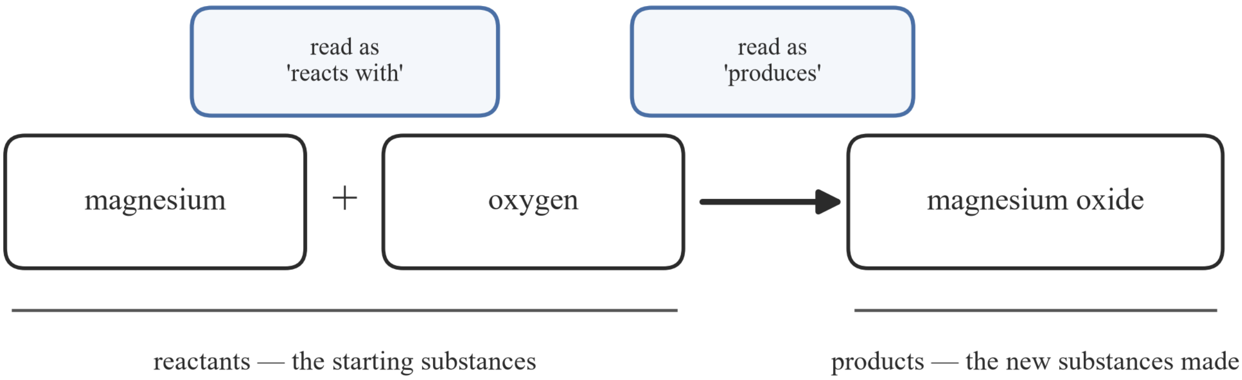
Chemists keep accounts too. In Subtopic 11A you met the two big ideas that sit under every chemical reaction: the **Law of Conservation of Mass** — the total mass of the products always equals the total mass of the reactants — and the reason behind it, that a reaction is nothing more than the **rearrangement of atoms**. The atoms of the starting substances are taken apart and re-joined in new combinations; none are created, none are destroyed. This subtopic gives you the shorthand chemists use to keep that account on paper: **chemical equations**. You will learn to write reactions as **word equations**, then as **symbol equations** using formulas, and to **balance** those symbol equations so they tell the truth about the atoms.

Word equations — names first. A **word equation** writes a reaction using the names of the substances. The starting substances, the **reactants**, are written on the left; the new substances made, the **products**, are written on the right; an arrow points from one side to the other.

> magnesium + oxygen → magnesium oxide

Read it like this: *magnesium* **reacts with** *oxygen* **to produce** *magnesium oxide*. The plus sign between two reactants reads as "reacts with" (or simply "and"); the arrow reads as "produces" or "forms", and it always points towards the products.

The parts of a word equation



The anatomy of a word equation. The reactants magnesium and oxygen sit on the left with a plus sign between them, an arrow points to the product magnesium oxide on the right, and each part is labelled: reactants are the starting *substances, products are the new substances made, the plus sign reads as reacts with, and the arrow reads as produces.*

Three writing rules keep word equations tidy:

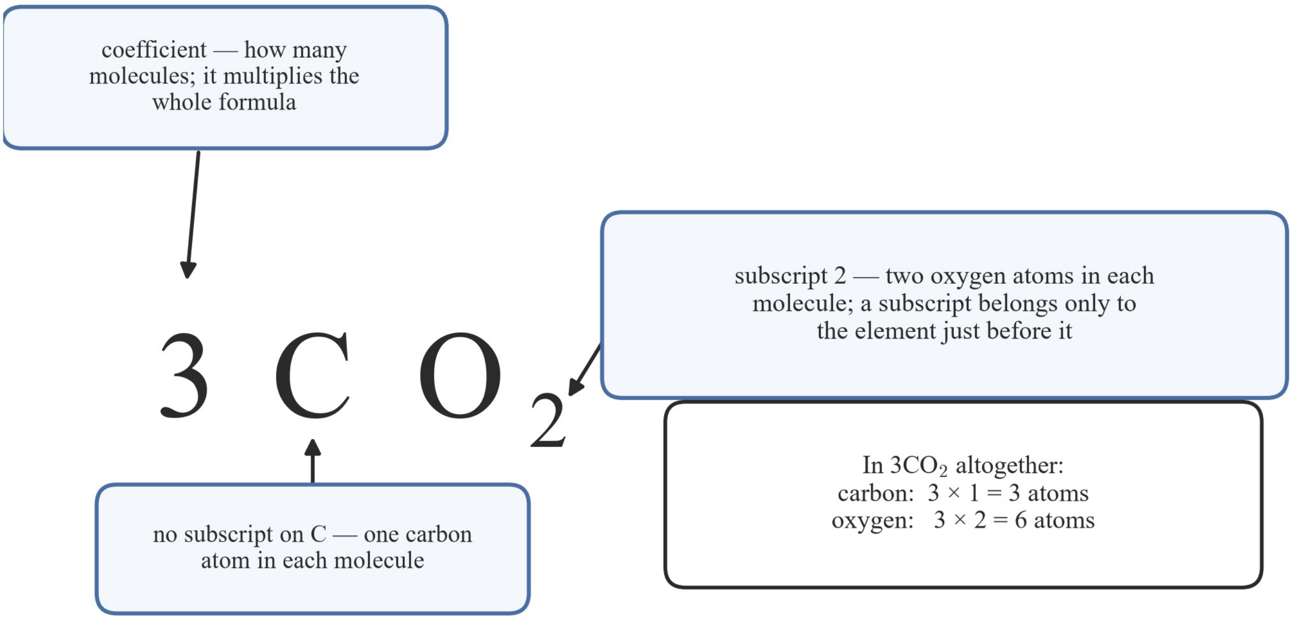
- Name every reactant and every product — nothing left out, nothing added.
- Reactants go on the left of the arrow, products on the right. The arrow points the way the change goes.
- If there is more than one reactant or product, join them with plus signs. The order of the names on one side does not change the meaning.

Word equations have one weakness: names carry no numbers. They tell you *what* reacts and *what* is made, but not *how much of each*. To keep the account of atoms, chemists need a second, more powerful kind of equation. First, a quick refresher on the building blocks that equation is made from.

What a chemical formula tells you. Every substance has a **chemical formula** built from element symbols (from the periodic table, Subtopic 10C) and small numbers. Two kinds of number appear, and they do very different jobs:

- A **subscript** — the small number written low, after an element symbol — tells how many atoms of that element are in **one** molecule or formula unit. The subscript belongs to the element directly before it and to no other. In CO_2, one molecule of carbon dioxide holds 1 carbon atom and 2 oxygen atoms. In H_2O, one molecule of water holds 2 hydrogen atoms and 1 oxygen atom. A symbol with no subscript has one atom of that element.
- A **coefficient** — the big number written in front of a formula — tells how many molecules or formula units there are, and it multiplies **everything** in the formula behind it. $3CO_2$ means three molecules of carbon dioxide: $3 \times 1 = 3$ carbon atoms and $3 \times 2 = 6$ oxygen atoms altogether.

The two kinds of number in a formula do different jobs

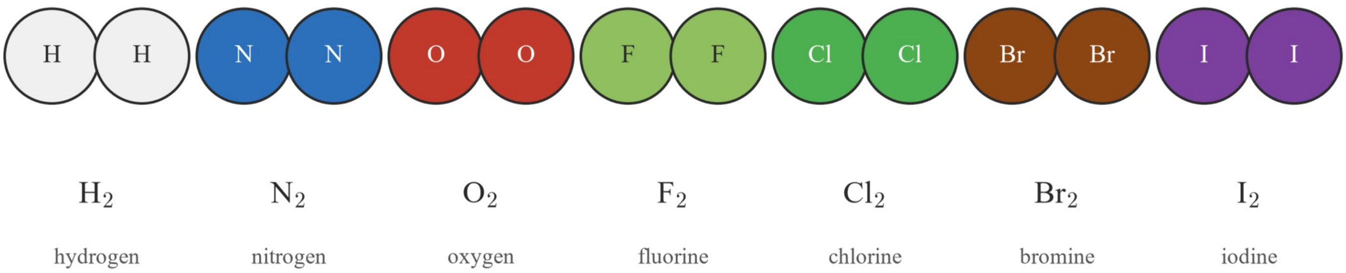


The anatomy of the written form 3CO2. The large 3 in front is the coefficient and multiplies the whole formula, the C has no subscript so each molecule holds one carbon atom, and the small subscript 2 belongs only to the oxygen, giving two oxygen atoms per molecule. A tally shows that 3CO2 contains 3 carbon atoms and 6 oxygen atoms altogether.

One more fact you must know before writing any symbol equation. Most elements are written as single atoms — magnesium is Mg, iron is Fe, carbon is C. But **seven elements are never found as single atoms in ordinary conditions; their atoms live in pairs**, so their formulas always carry the subscript 2. Chemists call these the **diatomic** elements, from a word meaning "two atoms":

element	formula	element	formula
hydrogen	H_2	chlorine	Cl_2
nitrogen	N_2	bromine	Br_2
oxygen	O_2	iodine	I_2
fluorine	F_2		

The seven diatomic elements — these atoms always live in pairs



The seven diatomic elements drawn as pairs of bonded atoms: hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine and iodine. Each molecule is two identical atoms joined together, so each formula carries the subscript 2.

The oxygen you breathe and the oxygen that burns things is O_2 — two oxygen atoms joined — never a lone O. Forgetting the 2 is the single most common way a symbol equation goes wrong before balancing even begins.

From words to symbols. A **symbol equation** (also called a **chemical equation** or **formula equation**) replaces every name in a word equation with its formula. Here is the whole process for burning magnesium, one step at a time.

Step 1 — write the word equation.

magnesium + oxygen → magnesium oxide

Step 2 — replace each name with its formula. Magnesium is Mg; oxygen is one of the seven diatomic elements, O_2; magnesium oxide is MgO.

$$Mg + O_2 \rightarrow MgO$$

At this point the equation is called **unbalanced** — a skeleton, correct in its formulas but not yet true in its numbers. Check the atoms: the left side has 1 magnesium and 2 oxygens, the right side has 1 magnesium and 1 oxygen. One oxygen atom has been lost, and that cannot happen in a real reaction.

Step 3 — balance the equation. This is the next section, and it turns the skeleton into

$$2Mg + O_2 \rightarrow 2MgO$$

with the same count of every atom on both sides.

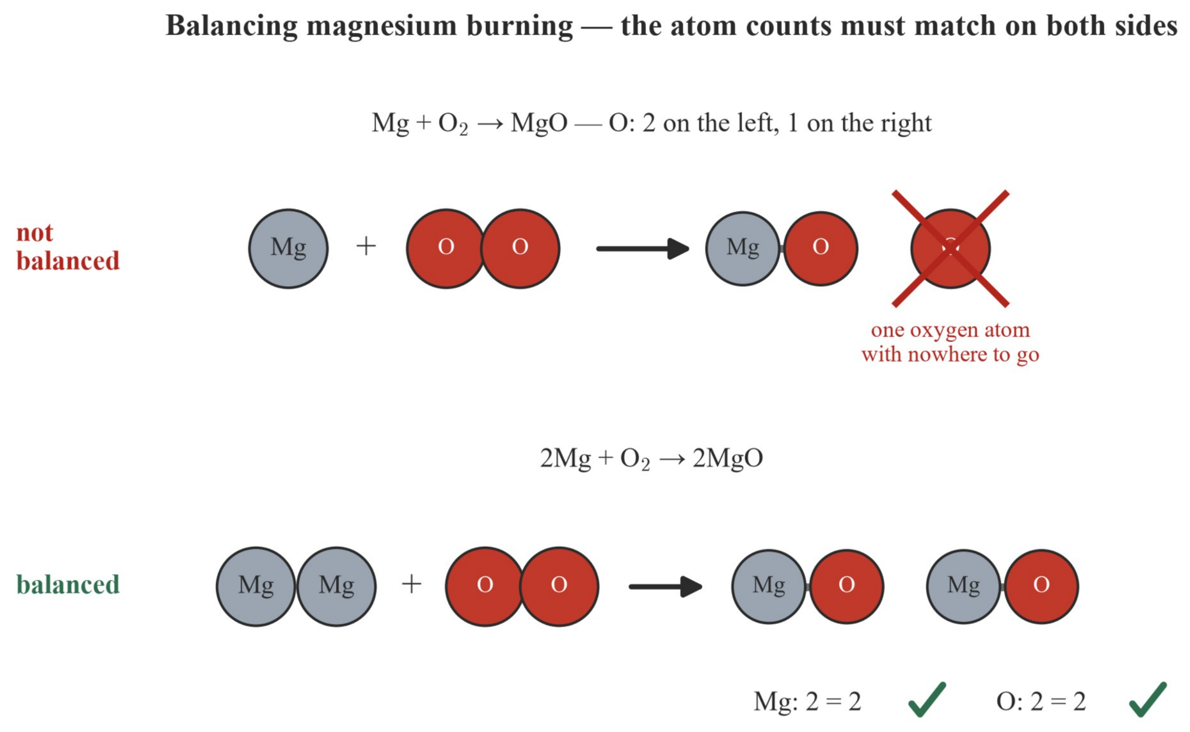
Here are the formulas used in this subtopic, so you can practise without looking anything up. You are not asked to work out new formulas from scratch in this book — formulas like these are given or drawn from this list, and your skill is in the writing and balancing.

name	formula	name	formula
magnesium	Mg	carbon	C
oxygen	O_2	carbon dioxide	CO_2
magnesium oxide	MgO	methane	CH_4
hydrogen	H_2	propane	C_3H_8
water	H_2O	nitrogen	N_2
hydrogen peroxide	H_2O_2	ammonia	NH_3

name	formula	name	formula
sodium	Na	chlorine	Cl_2
sodium chloride	$NaCl$	zinc	Zn
hydrochloric acid	HCl	zinc chloride	$ZnCl_2$
copper	Cu	copper(II) oxide	CuO
copper(II) carbonate	$CuCO_3$	calcium carbonate	$CaCO_3$
calcium oxide	CaO	calcium chloride	$CaCl_2$
iron	Fe	iron(III) oxide	Fe_2O_3
sulfur	S	iron(II) sulfide	FeS
aluminium	Al	aluminium oxide	Al_2O_3

Balancing — what it means. To **balance** an equation means to put coefficients in front of the formulas so that **the number of atoms of each element is the same on both sides**. Nothing else changes. The formulas stay exactly as they are; only the big numbers in front move.

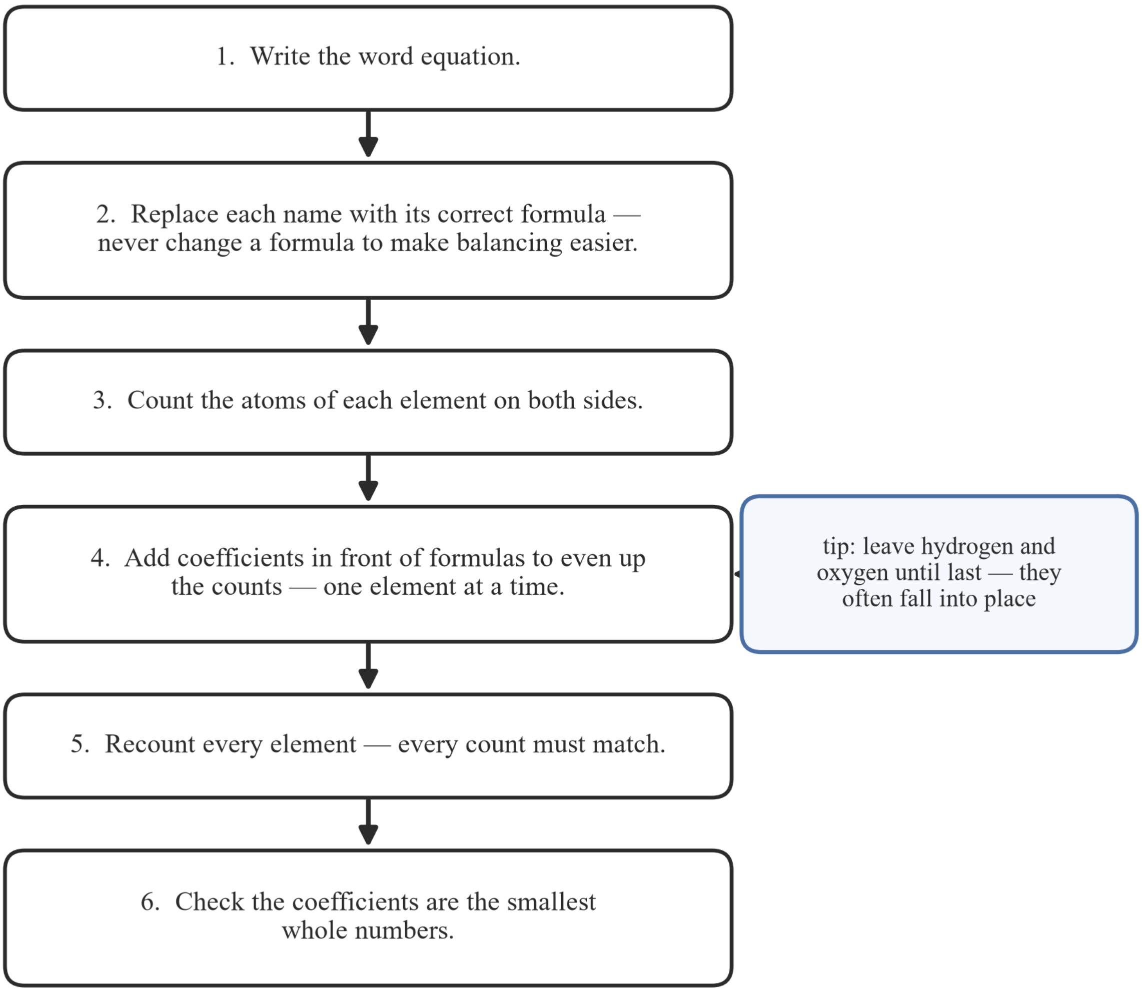
Look again at magnesium burning. The unbalanced skeleton $Mg + O_2 \rightarrow MgO$ has 2 oxygen atoms on the left but only 1 on the right. You cannot cut an oxygen atom in half, so the right side must hold 2 oxygen atoms too — which means 2 formula units of MgO. That gives 2 magnesium atoms on the right, so the left needs 2 Mg. Result: **$2Mg + O_2 \rightarrow 2MgO$**.



Two rows of particle pictures for magnesium burning. The top row is labelled not balanced: one magnesium atom and one oxygen molecule on the left give one unit of magnesium oxide on the right, leaving one oxygen atom with nowhere to go. The bottom row is labelled balanced: two magnesium atoms and one oxygen molecule on the left give two units of magnesium oxide on the right, with the counts of both elements matching.

The method, in full:

A method for balancing any symbol equation



A six-step method for balancing a chemical equation. Write the word equation, replace each name with its correct formula and never change a formula to make balancing easier, count the atoms of each element on both sides, add coefficients one element at a time to even up the counts, recount every element until every count matches, and check that the coefficients are the smallest whole numbers. A side note advises leaving hydrogen and oxygen until last.

1. **Write the word equation** first, so you know what reacts and what forms.
2. **Replace each name with its formula.** Watch for the seven diatomic elements. From here on, **never change a formula to make balancing easier** — the subscripts inside a formula describe *which substance it is*, and changing one changes the substance.
3. **Count the atoms of each element** on both sides.
4. **Add coefficients**, one element at a time, to even up the counts. A good habit is to balance elements that appear in only one formula on each side first, and leave hydrogen and oxygen until last — they often fall into place.
5. **Recount every element.** Every count must match. If one does not, adjust and recount.
6. **Check the coefficients are the smallest whole numbers.** $4Mg + 2O_2 \rightarrow 4MgO$ has matching counts but every coefficient could be halved; the correct form is $2Mg + O_2 \rightarrow 2MgO$.

Worked through methane burning — the reaction of the gas in a Bunsen burner and a kitchen stove — the count looks like this:

$CH_4 + O_2 \rightarrow CO_2 + H_2O$ (skeleton — unbalanced)

Carbon is already even: 1 on each side. Hydrogen: 4 on the left, so put a 2 in front of H_2O to make 4 on the right. Oxygen: the right side now holds 2 (from CO_2) + 2 (from $2H_2O$) = 4 atoms, so put a 2 in front of O_2. Recount — everything matches:

$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$

Atom tally for the balanced methane equation

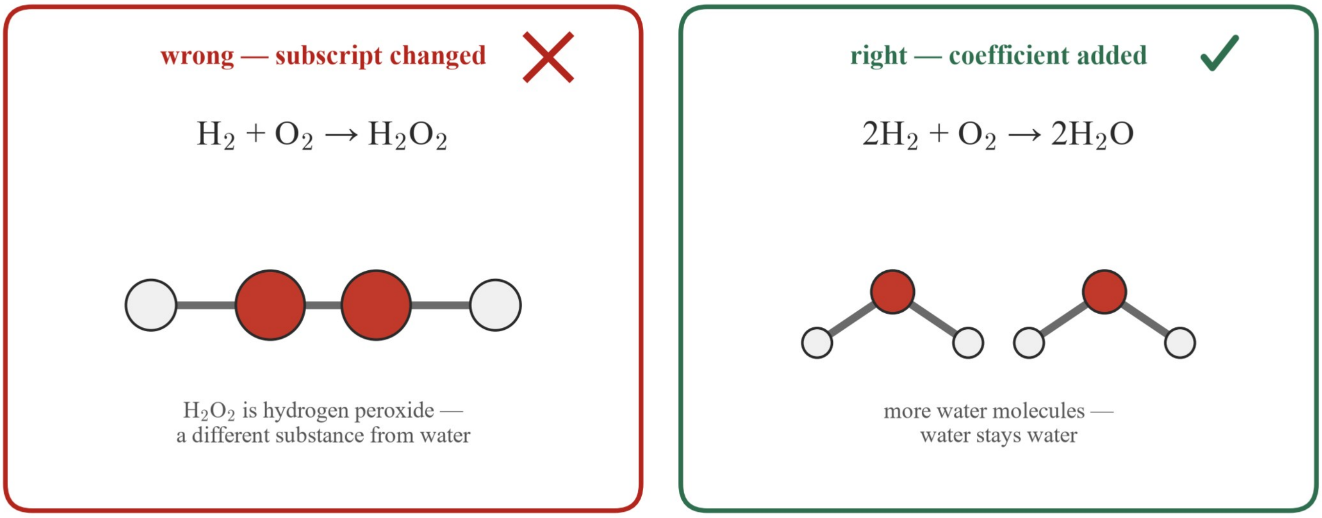
$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

element	atoms on the left	atoms on the right	
C	1 (in CH_4)	1 (in CO_2)	✓
H	4 (in CH_4)	$2 \times 2 = 4$ (in $2H_2O$)	✓
O	$2 \times 2 = 4$ (in $2O_2$)	$2 + 2 = 4$	✓

An atom-count table for the balanced methane equation CH4 plus 2O2 gives CO2 plus 2H2O. The table lists carbon, hydrogen and oxygen with the count on each side: carbon 1 and 1, hydrogen 4 and 4, oxygen 4 and 4, with a tick showing every count matches.

One thing balancing must never do — change a subscript. Faced with $H_2 + O_2 \rightarrow H_2O$, it is tempting to “fix” the oxygen by writing $H_2 + O_2 \rightarrow H_2O_2$. That does make the counts match — but H_2O_2 is **hydrogen peroxide**, a completely different substance from water. The equation no longer describes the reaction you started with. The rule is absolute: **balance with coefficients in front of formulas, never with subscripts inside them.** A coefficient adds more of the same molecules; a subscript changes what the molecule is.

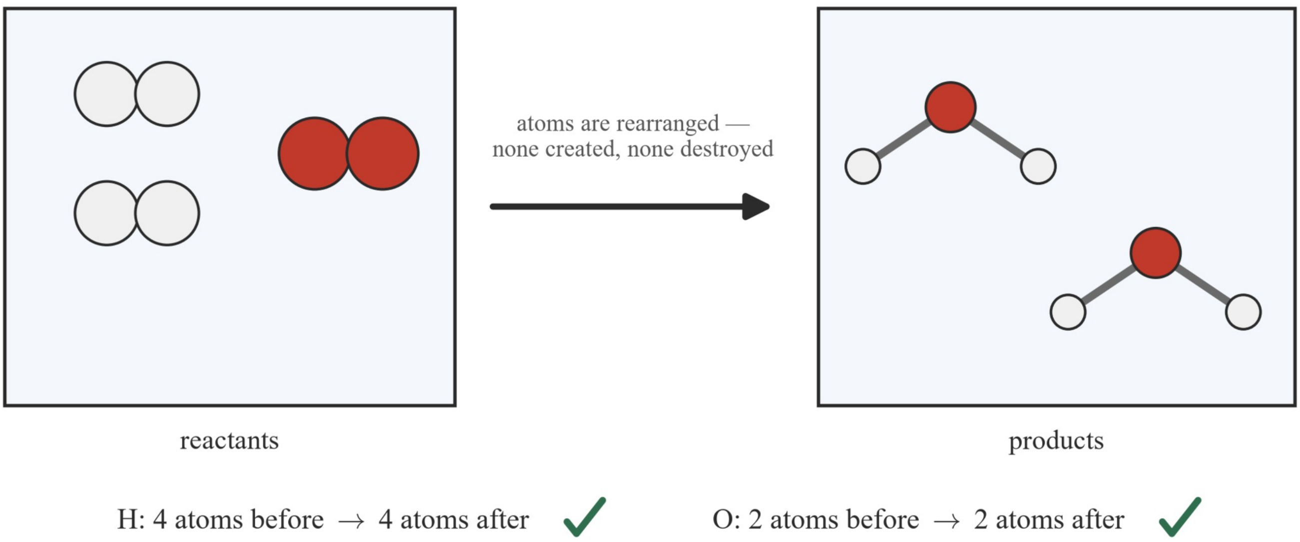
Balance with coefficients, never with subscripts



Two panels comparing a wrong fix with the right one. The wrong panel shows H2 plus O2 changed into H2O2 with the subscript edited, crossed out, because editing the subscript changes water into hydrogen peroxide, a different substance. The right panel shows 2H2 plus O2 giving 2H2O with a coefficient added in front, ticked, because a coefficient gives more water molecules while water stays water.

Why equations must balance (elaboration `VC2S10U08.E04`). The reason balancing works — and the reason it is not optional — is the Law of Conservation of Mass you met in Subtopic 11A. Mass is conserved in a reaction because atoms are conserved: every atom of every element present at the start is still present at the end, simply re-joined into new substances. A balanced equation says exactly that in symbols: the same number of atoms of each element on both sides. An unbalanced equation is not a rough version of the truth — it is false. Written literally, $Mg + O_2 \rightarrow MgO$ claims that one of the two oxygen atoms vanishes during the reaction, and no chemical reaction can make an atom vanish.

$2H_2 + O_2 \rightarrow 2H_2O$ — the same atoms, rearranged



Particle picture of the reaction 2H2 plus O2 gives 2H2O. The reactants box holds two hydrogen molecules and one oxygen molecule; an arrow labelled atoms are rearranged points to the products box holding two water molecules.

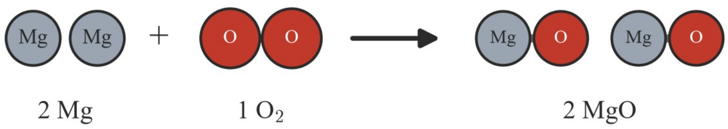
Tallies underneath show four hydrogen atoms before and four after, and two oxygen atoms before and two after — the same atoms, none created and none destroyed.

Balancing is therefore the written form of the conservation law. Every time you recount the atoms and find them equal, you are checking that your equation obeys the same rule the real reaction obeys.

Coefficients are numbers you can use. The coefficients of a balanced equation are not labels — they are counts, and they behave like the ratios you worked with in Subtopic 4B (Maths interlock `VC2M9M05`). In $2Mg + O_2 \rightarrow 2MgO$, the ratio of magnesium to oxygen to magnesium oxide is 2 : 1 : 2. That ratio holds at any scale:

- 2 atoms of Mg react with 1 molecule of O_2 to give 2 units of MgO;
- 20 atoms of Mg react with 10 molecules of O_2 to give 20 units of MgO;
- 2 000 000 000 atoms of Mg react with 1 000 000 000 molecules of O_2 to give 2 000 000 000 units of MgO.

Coefficients give a ratio that scales — $2Mg + O_2 \rightarrow 2MgO$



batch size	Mg atoms	O_2 molecules	MgO units
at the particle scale	2	1	2
× 10	20	10	20
× 1 000 000 000	2 000 000 000	1 000 000 000	2 000 000 000

The ratio 2 : 1 : 2 never changes — a balanced equation works for any size batch.

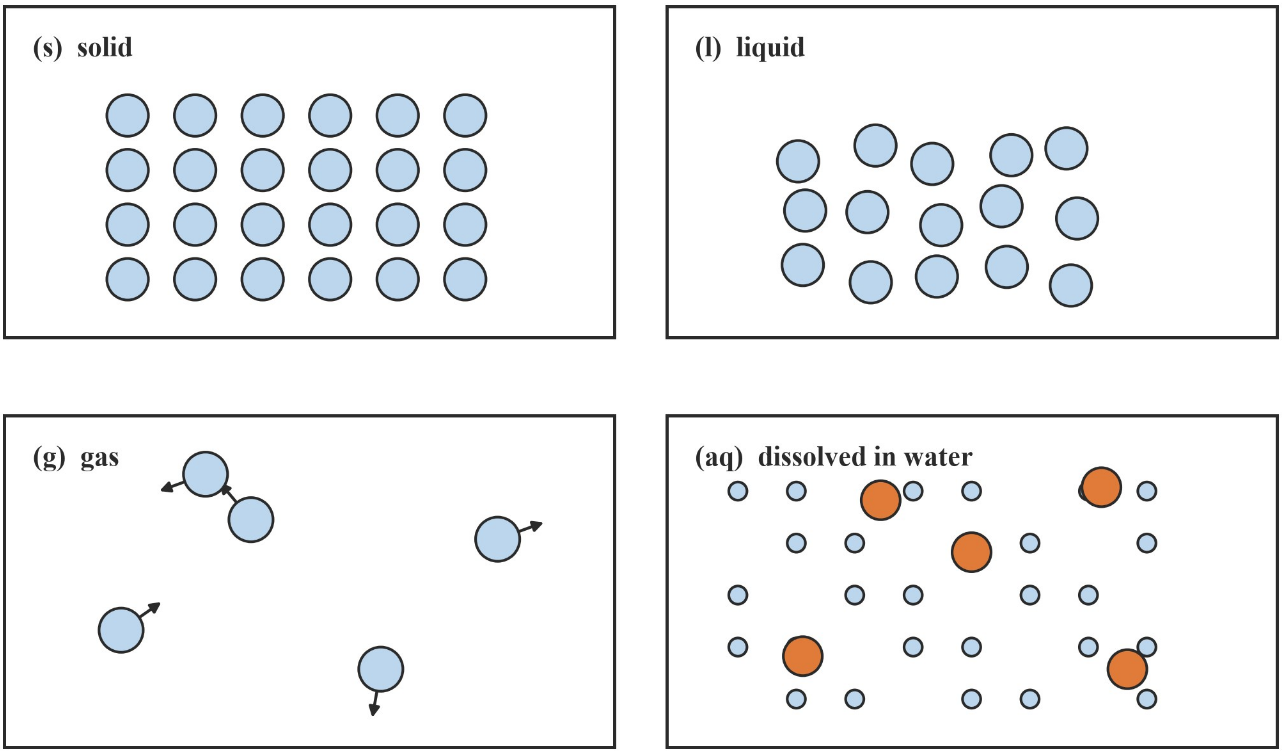
The balanced equation 2Mg plus O2 gives 2MgO shown as a ratio that scales. Rows show 2 to 1 to 2 at the particle level, then 20 to 10 to 20, then 2 billion to 1 billion to 2 billion, with the caption that the ratio never changes, so a balanced equation works for any size batch.

Reading coefficients this way is what makes equations useful beyond the page: a chemist making a batch of anything works from these ratios. This book stops at counting particles — the next step, using equations to calculate masses, belongs to later study (see *Where this leads*).

One step further — state symbols. Symbol equations can also record the physical state of each substance, using four short symbols written in brackets after each formula:

symbol	meaning	particle picture
(s)	solid	particles packed in a fixed arrangement
(l)	liquid	particles close but free to move
(g)	gas	particles far apart, moving freely
(aq)	dissolved in water	particles spread through water

State symbols say what form each substance is in



The four state symbols with small particle sketches. The solid panel shows particles in a fixed regular arrangement, the liquid panel shows particles close together but jumbled, the gas panel shows a few particles far apart with motion arrows, and the aqueous panel shows dissolved particles spread among many small water particles.

Magnesium burning, with states, reads **$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$**: solid magnesium reacts with oxygen gas to form solid magnesium oxide. State symbols do not change the balancing — the atom counts are checked exactly as before — but they make an equation say more about what you would actually see.

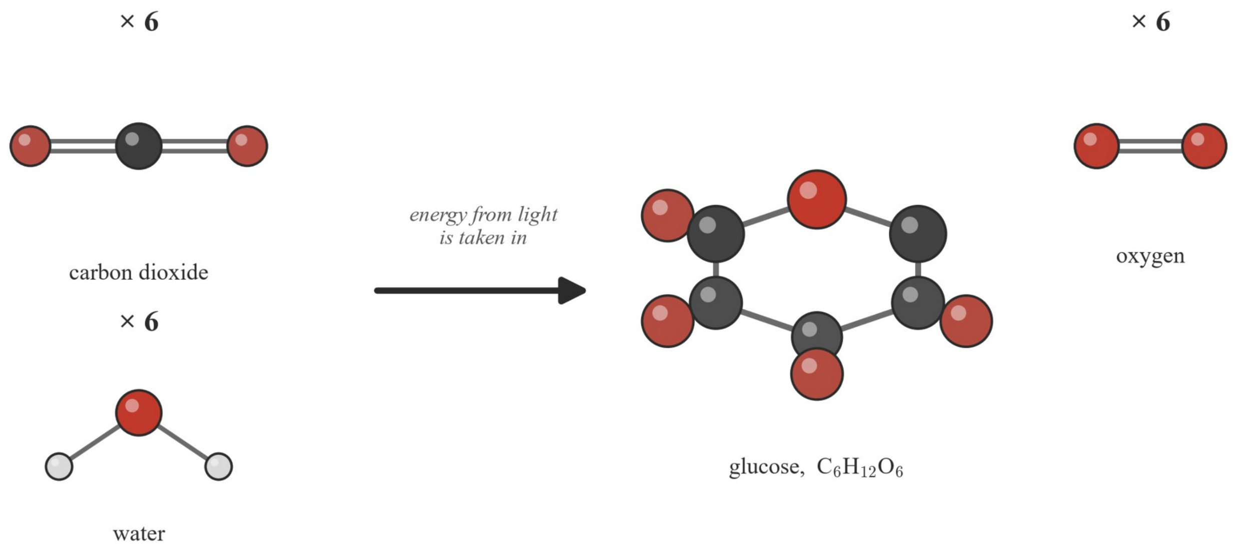
Writing equations that are easy to balance (elaboration `VC2S10U08.E04`). Some equations fight you; most only do so because of a slip in the setup. The habits that make balancing easy:

- **Get every formula right before you start counting.** Most “impossible” equations have one wrong formula — usually a missing 2 on a diatomic element. Check the seven diatomics every time one of them appears.
- **Never edit a formula once it is written.** If the balancing seems to demand it, the error is in a coefficient, not in the formula.
- **Balance one element at a time**, and leave hydrogen and oxygen to the end.
- **If a count comes out odd on one side and even on the other**, put a 2 in front of the formula with the odd count and try again — odd/even mismatches almost always clear with one doubling.
- **Finish by recounting every element**, and reduce the coefficients to the smallest whole numbers that work.

And equations are worth the trouble. The same few rules describe every reaction in this chapter and beyond — from rust forming on a gate to the reactions that power living things. Here is one you will meet again in Subtopic 12A, written with every coefficient in place: photosynthesis, the reaction that builds sugars in green plants.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

A bigger balanced equation: photosynthesis



$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2 \qquad C: 6 = 6 \qquad H: 12 = 12 \qquad O: 18 = 18$$

The balanced equation for photosynthesis drawn with molecule models: six carbon dioxide molecules and six water molecules on the left give one glucose molecule and six oxygen molecules on the right, with tallies showing six carbon atoms, twelve hydrogen atoms and eighteen oxygen atoms on each side.

Activities

Activity 1 — Build it, then balance it (elaboration `VC2S10U08.E04`). Using a molecular model kit — or coloured paper circles as atoms — build the reactants for hydrogen burning: two H_2 molecules and one O_2 molecule. Take them apart and re-join every atom into water molecules, using every atom with none left over. (a) Draw what you built on each side. (b) Write the balanced symbol equation. (c) Count the atoms of each element on both sides to show the equation is balanced. Repeat the whole process for methane burning, $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$, where the model makes the oxygen count visible: the products need 4 oxygen atoms, so the reactants must supply 2 O_2 molecules.

Activity 2 — Match and balance (elaboration `VC2S10U08.E04`). Work in pairs with a set of cards: one set carries word equations, the other carries the same reactions as symbol equations. Match each word equation to its symbol equation, then balance every symbol equation and check your balancing with an atom tally for each element. Swap sets with another pair and mark each other's tallies: every count must match on both sides before a card is put away.

Activity 3 — Heating copper(II) carbonate (elaboration `VC2S10U08.E04`). Heat a small spatula measure of green copper(II) carbonate in a test tube fitted with a delivery tube whose end stands in limewater. Record what you see of the solid and of the limewater. (a) Write the word equation for the reaction. (b) Write the symbol equation using the formula table in this subtopic, and show by an atom tally that it is balanced. (c) Explain how the limewater result identifies the gas. Wear eye protection; the glass stays hot after heating, and the teacher should set up and dispense the chemicals following Science ASSIST (ASTA) safety guidance.

Activity 4 — Zinc and dilute acid (elaboration `VC2S10U08.E04`). Add a few pieces of zinc to dilute hydrochloric acid in a test tube and collect some of the gas given off. Test it with a lit splint: a squeaky pop identifies hydrogen. (a) Write the word equation. (b) Write and balance the symbol equation. (c) Show the atom tally that proves your equation is balanced, and name the element whose atoms pair up to leave as a gas. Wear eye protection; dilute hydrochloric acid is an irritant, and hydrogen is flammable, so keep the collecting tube — not the reaction tube — near the flame and use small quantities. The teacher should prepare and dispense the acid following Science ASSIST (ASTA) safety guidance.

Worked examples

Example 1 — scaffolded

Magnesium ribbon burns in air with a bright white light, forming white magnesium oxide powder. (a) Write the word equation. (b) Write the skeleton symbol equation, replacing each name with its formula. (c) Balance the symbol equation, showing an atom count for each element. (d) Add state symbols to your balanced equation.

Working	Comment
(a) magnesium + oxygen → magnesium oxide	Reactants left, product right, arrow towards the product.
(b) $Mg + O_2 \rightarrow MgO$	Oxygen is diatomic — O_2, not O. The formulas are now fixed.
Left: Mg 1, O 2. Right: Mg 1, O 1	The oxygen count does not match, so the equation is unbalanced.
Put 2 in front of MgO: $Mg + O_2 \rightarrow 2MgO$	Now the right holds 2 O atoms — but also 2 Mg atoms.
Put 2 in front of Mg: $\mathbf{2Mg + O_2 \rightarrow 2MgO}$	Recount: Mg 2 = 2, O 2 = 2. Every count matches.

(d) $\mathbf{2Mg(s) + O_2(g) \rightarrow 2MgO(s)}$ — magnesium is a solid, oxygen a gas, magnesium oxide a solid.

Example 2 — scaffolded

Methane, the gas burned in a Bunsen burner, reacts with oxygen to form carbon dioxide and water. Balance the skeleton equation, one element at a time:

$CH_4 + O_2 \rightarrow CO_2 + H_2O$

Working	Comment
C: left 1, right 1	Carbon is already even — leave it.
H: left 4, right 2	Put 2 in front of H_2O: $CH_4 + O_2 \rightarrow CO_2 + \mathbf{2}H_2O$ gives 4 H on the right.
O: right now 2 + 2 = 4	Count the right carefully: CO_2 contributes 2, and $2H_2O$ contributes 2 more.
Left needs 4 O: put 2 in front of O_2	$\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$
Recount: C 1 = 1, H 4 = 4, O 4 = 4	Every count matches — the equation is balanced.

Notice the order: carbon first, hydrogen second, oxygen last — and the oxygen count was taken from *both* products together.

Example 3 — unscaffolded

Hydrogen peroxide slowly breaks down into water and oxygen — the reaction a catalyst can speed up, which you will meet in Subtopic 11D. (a) Write the word equation. (b) Write the balanced symbol equation. (c) Show by an atom tally that your equation is balanced.

(a) hydrogen peroxide → water + oxygen. One reactant, two products.
(b) $\mathbf{2H_2O_2 \rightarrow 2H_2O + O_2}$**.** Oxygen is a product in its diatomic form, O_2 — not O.
(c) Left: H = 2 × 2 = 4; O = 2 × 2 = 4. Right: H = 2 × 2 = 4; O = (2 × 1) + 2 = 4. Both elements match, so the equation is balanced.

Example 4 — unscaffolded

Two students balance the reaction of aluminium with oxygen, in which aluminium oxide, Al_2O_3, forms. Student A writes: $Al + O_2 \rightarrow AlO_2$ Student B writes: $4Al + 3O_2 \rightarrow 2Al_2O_3$ (a) Decide which student is correct, and verify the answer with an atom tally. (b) Explain exactly what the other student did wrong.

(a) Student B. Tally for $4Al + 3O_2 \rightarrow 2Al_2O_3$: left Al = 4, O = 3 × 2 = 6; right Al = 2 × 2 = 4, O = 2 × 3 = 6. Every count matches, and the formulas are the real substances — aluminium is Al, oxygen is O_2, aluminium oxide is Al_2O_3.

(b) Student A changed the formula of the product to AlO_2 to make the counts match. That breaks the one rule of balancing: formulas are fixed, because changing a subscript changes the substance. AlO_2 is not aluminium oxide. Coefficients alone may be adjusted — which is exactly what Student B did.

Practice questions

Scaffolded questions

Question 1 Reading a word equation. Consider: calcium carbonate + hydrochloric acid → calcium chloride + water + carbon dioxide (a) Name the reactants. (b) Name the products. (c) State what the plus signs and the arrow are read as. (d) Write the equation as a sentence.

Question 2 Reading formulas. (a) How many atoms of each element are in one molecule of CO_2? (b) How many atoms of each element are in one molecule of H_2O_2? (c) In $3CO_2$, how many carbon atoms and how many oxygen atoms are there altogether? (d) State what a coefficient in front of a formula multiplies.

Question 3 The diatomic seven. (a) Name the seven elements whose atoms always live in pairs. (b) Write the formula for oxygen gas and for nitrogen gas. (c) Explain why writing the oxygen in air as O rather than O_2 would be wrong.

Question 4 From words to symbols. Write the skeleton symbol equation (unbalanced is fine here; use the formula table in this subtopic) for each: (a) sodium + chlorine → sodium chloride (b) zinc + hydrochloric acid → zinc chloride + hydrogen (c) copper + oxygen → copper(II) oxide

Question 5 Balance with a table. Copy and complete the atom tally, then write the balanced equation for hydrogen reacting with chlorine to form hydrogen chloride, HCl: $H_2 + Cl_2 \rightarrow HCl$

element	atoms on the left	atoms on the right
H	2	?
Cl	2	?

Question 6 Balance these. (a) $Na + Cl_2 \rightarrow NaCl$ (b) $Zn + HCl \rightarrow ZnCl_2 + H_2$ (c) $Fe + S \rightarrow FeS$ — state what you changed, if anything. (d) $Cu + O_2 \rightarrow CuO$

Unscaffolded questions

Question 7 Balance these equations. (a) $Al + O_2 \rightarrow Al_2O_3$ (b) $CH_4 + O_2 \rightarrow CO_2 + H_2O$ (c) $Fe + O_2 \rightarrow Fe_2O_3$ (d) $H_2O_2 \rightarrow H_2O + O_2$

Question 8 The subscript trap. A student asked to balance hydrogen + oxygen → water writes $H_2 + O_2 \rightarrow H_2O_2$, and points out that the atom counts now match. Find the error and write the correct balanced equation.

Question 9 Coefficients as ratios. For $2H_2 + O_2 \rightarrow 2H_2O$: (a) State the ratio hydrogen : oxygen : water. (b) If 40 molecules of hydrogen react, how many molecules of oxygen are needed, and how many molecules of water form? (c) Explain why the same ratio holds no matter how large the batch.

Question 10 A big equation. Photosynthesis is written $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. (a) Tally the atoms of carbon, hydrogen and oxygen on each side to verify the equation is balanced. (b) How many molecules of carbon dioxide are needed for each molecule of glucose, $C_6H_{12}O_6$? (c) Explain why 6, 6, 1 and 6 are the smallest whole-number coefficients that work.

Question 11 Write from descriptions. For each reaction write the word equation and the balanced symbol equation. (a) Iron burns in oxygen, forming iron(III) oxide. (b) Copper(II) carbonate breaks down when heated, forming copper(II) oxide and carbon dioxide.

Question 12 State symbols. (a) State the meaning of (s), (l), (g) and (aq). (b) Add state symbols to $2Mg + O_2 \rightarrow 2MgO$. (c) Add state symbols to $CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$, given that calcium carbonate is a solid, hydrochloric acid and calcium chloride are dissolved in water, and carbon dioxide is a gas.

Question 13 Why equations must balance. (a) Use an atom tally on $H_2 + Cl_2 \rightarrow 2HCl$ to explain how a balanced equation agrees with the Law of Conservation of Mass. (b) State what an unbalanced equation would claim that cannot happen in a real reaction. (c) Explain why an unbalanced equation cannot be fixed by changing a subscript.

Question 14 From a particle model. A model shows one molecule made of two blue atoms joined (nitrogen) and three molecules each made of two white atoms joined (hydrogen). They react to form two molecules, each made of one blue atom joined to three white atoms (ammonia). (a) Write the formula of each substance. (b) Write the balanced symbol equation. (c) Verify your equation with an atom tally.

Question 15 The propane challenge. Propane, C_3H_8, burns in oxygen to form carbon dioxide and water. Balance $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$ and show the full atom tally that proves your answer.

Question 16 Reading back. Consider $2Cu + O_2 \rightarrow 2CuO$. (a) Write the word equation. (b) Count the atoms of each element on both sides. (c) State the coefficient ratio copper : oxygen : copper(II) oxide. (d) A student heats copper in air and finds the product weighs more than the copper did. They claim mass has been created. Evaluate the claim using the Law of Conservation of Mass.

Answers

Question 1 (a) calcium carbonate, hydrochloric acid; (b) calcium chloride, water, carbon dioxide; (c) “reacts with” / “produces”; (d) see solution. **Question 2** (a) C 1, O 2; (b) H 2, O 2; (c) C 3, O 6; (d) everything in the formula behind it. **Question 3** (a) see solution; (b) O_2, N_2; (c) see solution. **Question 4** (a) $Na + Cl_2 \rightarrow NaCl$; (b) $Zn + HCl \rightarrow ZnCl_2 + H_2$; (c) $Cu + O_2 \rightarrow CuO$. **Question 5** right side H 1, Cl 1; balanced: $H_2 + Cl_2 \rightarrow 2HCl$. **Question 6** (a) $2Na + Cl_2 \rightarrow 2NaCl$; (b) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$; (c) nothing — already balanced; (d) $2Cu + O_2 \rightarrow 2CuO$. **Question 7** (a) $4Al + 3O_2 \rightarrow 2Al_2O_3$; (b) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$; (c) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$; (d) $2H_2O_2 \rightarrow 2H_2O + O_2$. **Question 8** see solution (subscript changed — different substance); $2H_2 + O_2 \rightarrow 2H_2O$. **Question 9** (a) 2 : 1 : 2; (b) 20 O_2, 40 H_2O; (c) see solution. **Question 10** (a) C 6 = 6, H 12 = 12, O 18 = 18; (b) 6; (c) see solution. **Question 11** (a) iron + oxygen → iron(III) oxide; $4Fe + 3O_2 \rightarrow 2Fe_2O_3$; (b) copper(II) carbonate → copper(II) oxide + carbon dioxide; $CuCO_3 \rightarrow CuO + CO_2$. **Question 12** (a) see solution; (b) $2Mg(s) + O_2(g) \rightarrow 2MgO(s)$; (c) see solution. **Question 13** (a)–(c) see solution. **Question 14** (a) N_2, H_2, NH_3; (b) $N_2 + 3H_2 \rightarrow 2NH_3$; (c) see solution. **Question 15** $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$; see solution for the tally. **Question 16** (a) copper + oxygen → copper(II) oxide; (b) Cu 2 = 2, O 2 = 2; (c) 2 : 1 : 2; (d) see solution.

Fully-worked solutions

Question 1 (a) The reactants are **calcium carbonate** and **hydrochloric acid** — the substances on the left of the arrow. (b) The products are **calcium chloride**, **water** and **carbon dioxide** — the substances on the right of the arrow. (c) Each plus sign reads as **“reacts with”** (or “and”); the arrow reads as **“produces”** (or “forms”). (d) *Calcium carbonate reacts with hydrochloric acid to produce calcium chloride, water and carbon dioxide.*

Question 2 (a) One molecule of CO_2 holds **1 carbon atom and 2 oxygen atoms**. (b) One molecule of H_2O_2 holds **2 hydrogen atoms and 2 oxygen atoms**. (c) The coefficient 3 multiplies everything: C = 3 × 1 = **3 carbon atoms**; O = 3 × 2 = **6 oxygen atoms**. (d) A coefficient multiplies **every atom in the formula behind it** — the whole molecule or formula unit, not just the first element.

Question 3 (a) **Hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine and iodine.** (b) Oxygen gas is $\mathbf{O_2}$; nitrogen gas is $\mathbf{N_2}$. (c) Oxygen in the air exists as pairs of joined atoms, O_2 — that is the substance itself. A lone O would describe single oxygen atoms, which is not the form oxygen takes in ordinary conditions, so any equation using O for the oxygen in air starts from a wrong formula.

Question 4 (a) $\mathbf{Na + Cl_2 \rightarrow NaCl}$ — chlorine is diatomic, Cl_2. (b) $\mathbf{Zn + HCl \rightarrow ZnCl_2 + H_2}$ — hydrogen leaves as diatomic H_2. (c) $\mathbf{Cu + O_2 \rightarrow CuO}$ — oxygen is O_2. These are skeletons; each still needs balancing (sodium + chlorine becomes $2Na + Cl_2 \rightarrow 2NaCl$, and so on).

Question 5 The right side of $H_2 + Cl_2 \rightarrow HCl$ holds **1 H atom and 1 Cl atom** — one of each short. Placing a coefficient 2 in front of HCl gives 2 H and 2 Cl on the right, matching the left: $\mathbf{H_2 + Cl_2 \rightarrow 2HCl}$.

Question 6 (a) $\mathbf{2Na + Cl_2 \rightarrow 2NaCl}$ — the 2 in front of NaCl fixes the chlorine count, and the extra sodium atom is added to the left. (b) $\mathbf{Zn + 2HCl \rightarrow ZnCl_2 + H_2}$ — zinc and chlorine were already even; the coefficient 2 in front of HCl supplies the second hydrogen atom and the second chlorine atom. (c) $\mathbf{Fe + S \rightarrow FeS}$ — nothing changes: Fe 1 = 1 and S 1 = 1 already. An equation can arrive already balanced, and the correct move is to check it and leave it. (d) $\mathbf{2Cu + O_2 \rightarrow 2CuO}$ — the 2 in front of CuO fixes oxygen and adds a copper atom to the right, which the 2 in front of Cu then matches.

Question 7 (a) $\mathbf{4Al + 3O_2 \rightarrow 2Al_2O_3}$**.** The even/odd trick: oxygen appears as O_2 (always even) but Al_2O_3 holds 3 oxygens (odd), so start with $2Al_2O_3$ to make 6 oxygens, which needs $3O_2$; the aluminium count of 4 then follows. (b) $\mathbf{CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O}$ — carbon first (already even), hydrogen second (2 in front of H_2O), oxygen last (right side holds 2 + 2 = 4, so 2 in front of O_2). (c) $\mathbf{4Fe + 3O_2 \rightarrow 2Fe_2O_3}$ — the same even/odd pattern as (a): $2Fe_2O_3$ gives 6 oxygens and 4 irons, supplied by $3O_2$ and 4Fe. (d) $\mathbf{2H_2O_2 \rightarrow 2H_2O + O_2}$ — left: H 4, O 4; right: H 4, O 2 + 2 = 4.

Question 8 The student changed a **subscript —** the formula of the product became H_2O_2, hydrogen peroxide, which is a different substance from water. Matching counts by editing a formula describes the wrong reaction. The fix must use a coefficient: $\mathbf{2H_2 + O_2 \rightarrow 2H_2O}$, where left H 4 = right H 4 and left O 2 = right O 2, and the product is still water.

Question 9 (a) The coefficients give the ratio **2 : 1 : 2**. (b) Everything doubles when 2 hydrogen molecules become 40: **20 molecules of oxygen** are needed and **40 molecules of water** form. (c) The coefficients count particles in a fixed proportion, and a reaction always joins the same atoms in the same way — 2 molecules of hydrogen always need exactly 1 molecule of oxygen. Scaling the batch up scales every count by the same factor, so the ratio 2 : 1 : 2 holds for any size.

Question 10 (a) Left: C = 6 × 1 = 6; H = 6 × 2 = 12; O = (6 × 2) + (6 × 1) = 18. Right: C = 6; H = 12; O = 6 + (6 × 2) = 18. Every element matches, so the equation is balanced. (b) **6** molecules of carbon dioxide for each molecule of glucose. (c) The four coefficients are 6, 6, 1 and 6. They share no common factor greater than 1 — the 1 in front of glucose makes that certain — so the set cannot be divided through to smaller whole numbers.

Question 11 (a) Word equation: **iron + oxygen → iron(III) oxide**. Symbol equation: **$4Fe + 3O_2 \rightarrow 2Fe_2O_3$** (left: Fe 4, O 6; right: Fe 4, O 6). (b) Word equation: **copper(II) carbonate → copper(II) oxide + carbon dioxide**. Symbol equation: **$CuCO_3 \rightarrow CuO + CO_2$** (left: Cu 1, C 1, O 3; right: Cu 1, C 1, O 1 + 2 = 3) — already balanced.

Question 12 (a) **(s)** solid; **(l)** liquid; **(g)** gas; **(aq)** dissolved in water. (b) **$2Mg(s) + O_2(g) \rightarrow 2MgO(s)$.** (c) **$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$.** The balancing is unchanged — state symbols only record the form each substance is in.

Question 13 (a) Left: H = 2, Cl = 2. Right: H = 2 × 1 = 2, Cl = 2 × 1 = 2. Every atom present at the start is present at the end — none created, none destroyed — which is exactly what the Law of Conservation of Mass says, since mass is carried by those atoms. (b) An unbalanced equation claims that atoms appear from nowhere or vanish during the reaction — and no real reaction can create or destroy an atom. (c) A subscript says which substance a formula describes. Changing one changes the substance itself, so the equation would no longer describe the reaction it was written for. Only coefficients — the numbers of molecules — may be adjusted.

Question 14 (a) Nitrogen **N_2**, hydrogen **H_2**, ammonia **NH_3**. (b) The model shows 1 N_2 and 3 H_2 forming 2 NH_3: **$N_2 + 3H_2 \rightarrow 2NH_3$**. (c) Left: N = 2, H = 3 × 2 = 6. Right: N = 2 × 1 = 2, H = 2 × 3 = 6. Both elements match.

Question 15 $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$. Working: carbon first — 3 on the left, so $3CO_2$; hydrogen second — 8 on the left, so $4H_2O$; oxygen last — the right side now holds (3 × 2) + (4 × 1) = 10 atoms, so $5O_2$ on the left. Tally: C 3 = 3; H 8 = 8; O 10 = 10.

Question 16 (a) **copper + oxygen → copper(II) oxide.** (b) Left: Cu 2, O 2. Right: Cu 2, O 2 — the counts match. (c) **2 : 1 : 2.** (d) The claim is wrong. The extra mass is the mass of the **oxygen from the air** that has joined the copper to make copper(II) oxide. If the oxygen were included in the starting total, the mass before and after would be equal — as the Law of Conservation of Mass requires and as Subtopic 11A showed. Mass has been *added from the air*, not created.

Where this leads: the balanced equation taught here is the object every later calculation in chemistry operates on. In VCE Chemistry Unit 1, Area of Study 2 ("How are materials quantified and classified?"), students use balanced equations to calculate amounts and masses; that work assumes the equation is already balanced and the coefficients can be read as a ratio. Those calculations sit above this book's ceiling and are not taught here (TOC D9); the ratio-reading skill built in this subtopic (Maths interlock `VC2M9M05`) is the preparation for them. Within this book, Subtopic 11A delivers the other limb of `VC2S10U08` — the Law of Conservation of Mass and the rearrangement of atoms — that gives balancing its reason; Subtopic 11C sorts the reactions of this chapter into types and re-uses every equation written here; and Subtopic 12A takes the photosynthesis equation further as part of the carbon cycle. The investigation skills practised in Activities 3 and 4 feed directly into SIT-2, the full investigation report that follows this chapter.

Reaction types: synthesis, decomposition and displacement

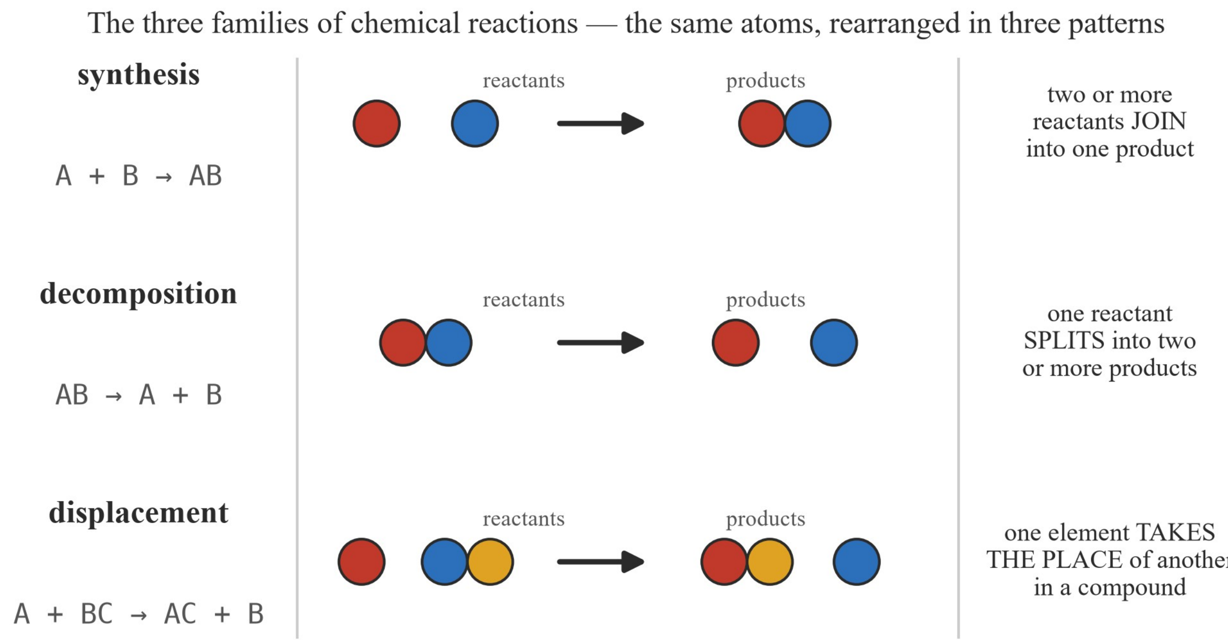
Chapter 11 — Chemical sciences B: chemical reactions (Science, Levels 9 and 10)

Subtopic 11C · VC2 Science Understanding — Chemical sciences

CD code: `VC2S10U09` (split delivery †; this subtopic is the accountable owner) **Content description (verbatim):** "chemical reactions include synthesis, decomposition and displacement reactions and can be classified as exothermic or endothermic; reaction rates are affected by factors including temperature, concentration, surface area of solid reactants, and catalysts" **This subtopic's limb (TOC §4 clause split):** synthesis, decomposition and displacement reactions — their definitions, representations and examples. The partner `11D` delivers the other limb: exothermic/endothermic classification and rate factors. **Elaboration ids drawn on:** `VC2S10U09.E01` · `VC2S10U09.E02` · `VC2S10U09.E03` (ids `VC2S10U09.E04` and `VC2S10U09.E05` are drawn on by Subtopic 11D; ids `VC2S10U09.E06` and `VC2S10U09.E07` are not authored, under the TOC's D10 ICIP decision) **Achievement standard (extract):** "They classify energy changes in chemical reactions as exothermic or endothermic." — this extract is served by the partner, Subtopic 11D; 11C builds the reaction types that classification sorts.

Theory

Sorting reactions into families. In Subtopic 11A you saw that a chemical reaction rearranges atoms: the **reactants** (the starting substances) are taken apart, and their atoms rejoin in new combinations to form the **products** (the new substances). No atoms are made or destroyed in the process. Reactions can be sorted into families by comparing their reactants and products, and this subtopic teaches the three families named in the curriculum: **synthesis**, **decomposition** and **displacement**.



Three rows of atom tokens, one row per family. The synthesis row shows a red atom and a blue atom joining into one bonded pair. The decomposition row shows one bonded pair splitting into a separate red atom and a separate blue atom. The displacement row shows a red atom plus a bonded blue-and-amber pair becoming a bonded red-and-amber pair plus a separate blue atom. Each row is labelled with its family name and its general pattern.

The three patterns, in short:

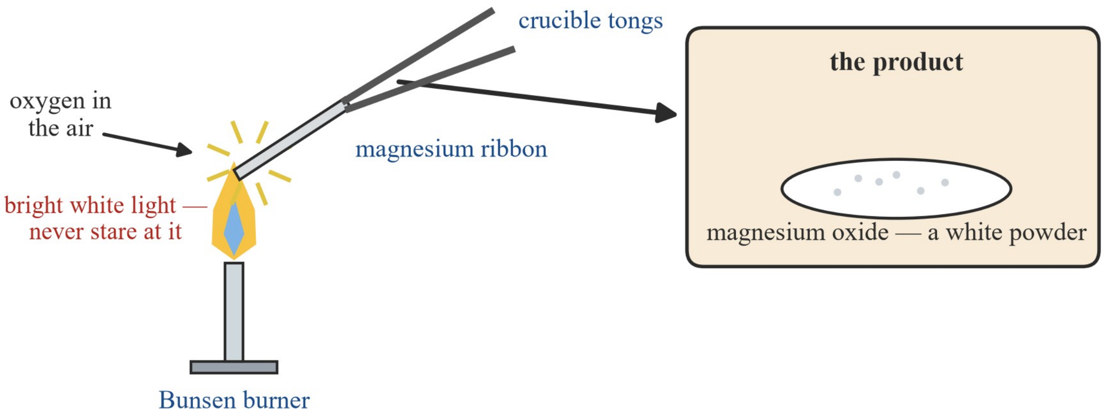
- **synthesis** — two or more reactants join to form a single product (A + B → AB);
- **decomposition** — a single reactant splits into two or more products (AB → A + B);
- **displacement** — one element takes the place of another in a compound (A + BC → AC + B).

Every reaction in this subtopic is one of these three. Whether a reaction also gives out or takes in energy is a separate question, and belongs to Subtopic 11D.

Synthesis reactions. A **synthesis** reaction is a reaction in which two or more substances join to form a single new substance. The reactants may be elements or simple compounds; the product is one, more complex substance. Three familiar examples follow.

Metals with oxygen. When magnesium burns, each magnesium atom joins with oxygen from the air to form the single product magnesium oxide — a white powder.

A synthesis reaction: magnesium and oxygen join to form one product



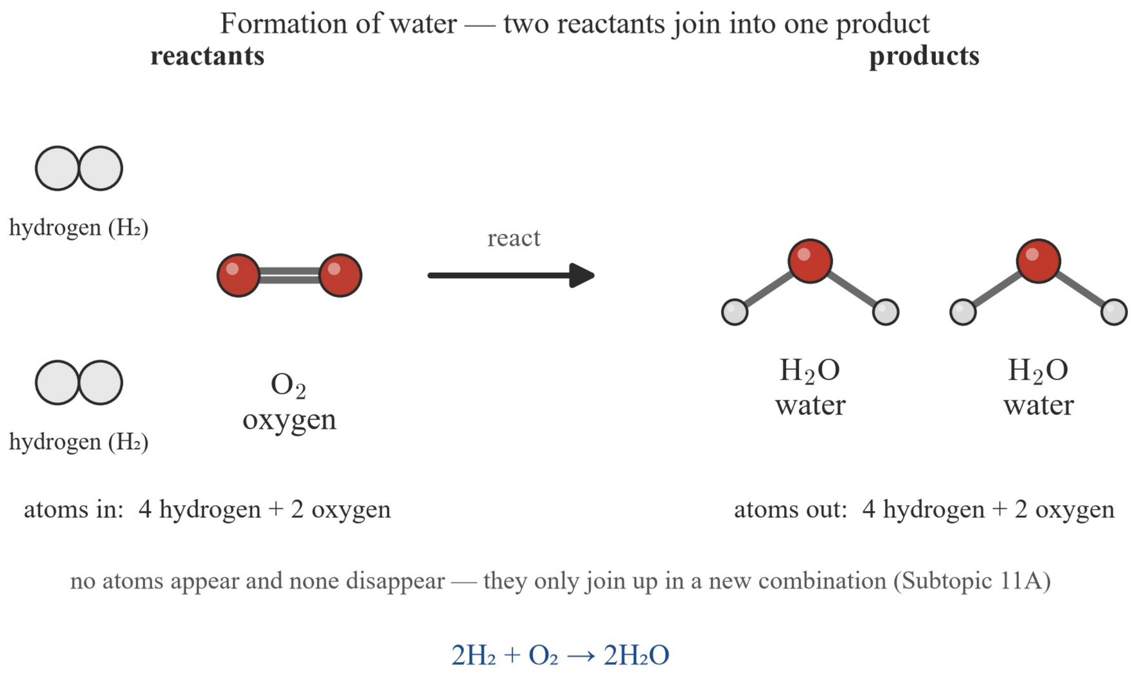
magnesium + oxygen → magnesium oxide

$2Mg + O_2 \rightarrow 2MgO$ — a synthesis reaction

A labelled lab sketch. Crucible tongs hold a magnesium ribbon in a Bunsen burner flame; the ribbon gives out bright white light, and oxygen from the air joins the reaction. The product panel shows magnesium oxide as a white powder. The word equation reads magnesium plus oxygen gives magnesium oxide, and the symbol equation reads 2Mg + O2 gives 2MgO.

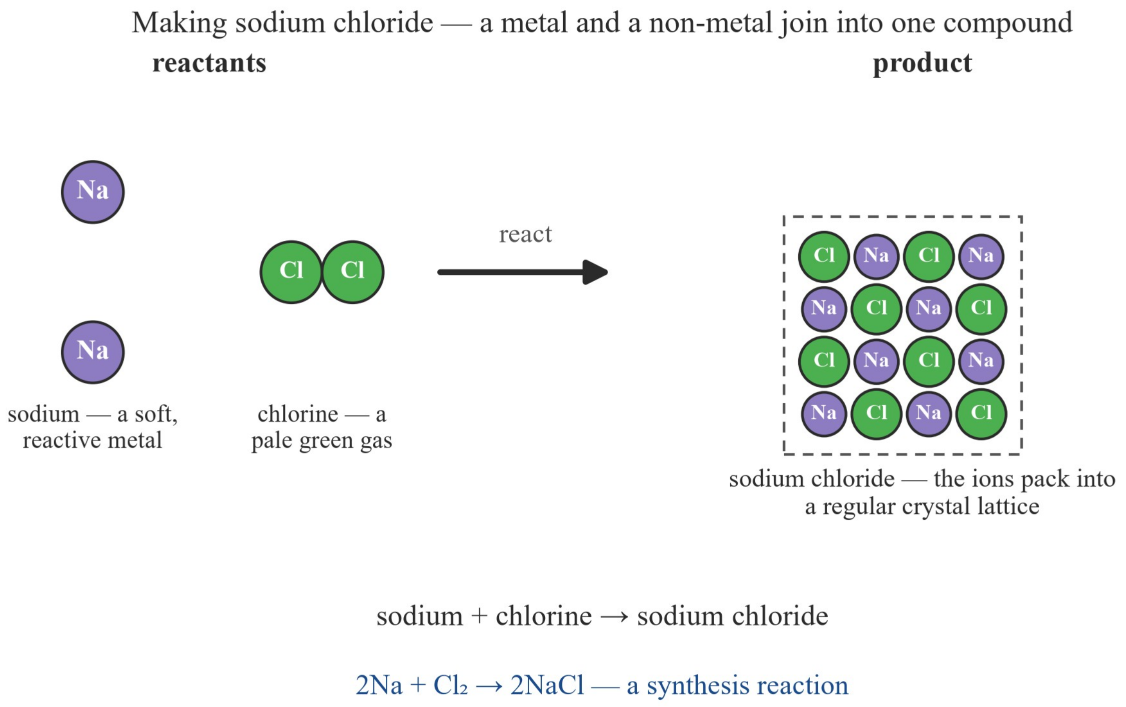
The same pattern holds for other metals: copper heated in air gains a black coat of copper oxide, and iron burns in pure oxygen to form iron oxide. Metal + oxygen → metal oxide is one of the most common synthesis patterns in chemistry. (Never look straight at a burning magnesium ribbon — the white light is far too bright for your eyes.)

Formation of water. Two gases join to make one compound: hydrogen burns in oxygen to form water. The particle view makes the pattern clear — four hydrogen atoms and two oxygen atoms go in, and the same six atoms come out joined up as two water molecules.



A particle model of the formation of water. On the reactant side are two hydrogen molecules, each drawn as two small white atoms bonded together, and one oxygen molecule drawn as two red atoms with a double bond. An arrow leads to the product side: two water molecules, each a red oxygen atom bonded to two white hydrogen atoms at an angle. Tallies below state that four hydrogen atoms and two oxygen atoms enter and the same atoms leave. The balanced equation reads 2H2 + O2 gives 2H2O.

Formation of sodium chloride. A metal and a non-metal can also join into one compound. Sodium is a soft, reactive metal; chlorine is a pale green, poisonous gas. Together they synthesise sodium chloride — ordinary table salt — in which the sodium and chlorine atoms have become charged particles (**ions**) packed into a regular crystal **lattice**.

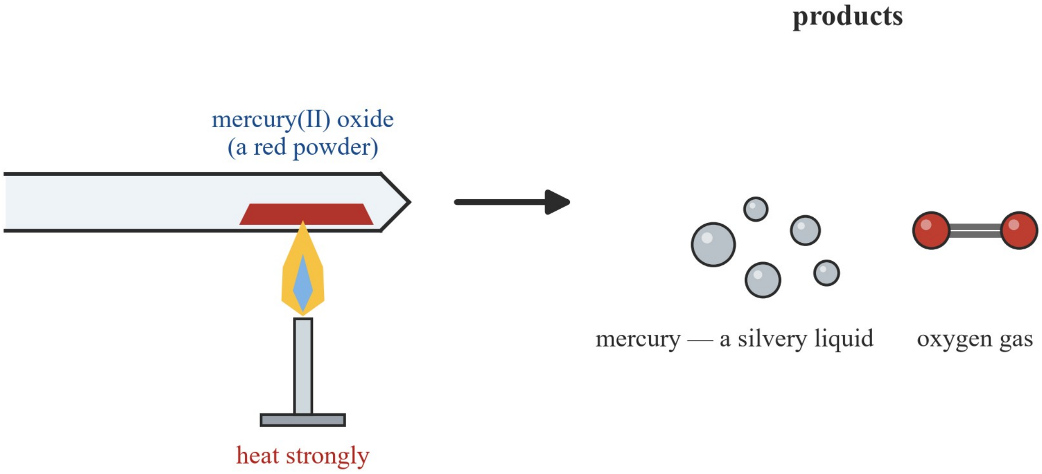


A particle model of sodium chloride forming. On the reactant side are two violet sodium atoms and one chlorine molecule drawn as two green atoms bonded together. An arrow leads to the product: a four-by-four grid of *alternating violet sodium ions and green chloride ions inside a dashed square, labelled as the regular crystal lattice of sodium chloride. The balanced equation reads 2Na + Cl2 gives 2NaCl.*

Decomposition reactions. A **decomposition** reaction is the reverse pattern: a single compound splits into two or more simpler substances. Decomposition usually needs a continuous supply of energy to keep going, delivered as heat (thermal decomposition), electricity (electrolysis) or light.

Winning metals from their compounds. Some metals are extracted from their compounds by decomposition. Strongly heating the red powder mercury(II) oxide splits it into the silvery liquid metal mercury and oxygen gas. In the 1770s this was one of the first reactions used to win a metal from its compound — and the reaction that first showed chemists that air contains oxygen.

Decomposition can win a metal from its compound



$2HgO \rightarrow 2Hg + O_2$ — a decomposition reaction

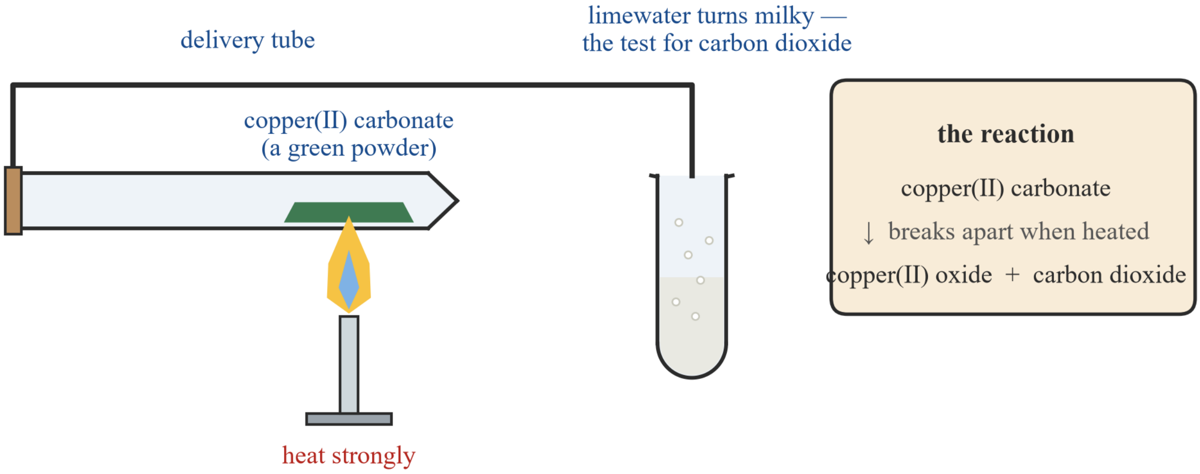
Heating mercury(II) oxide was one of the first ways chemists won a metal from a compound — and the reaction that first revealed oxygen gas in the 1770s

A labelled sketch. A tube of red mercury(II) oxide powder is heated strongly by a Bunsen burner. An arrow leads to the products: a cluster of silvery drops labelled mercury, a silvery liquid metal, and one oxygen molecule drawn as two red atoms, labelled oxygen gas. The balanced equation reads 2HgO gives 2Hg + O2.

On the industrial scale, aluminium is won the same way in principle: electricity splits molten aluminium oxide into aluminium metal and oxygen gas ($2Al_2O_3 \rightarrow 4Al + 3O_2$). Australian aluminium smelters run this decomposition day and night.

Carbonates break down when heated. Metal carbonates decompose on strong heating into a metal oxide plus carbon dioxide. The classic school test uses green copper(II) carbonate: the gas given off turns limewater milky, which identifies it as carbon dioxide, and the green powder leaves a black residue of copper(II) oxide.

Thermal decomposition of copper(II) carbonate — heat splits one compound in two



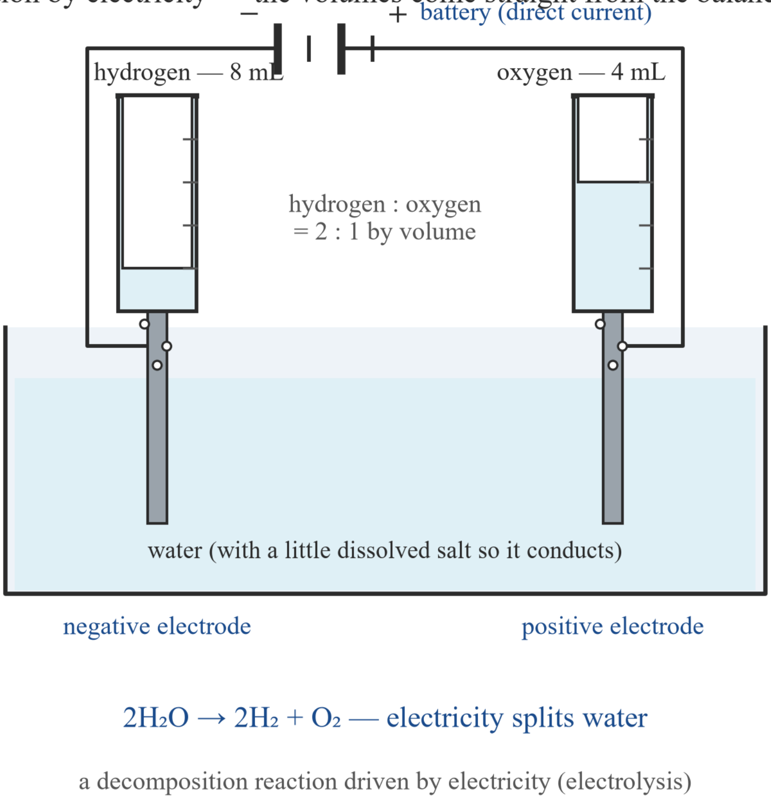
$CuCO_3 \rightarrow CuO + CO_2$ — one reactant splits into two products

a thermal decomposition reaction

A labelled lab sketch of thermal decomposition. A horizontal hard-glass tube holds green copper(II) carbonate powder at its closed end, heated strongly by a Bunsen burner. A delivery tube leads from the open end, through a bung, down into a second tube of limewater, which turns milky — the test for carbon dioxide. A panel gives the reaction: copper(II) carbonate breaks apart when heated into copper(II) oxide plus carbon dioxide. The symbol equation reads CuCO3 gives CuO + CO2.

Water split by electricity. Passing electricity through water decomposes it into its two elements, hydrogen and oxygen. The volumes of gas collected tell the story of the balanced equation: twice as much hydrogen as oxygen, because each water molecule holds two hydrogen atoms for every one oxygen atom.

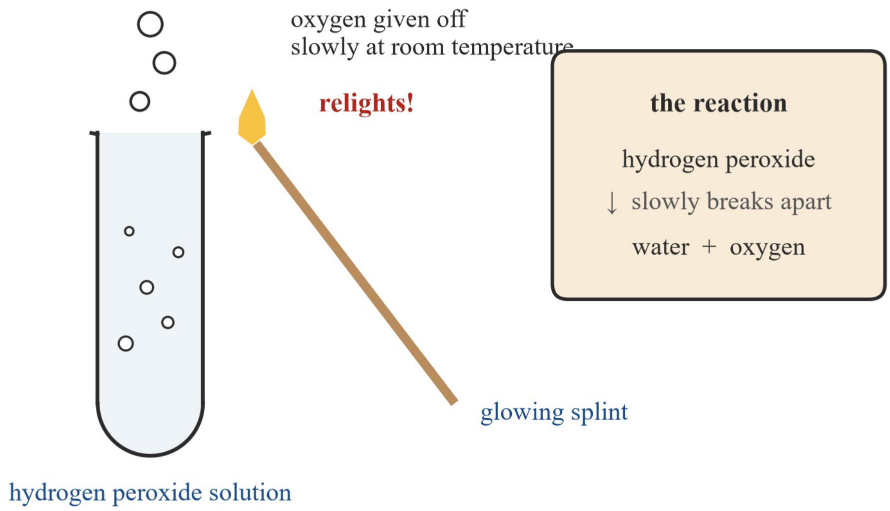
Decomposition by electricity — the volumes come straight from the balanced equation



A labelled lab sketch of the electrolysis of water. A beaker of water holds two electrodes connected by wires to a battery. An inverted collecting tube over the negative electrode holds 8 mL of hydrogen; a second tube over the positive electrode holds 4 mL of oxygen, and a note states the ratio is two to one by volume, taken straight from the balanced equation 2H2O gives 2H2 + O2.

Hydrogen peroxide falls apart. Hydrogen peroxide slowly decomposes at room temperature into water and oxygen, which is why it is stored in dark bottles. The oxygen given off can be caught and tested: a glowing splint held in the gas relights.

Hydrogen peroxide decomposes — the glowing splint proves the gas is oxygen



$2H_2O_2 \rightarrow 2H_2O + O_2$ — a decomposition reaction

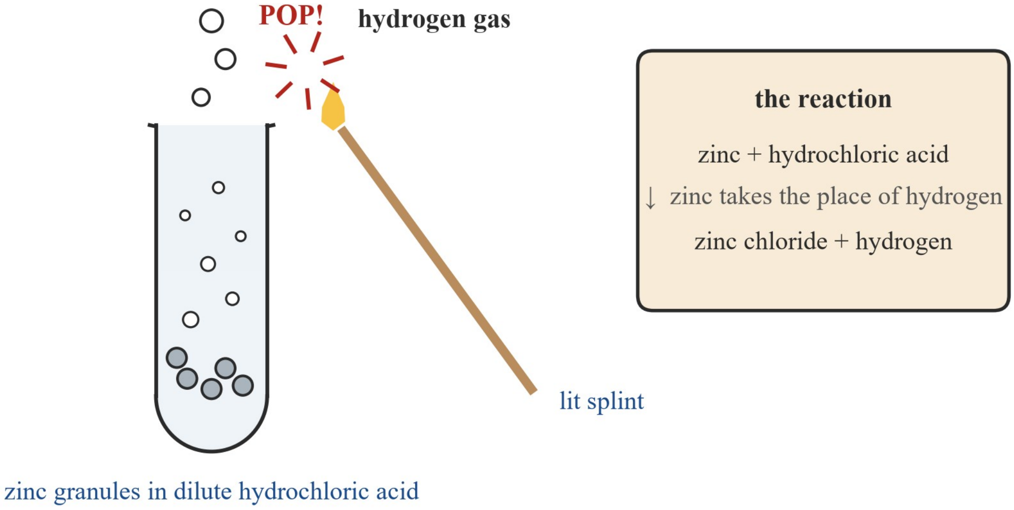
Subtopic 11D shows how a catalyst can speed this same reaction up

A labelled lab sketch. A tube of hydrogen peroxide solution gives off bubbles of oxygen slowly at room temperature; a glowing splint held at the mouth of the tube relights. A panel gives the reaction: hydrogen peroxide slowly breaks apart into water plus oxygen. The balanced equation reads 2H2O2 gives 2H2O + O2. A note says Subtopic 11D shows how a catalyst can speed this same reaction up.

Displacement reactions. In a **displacement** reaction, one element takes the place of another element in a compound. The pattern is A + BC → AC + B: element A pushes element B out of its compound and bonds with C instead. Whether a metal can displace another depends on **reactivity** — how easily a substance reacts. In every example in this book you are told which element is the more reactive; the more reactive one wins the place.

Metals with acids. Zinc is more reactive than hydrogen, so zinc pushes the hydrogen out of hydrochloric acid: the metal slowly disappears, the tube fizzes, and the gas given off burns with a squeaky pop when a lit splint is held to it — the test for hydrogen. The compound left in solution is zinc chloride.

A metal with an acid — zinc displaces hydrogen



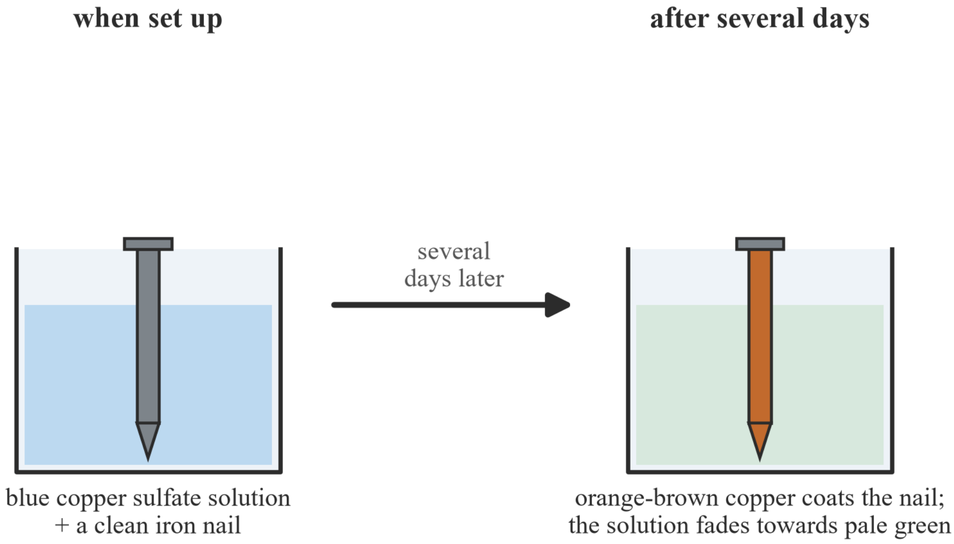
$Zn + 2HCl \rightarrow ZnCl_2 + H_2$ — a displacement reaction

hydrogen is pushed out of the acid by a more reactive metal

A labelled lab sketch. A tube holds zinc granules in dilute hydrochloric acid; bubbles of hydrogen rise and a lit splint at the mouth gives a pop. A panel gives the reaction: zinc plus hydrochloric acid, with zinc taking the place of hydrogen, gives zinc chloride plus hydrogen. The balanced equation reads Zn + 2HCl gives ZnCl2 + H2.

One metal displacing another. Iron is more reactive than copper. Drop a clean iron nail into blue copper sulfate solution and the iron slowly pushes the copper out of its compound: the nail gains an orange-brown coat of copper, and the solution fades towards the pale green of iron sulfate.

Displacement in action — iron pushes copper out of its compound



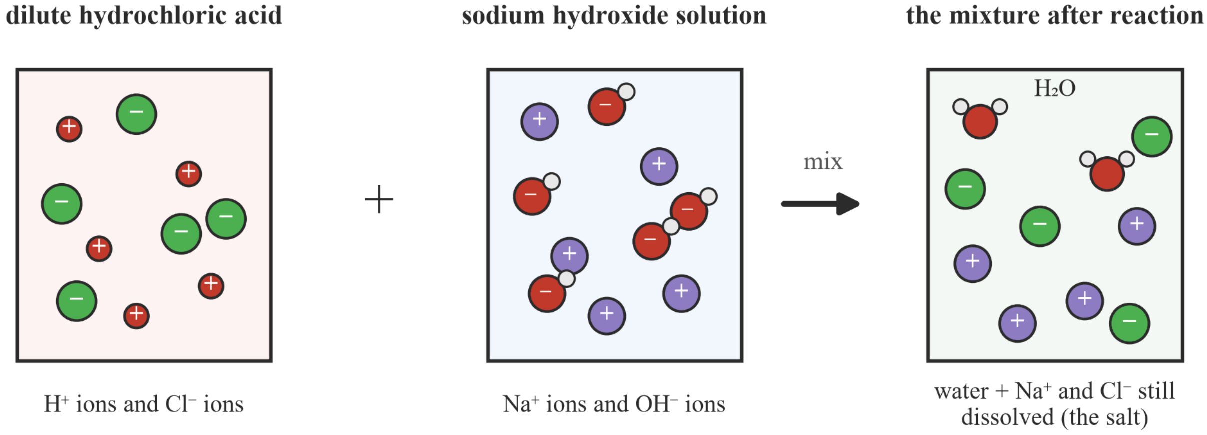
iron + copper sulfate → copper + iron sulfate

$Fe + CuSO_4 \rightarrow Cu + FeSO_4$ — iron, the more reactive metal, displaces copper

Two labelled panels. The first shows a clean grey iron nail standing in a beaker of blue copper sulfate solution when set up. The second, several days later, shows the same nail coated orange-brown with copper while the solution has faded towards pale green. The word equation reads iron plus copper sulfate gives copper plus iron sulfate; the symbol equation reads Fe + CuSO4 gives Cu + FeSO4.

Neutralisation. Acids and alkalis (bases that dissolve in water) are made of ions in solution. Dilute hydrochloric acid holds hydrogen ions (H^+) and chloride ions (Cl^-); sodium hydroxide solution holds sodium ions (Na^+) and hydroxide ions (OH^-). When the two solutions mix, the partners swap: each hydrogen ion joins a hydroxide ion to form water, the new substance, while the sodium and chloride ions remain dissolved as the salt sodium chloride. The ions have displaced one another's partners, so neutralisation belongs to the displacement family.

Neutralisation — the ions swap partners, and water is the new substance

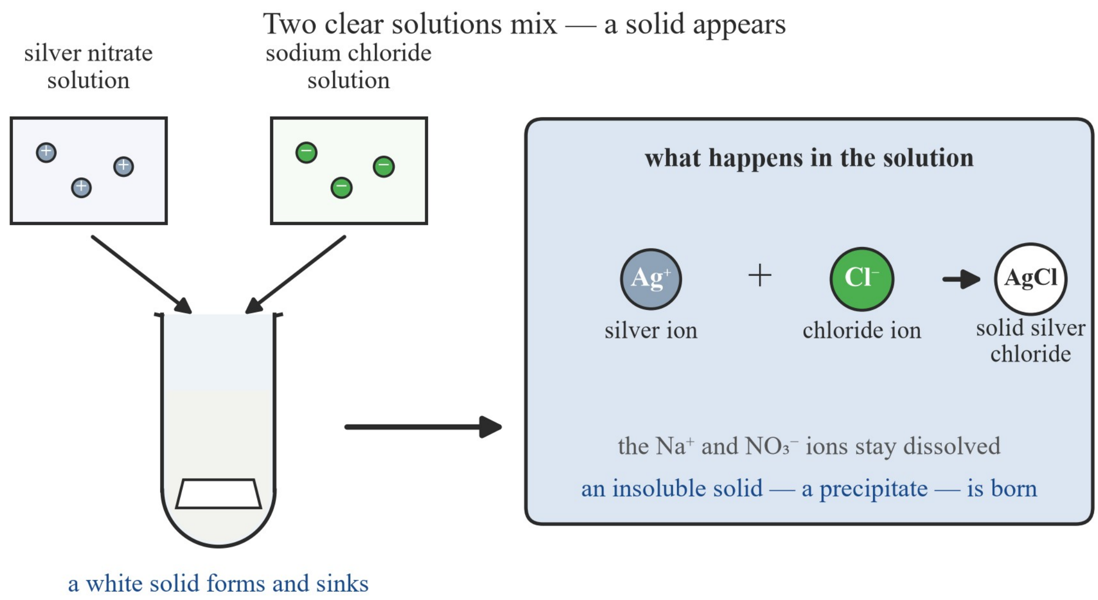


$HCl + NaOH \rightarrow NaCl + H_2O$ — a neutralisation reaction

each H^+ ion joins an OH^- ion to make water — the other ions stay in solution

Three labelled panels of ions in beakers. The first, dilute hydrochloric acid, holds small red positive hydrogen ions and green negative chloride ions. The second, sodium hydroxide solution, holds violet positive sodium ions and negative hydroxide ions drawn as a red oxygen with one white hydrogen. After mixing, the third beaker holds water molecules plus the sodium and chloride ions still dissolved as the salt. The equation reads HCl + NaOH gives NaCl + H2O.

Precipitation. Two clear solutions can also swap partners to make an insoluble solid — a **precipitate** — that falls out of the mixture. Mixing silver nitrate solution with sodium chloride solution gives a white solid, silver chloride: the silver ion and the chloride ion join into a compound that will not stay dissolved, and sinks. The sodium and nitrate ions stay in solution. Silver chloride darkens in light — the change at the heart of black-and-white photography.



$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$ — a precipitation reaction

Silver chloride darkens in light — the change at the heart of black-and-white photography

A labelled sketch. Two small beakers, silver nitrate solution and sodium chloride solution, are poured into one tube; a white solid forms and sinks. A zoom panel shows what happens in the solution: a silver ion plus a chloride ion join into solid silver chloride, while the sodium and nitrate ions stay dissolved. The equation reads AgNO3 + NaCl gives AgCl + NaNO3.

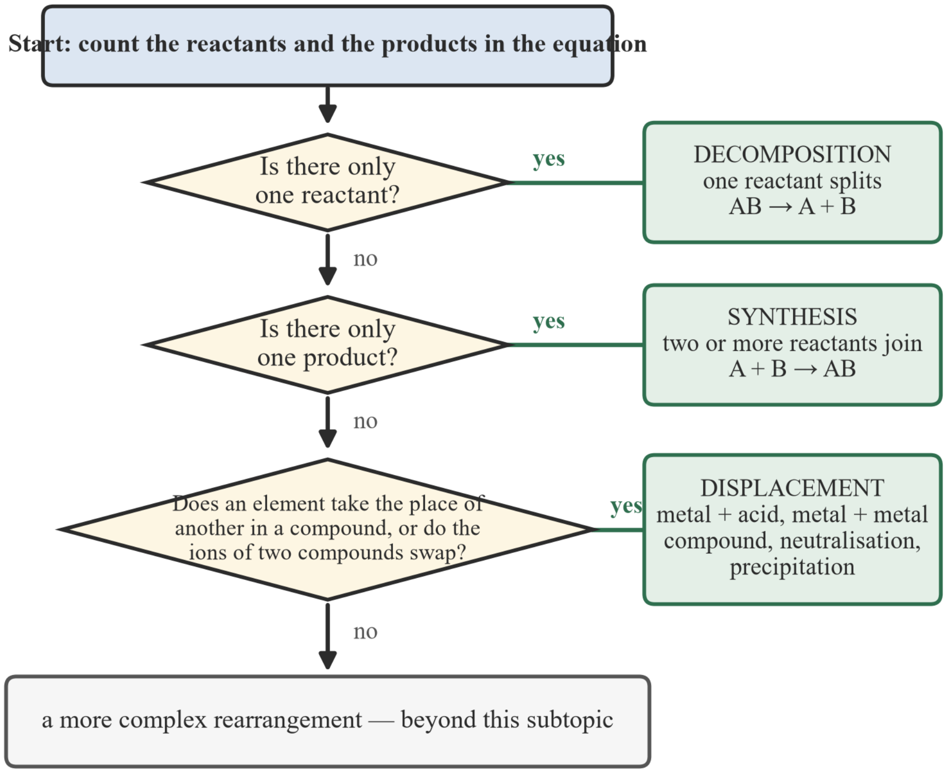
Representing the families (elaboration `VC2S10U09.E01`). Any reaction can be shown in several formats, and each format carries the same information:

- **molecular models** — built from balls and sticks, or drawn as particle diagrams, as in the figures above;
- **word equations** — magnesium + oxygen → magnesium oxide;
- **balanced symbol equations** — $2Mg + O_2 \rightarrow 2MgO$, where the numbers in front make the atom count match on both sides, because atoms are neither made nor destroyed (the conservation of mass, Subtopic 11A).

Practise moving between the formats: a model you can build, a word equation you can say, and a symbol equation you can balance are three views of the one reaction.

Identifying the type and predicting the products (elaboration `VC2S10U09.E02`). Given an equation, use the key: count the reactants and the products, and ask who takes whose place.

The identification key — count the reactants and products, then follow the arrows



A decision-tree flowchart. The start box says: count the reactants and the products in the equation. The first diamond asks whether there is only one reactant; yes leads to decomposition, one reactant splits, AB gives A + B. No leads to a second diamond asking whether there is only one product; yes leads to synthesis, two or more reactants join, A + B gives AB. No leads to a third diamond asking whether an element takes the place of another in a compound, or the ions of two compounds swap; yes leads to displacement, covering metal plus acid, metal plus metal compound, neutralisation and precipitation. No leads to a more complex rearrangement beyond this subtopic.

Given only the reactants, the family lets you predict the product:

- synthesis of a metal with oxygen gives the **metal oxide**; two elements joining give the compound of those elements;
- decomposition gives the simpler substances the compound is made of — its elements, or a metal oxide plus carbon dioxide for a carbonate;
- displacement gives the more reactive element bonded to the compound's other part, plus the displaced element on its own.

Then check the atom count and balance the equation, as taught in Subtopic 11B.

Activities

Activity 1 — Modelling the three families (elaboration `VC2S10U09.E01`). Using ball and stick molecular models (or drawn particle diagrams if models are not available), build the reaction $2H_2 + O_2 \rightarrow 2H_2O$: two hydrogen molecules and one oxygen molecule as the reactants, then rearrange the same six atoms into two water molecules as the products. Count the atoms before and after to check that none appear or disappear. Then represent the same reaction three more ways — as a labelled diagram, as a word equation, and as a balanced symbol equation — and state which family the reaction belongs to and why. Repeat for the decomposition of water, $2H_2O \rightarrow 2H_2 + O_2$, and compare the two patterns.

Activity 2 — A displacement you can see (elaboration `VC2S10U09.E03`). Under teacher supervision, place a cleaned iron nail in a beaker of blue copper sulfate solution and leave it for several days. Record the starting appearance of the nail and the solution, then record both again at the end. State the evidence that a reaction happened, name the two products, write the word and balanced symbol equations, and identify the family, naming the element that displaced the other. Wear eye protection; copper sulfate is an irritant and is harmful to the environment, so keep it off skin and dispose of solutions as the teacher directs, following Science ASSIST (ASTA) safety guidance.

Activity 3 — Making a precipitate (elaboration `VC2S10U09.E03`). Under teacher supervision, pour a small volume of sodium chloride solution into a tube, then add a few drops of silver nitrate solution. Record what you see. Name the precipitate and the ions that stay in solution, write the balanced symbol equation, and use the key to identify the family, explaining which partners swapped. Wear eye protection and nitrile gloves; silver nitrate stains skin and clothing brown-black, and solutions are prepared dilute by the teacher following Science ASSIST (ASTA) guidance.

Activity 4 — The identification key as a card sort (elaboration `VC2S10U09.E02`). Make a set of cards, each with one of the following reactions written on it: $2Mg + O_2 \rightarrow 2MgO$; $CuCO_3 \rightarrow CuO + CO_2$; $Fe + CuSO_4 \rightarrow Cu + FeSO_4$; $HCl + NaOH \rightarrow NaCl + H_2O$; $2H_2O \rightarrow 2H_2 + O_2$; $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$; $2Na + Cl_2 \rightarrow 2NaCl$; $2HgO \rightarrow 2Hg + O_2$. Sort the cards into the three families using the key, and for each card state the question in the key that decided the sorting. Then, on a blank card, write one new equation of your own for each family and swap with a partner to check.

Worked examples

Example 1 — scaffolded

Sodium burns in chlorine to form sodium chloride. (a) Write the word equation for this reaction. (b) Write the symbol equation and balance it. (c) Describe a particle diagram for the reaction. (d) Identify the family using the key, giving the deciding question.

Working	Comment
(a) sodium + chlorine → sodium chloride	Word equations name every substance.
(b) $Na + Cl_2 \rightarrow NaCl$, unbalanced	Symbols replace names; chlorine is a Cl_2 molecule.
Cl: 2 on the left, 1 on the right → put 2 in front of NaCl	The numbers in front balance atoms; never change the small numbers inside a formula.
Na now 1 left, 2 right → put 2 in front of Na	Balance each element in turn.
$2Na + Cl_2 \rightarrow 2NaCl$, balanced	Two of each atom on both sides.
(c) two sodium atoms and one chlorine molecule go in; the same atoms come out packed as sodium ions and chloride ions in a lattice	Atoms are rearranged, never made or destroyed.
(d) two reactants, one product → synthesis	The key's second question decides it: is there only one product? Yes.

Example 2 — scaffolded

Use the patterns to predict the products, then balance. (a) Aluminium burns in oxygen. Predict the product and write the balanced symbol equation. (b) Water is decomposed by electricity. Predict the products and write the balanced symbol equation.

Working	Comment
(a) metal + oxygen → metal oxide, so the product is aluminium oxide, Al_2O_3	Synthesis: the two elements join into one compound.
$Al + O_2 \rightarrow Al_2O_3$, unbalanced	Count atoms: O is 2 against 3.
use 3 O_2 and 2 Al_2O_3 → 6 O each side; then 4 Al	The lowest common multiple of 2 and 3 is 6.
$4Al + 3O_2 \rightarrow 2Al_2O_3$, balanced	Al: 4 = 4; O: 6 = 6.
(b) decomposition gives the elements water is made of: hydrogen and oxygen	A compound splits into its simpler parts.
$H_2O \rightarrow H_2 + O_2$, unbalanced; O balances with 2 H_2O	Two oxygen atoms each side.

Working	Comment
and 1 O_2	
$2H_2O \rightarrow 2H_2 + O_2$, balanced	H: 4 = 4; O: 2 = 2 — and the 2 : 1 ratio matches the gas volumes in the electrolysis figure.

Example 3 — unscaffolded

A student drops a piece of zinc into dilute hydrochloric acid. Bubbles form on the metal, and the gas given off burns with a squeaky pop when a lit splint is held to it. After a week, the zinc has gone and a white solid, zinc chloride, is left when the solution is dried. (a) Name the gas and the test that identifies it. (b) Write the word equation and the balanced symbol equation for the reaction. (c) Identify the family and explain, in one sentence, why this reaction belongs to it. (d) Copper is less reactive than hydrogen. Predict whether copper will fizz in dilute hydrochloric acid, and give the reason.

(a) The gas is **hydrogen**; the test is the squeaky pop with a lit splint.
(b) zinc + hydrochloric acid → zinc chloride + hydrogen; $Zn + 2HCl \rightarrow ZnCl_2 + H_2$.
(c) **Displacement.** Zinc, the more reactive element, takes the place of hydrogen in the compound, pushing the hydrogen out as the free element.
(d) No fizzing. Copper cannot displace hydrogen because it is less reactive than hydrogen, so no reaction happens.

Example 4 — unscaffolded

Classify each reaction as synthesis, decomposition or displacement, giving the one line of the key that decides each answer. (a) $2H_2 + O_2 \rightarrow 2H_2O$ (b) $CaCO_3 \rightarrow CaO + CO_2$ (c) $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$ (d) A student claims reaction (b) is displacement, “because the calcium ends up with a new partner”. Evaluate the claim.

(a) **Synthesis** — two reactants join into one product (the key’s second question: only one product? yes).
(b) **Decomposition** — one reactant splits into two products (the key’s first question: only one reactant? yes).
(c) **Displacement** — two reactants and two products, and the ions of the two compounds swap partners (the key’s third question: yes).
(d) The claim is wrong. Displacement needs an element to take the place of another in a compound. Calcium carbonate holds no free element as a reactant — it is a single compound that splits — so the first question of the key already sorts it as decomposition. Changing partners after a split is not the displacement pattern.

Practice questions

Scaffolded questions

Question 1 Definitions first. (a) Define a synthesis reaction and give its general pattern. (b) Define a decomposition reaction and give its general pattern. (c) Define a displacement reaction and give its general pattern.

Question 2 Pattern spotting. Name the family for each equation and give the one-line reason. (a) $2Mg + O_2 \rightarrow 2MgO$ (b) $2HgO \rightarrow 2Hg + O_2$ (c) $Fe + CuSO_4 \rightarrow Cu + FeSO_4$

Question 3 From words to symbols. Magnesium burns in oxygen to form magnesium oxide. (a) Write the word equation. (b) Write the symbol equation and balance it. (c) State which family the reaction belongs to.

Question 4 Four formats. For the formation of water, complete the table.

Format	Representation
molecular model	(i) describe the models you would build for the reactants and the products
diagram	see the formation-of-water figure in the theory
word equation	(ii) write it
balanced symbol equation	(iii) write it

Question 5 Gas tests. Name the gas that: (a) burns with a squeaky pop with a lit splint; (b) relights a glowing splint; (c) turns limewater milky. For each, name one reaction from this subtopic that gives off that gas.

Question 6 Using the key. Follow the identification key for the reaction $HCl + NaOH \rightarrow NaCl + H_2O$. State the answer at each question in the key and the family the reaction is sorted into.

Unscaffolded questions

Question 7 Predicting a synthesis product. Sodium burns in oxygen to form sodium oxide, Na_2O. (a) Predict the product from the synthesis pattern, before you look at the formula. (b) Write the balanced symbol equation. (c) State how the key sorts this reaction.

Question 8 Limestone into lime. Strongly heating calcium carbonate (limestone) breaks it down into calcium oxide (lime) and carbon dioxide. The reaction only continues while the heating is kept up. (a) Write the word equation and the balanced symbol equation. (b) Identify the family. (c) Explain how the limewater test would show that carbon dioxide is one of the products.

Question 9 Reading the electrolysis of water. A class decomposes water by electricity and collects 60 mL of hydrogen over the negative electrode. (a) Predict the volume of oxygen collected over the positive electrode, and say where the ratio comes from. (b) Name the test for each gas. (c) Identify the family.

Question 10 Zinc and acid, fully described. (a) Describe two observations when zinc granules are added to dilute hydrochloric acid. (b) Write the word equation and the balanced symbol equation. (c) Explain in one sentence why this reaction is a displacement.

Question 11 Reactivity decides. Iron is more reactive than copper; copper is more reactive than silver. (a) Predict whether iron will displace copper from copper sulfate solution, and state the two products if it does. (b) Predict whether copper will displace iron from iron sulfate solution. (c) A silver coin is dropped into copper sulfate solution. Predict what happens, given that silver is less reactive than copper.

Question 12 Neutralisation as displacement. (a) Name the four ions present when dilute hydrochloric acid and sodium hydroxide solution are mixed. (b) State which two ions join to form the new substance, and name it. (c) Explain why neutralisation is sorted into the displacement family in this book.

Question 13 A precipitate forms. (a) Predict the two products when silver nitrate solution is mixed with sodium chloride solution, and name the precipitate. (b) Write the balanced symbol equation. (c) Name the two ions that stay dissolved.

Question 14 Sort the set. Classify each reaction, showing the deciding line of the key. (a) $2Na + Cl_2 \rightarrow 2NaCl$ (b) $CuCO_3 \rightarrow CuO + CO_2$ (c) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$ (d) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ — and state honestly whether the key sorts this into one of the three families.

Question 15 Find the error. A student writes: "$2H_2O_2 \rightarrow 2H_2O + O_2$ is a synthesis reaction, because two products are made, and synthesis means making things." Find the error and correct it, using the key.

Question 16 Represent a reaction three ways. Choose the burning of magnesium or the burning of iron in oxygen. (a) Describe a particle diagram for the reaction. (b) Write the word equation and the balanced symbol equation. (c) Identify the family and state one safety precaution for the real reaction, with the reason for it.

Answers

Question 1 (a) two or more substances join to form a single product; A + B → AB; (b) a single compound splits into two or more simpler substances; AB → A + B; (c) one element takes the place of another in a compound; A + BC → AC + B. **Question 2** (a) synthesis — two reactants, one product; (b) decomposition — one reactant, two products; (c) displacement — iron takes copper's place in the compound. **Question 3** (a) magnesium + oxygen → magnesium oxide; (b) $2Mg + O_2 \rightarrow 2MgO$; (c) synthesis. **Question 4** (i) two H_2 models and one O_2 model as reactants; two H_2O models, using the same six atoms, as products; (ii) hydrogen + oxygen → water; (iii) $2H_2 + O_2 \rightarrow 2H_2O$. **Question 5** (a) hydrogen — zinc with dilute hydrochloric acid; (b) oxygen — decomposition of hydrogen peroxide (or electrolysis of water, or heated mercury(II) oxide); (c) carbon dioxide — heated copper(II) carbonate. **Question 6** one reactant? no; one product? no; ions swap partners? yes → displacement. **Question 7** (a) the metal oxide of the two elements, sodium oxide; (b) $4Na + O_2 \rightarrow 2Na_2O$; (c) synthesis — one product. **Question 8** (a) calcium carbonate → calcium oxide + carbon dioxide; $CaCO_3 \rightarrow CaO + CO_2$; (b) decomposition; (c) see solution. **Question 9** (a) 30 mL; the 2 : 1 ratio in $2H_2O \rightarrow 2H_2 + O_2$; (b) hydrogen: lit splint, squeaky pop; oxygen: glowing splint relights; (c) decomposition. **Question 10** (a) fizzing; the zinc slowly disappears (tube also warms — energy is 11D's story); (b) zinc + hydrochloric acid → zinc chloride + hydrogen; $Zn + 2HCl \rightarrow ZnCl_2 + H_2$; (c) see solution. **Question 11** (a) yes — copper and iron sulfate; (b) no; (c) nothing happens — silver cannot displace copper. **Question 12** (a) H^+, Cl^-, Na^+, OH^-; (b) H^+ and OH^-; water; (c) see solution. **Question 13** (a) silver chloride (the precipitate) and sodium nitrate; (b) $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$; (c) Na^+ and NO_3^-. **Question 14** (a) synthesis; (b) decomposition; (c) displacement; (d) none of the three — see solution. **Question 15** see solution (one reactant splitting is decomposition). **Question 16** see solution.

Fully-worked solutions

Question 1 (a) A **synthesis** reaction is one in which two or more substances join to form a single new substance: A + B → AB. (b) A **decomposition** reaction is one in which a single compound splits into two or more simpler substances: AB → A + B. (c) A **displacement** reaction is one in which a more reactive element takes the place of another element in a compound: A + BC → AC + B.

Question 2 (a) **Synthesis** — two reactants join into one product. (b) **Decomposition** — one reactant splits into two products. (c) **Displacement** — the element iron takes the place of copper in the compound, pushing copper out on its own.

Question 3 (a) magnesium + oxygen → magnesium oxide. (b) $Mg + O_2 \rightarrow MgO$ is unbalanced (O: 2 against 1). Doubling the oxide gives $2Mg + O_2 \rightarrow 2MgO$: Mg 2 = 2, O 2 = 2. (c) **Synthesis** — two reactants, one product.

Question 4 (i) Build two hydrogen molecules (two white atoms each) and one oxygen molecule (two red atoms) for the reactants; then rearrange exactly those six atoms into two water models, each a red atom bonded to two white atoms, for the products. (ii) hydrogen + oxygen → water. (iii) $2H_2 + O_2 \rightarrow 2H_2O$.

Question 5 (a) **Hydrogen** — given off when zinc displaces hydrogen from dilute hydrochloric acid. (b) **Oxygen** — given off when hydrogen peroxide decomposes (also by the electrolysis of water, and by strongly heated mercury(II) oxide). (c) **Carbon dioxide** — given off when copper(II) carbonate is heated.

Question 6 First question: is there only one reactant? **No** — there are two. Second question: is there only one product? **No** — there are two. Third question: do the ions of two compounds swap partners? **Yes** — H^+ pairs with OH^- to make water and Na^+ stays with Cl^-. The key sorts the reaction into the **displacement** family (neutralisation).

Question 7 (a) Synthesis of a metal with oxygen gives the metal oxide, so the product is sodium oxide. (b) $Na + O_2 \rightarrow Na_2O$ is unbalanced (O: 2 against 1). Use 2 Na_2O to balance oxygen, then 4 Na: $\mathbf{4Na + O_2 \rightarrow 2Na_2O}$. (c) **Synthesis** — the key's second question: only one product? Yes.

Question 8 (a) calcium carbonate → calcium oxide + carbon dioxide; $CaCO_3 \rightarrow CaO + CO_2$ (already balanced: one Ca, one C, three O on each side). (b) **Decomposition** — one reactant splitting into two products. (c) Bubble the gas through limewater: carbon dioxide turns limewater milky, so a milky result identifies the gas. This is exactly what the copper(II) carbonate figure shows.

Question 9 (a) **30 mL.** The balanced equation $2H_2O \rightarrow 2H_2 + O_2$ shows two hydrogen molecules for every oxygen molecule, so the hydrogen volume is twice the oxygen volume: 60 ÷ 2 = 30 mL. (b) Hydrogen: a lit splint gives a squeaky pop. Oxygen: a glowing splint relights. (c) **Decomposition** — one reactant (water) splitting into two products (the two elements).

Question 10 (a) The tube **fizzes** as bubbles of gas rise, and the **zinc granules slowly disappear** as the reaction runs. (b) zinc + hydrochloric acid → zinc chloride + hydrogen; $Zn + 2HCl \rightarrow ZnCl_2 + H_2$. (c) Zinc, the more reactive element, takes the place of hydrogen in the compound, and hydrogen is pushed out as the free element — the pattern A + BC → AC + B.

Question 11 (a) **Yes.** Iron is more reactive than copper, so iron displaces copper: the products are **copper** (coating the iron) and **iron sulfate** in solution. (b) **No.** Copper is less reactive than iron, so it cannot take iron's place; nothing happens. (c) **Nothing happens.** Silver is less reactive than copper, so silver cannot displace copper from its compound; the coin simply sits in the blue solution.

Question 12 (a) Hydrogen ions (H^+) and chloride ions (Cl^-) from the acid; sodium ions (Na^+) and hydroxide ions (OH^-) from the alkali. (b) The **hydrogen ion and the hydroxide ion** join to form **water**, the new substance. (c) The ions swap partners: H^+ leaves Cl^- for OH^-, making water, while Na^+ stays with Cl^- as the salt. One set of ions has taken the other's place, which is the displacement pattern — so this book sorts neutralisation into the displacement family.

Question 13 (a) The products are **silver chloride** and **sodium nitrate**; the precipitate is the insoluble silver chloride (the white solid). (b) $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$ (balanced as written: one of each atom on both sides). (c) **Na^+ and NO_3^-** — the sodium and nitrate ions stay dissolved.

Question 14 (a) **Synthesis** — two reactants join into one product. (b) **Decomposition** — one reactant splits into two products. (c) **Displacement** — the element zinc takes hydrogen's place in the compound. (d) **None of the three.** There are two reactants and two products, so the first two questions say no; and no element takes the place of another — the reactants are a compound plus an element, but the products are two compounds, with no free element pushed out. The key's third question says no, so methane burning is a more complex rearrangement beyond this subtopic's three families.

Question 15 The error is reading "making" as synthesis. The key counts substances: the reaction has **one reactant** (hydrogen peroxide), and one reactant splitting into two products is the **decomposition** pattern. Synthesis needs two or more reactants joining into one product — the opposite of what is written.

Question 16 (magnesium chosen) (a) Draw two single magnesium atoms and one oxygen molecule (two oxygen atoms bonded); then draw the products as two magnesium oxide units, each one magnesium joined to one oxygen — the same four atoms, rearranged. (b) magnesium + oxygen → magnesium oxide; $2Mg + O_2 \rightarrow 2MgO$. (c) **Synthesis** — two reactants join into one product. Safety: **do not stare at the burning ribbon**, because the white light is intense enough to damage the eyes; wear eye protection and hold the ribbon with tongs, not fingers, because the flame is hot.

Where this leads: the three reaction families taught here are the starting point for VCE Chemistry Unit 1, where reactions are revisited with the mole, and for Unit 3, where displacement is extended to the full reactivity series — all reference-only for this book, and above its ceiling (TOC D9). Inside the book, this subtopic hands tools forward: the balanced equations practised here feed the assessment plan's equation balancing, the gas tests and precipitate observations feed SIT-2, the full investigation report that follows this chapter, and every reaction classified here is ready to be sorted by energy flow in Subtopic 11D, the partner limb of `VC2S10U09`. Subtopics 11A and 11B supply the conservation-of-mass picture and the balancing method used throughout.

Energy changes and reaction rate: exothermic and endothermic reactions; temperature, concentration, surface area and catalysts

Chapter 11 — Chemical sciences B: chemical reactions (Science, Levels 9 and 10)

Subtopic 11D · VC2 Science Understanding — Chemical sciences

CD code: `VC2S10U09` (split delivery †; this subtopic is the partner, not the accountable owner) **Content description (verbatim):** “chemical reactions include synthesis, decomposition and displacement reactions and can be classified as exothermic or endothermic; reaction rates are affected by factors including temperature, concentration, surface area of solid reactants, and catalysts” **This subtopic’s limb (TOC §4 clause split):** exothermic/endothermic classification and rate factors. The accountable owner `11C` delivers the other limb: synthesis, decomposition and displacement. **Elaboration ids drawn on:** `VC2S10U09.E04` · `VC2S10U09.E05` (ids `VC2S10U09.E01`–`VC2S10U09.E03` are drawn on by Subtopic 11C; ids `VC2S10U09.E06` and `VC2S10U09.E07` are not authored, under the TOC’s D10 ICIP decision) **Achievement standard (extract served):** “They classify energy changes in chemical reactions as exothermic or endothermic.”

Theory

Reactions move energy. In Subtopic 11A you saw that a chemical reaction rearranges atoms: the reactants are taken apart and their atoms rejoin in new combinations to form the products. That rearrangement always involves energy. The atoms in every substance are held together by **bonds** — the links between atoms — and a reaction can only happen when some bonds are broken and new ones are formed. Energy is what gets moved around when that happens, and in this subtopic you will learn to sort reactions by which way the energy moves, and to control how fast reactions go.

To keep the bookkeeping straight, we watch two places. The **reaction mixture** is the chemicals that are actually reacting. The **surroundings** are everything else — the container, the thermometer, the bench, the air, your hands. Energy is measured in **joules** (J), and the one rule we rely on is that energy is conserved: it is never made or destroyed, only moved from one place to another (an idea developed fully in Subtopic 14C).

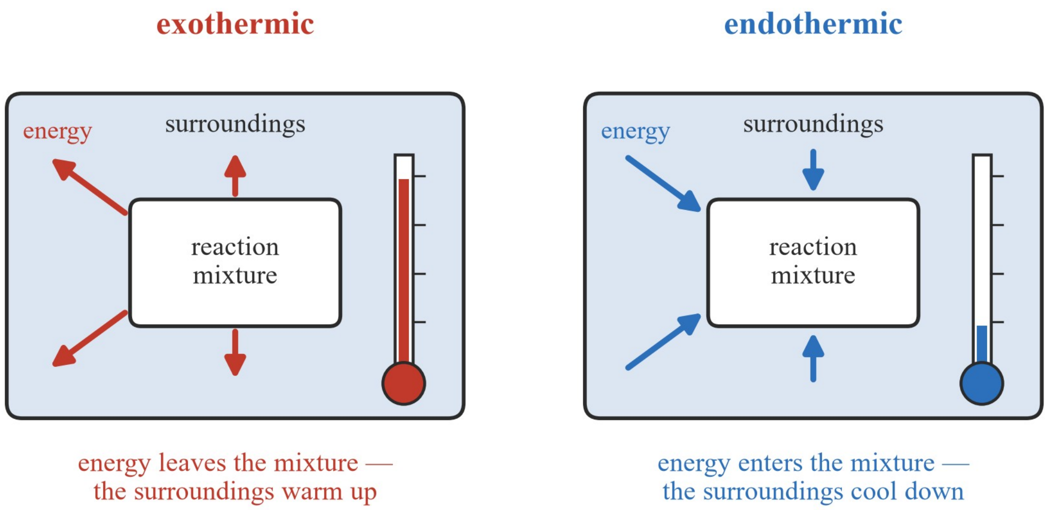
Exothermic reactions. An **exothermic** reaction is a reaction that releases energy from the reaction mixture out into the surroundings. In this subtopic, *exothermic* is defined by exactly that direction of energy flow, and every question here can be answered with that definition. Because energy is arriving in the surroundings, the temperature of the surroundings rises. If you hold the container, it feels warm or hot; a thermometer in the mixture climbs.

Familiar exothermic reactions include:

- **combustion** — the burning of any fuel. Methane in a Bunsen burner and petrol in a car engine both react with oxygen and release energy, mostly as heat and light;
- **metals with acid** — magnesium added to dilute hydrochloric acid fizzes and the test tube warms up (a reaction you met in Subtopic 11C);
- **neutralisation** — mixing an acid and an alkali raises the temperature of the mixture by a few degrees;
- **rusting** — the slow reaction of iron with oxygen is exothermic too, but it releases energy so slowly that you never feel the warmth.

Endothermic reactions. An **endothermic** reaction is a reaction that takes in energy from the surroundings into the reaction mixture. The energy flow is the other way around: energy leaves the surroundings, so the temperature of the surroundings falls. The container feels cold, and a thermometer in the mixture drops.

Where the energy moves: exothermic and endothermic



Two panels showing where the energy moves. In the exothermic panel, arrows show energy leaving the reaction mixture and entering the surroundings, and the thermometer reading rises. In the endothermic panel, arrows show energy leaving the surroundings and entering the reaction mixture, and the thermometer reading falls.

Endothermic reactions you will meet in this book include:

- **thermal decomposition** — breaking calcium carbonate into calcium oxide and carbon dioxide only happens while strong heating is continued (a decomposition reaction, from Subtopic 11C); take the heat away and the reaction stops;
- **mixing citric acid and sodium hydrogen carbonate in water** — the temperature of the mixture can fall by several degrees;
- **photosynthesis** — the reaction that builds sugars in green plants needs a continuous supply of energy from light (developed in Subtopic 12A).

The classification test. Classifying a reaction as exothermic or endothermic is the skill the achievement standard asks for, and the test is direct: watch the temperature.

Observation of the reaction mixture	Energy flow	Classification
temperature rises	energy leaves the mixture and enters the surroundings	**exothermic**
temperature falls	energy leaves the surroundings and enters the mixture	**endothermic**

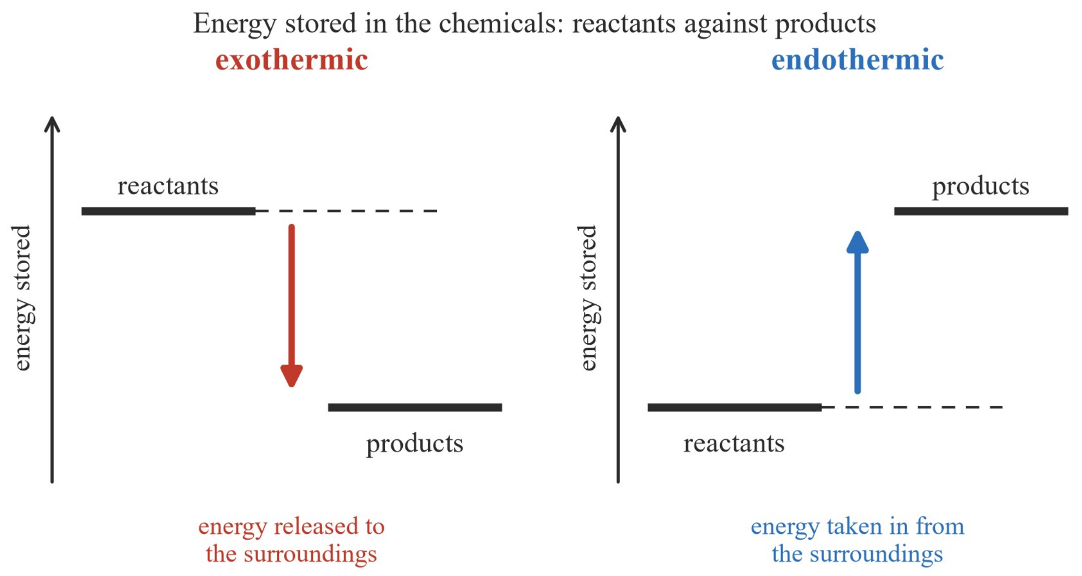
The two classes can also be shown inside word equations, by writing the energy where it belongs:

methane + oxygen → carbon dioxide + water (energy is released) — exothermic

calcium carbonate → calcium oxide + carbon dioxide (energy is taken in) — endothermic

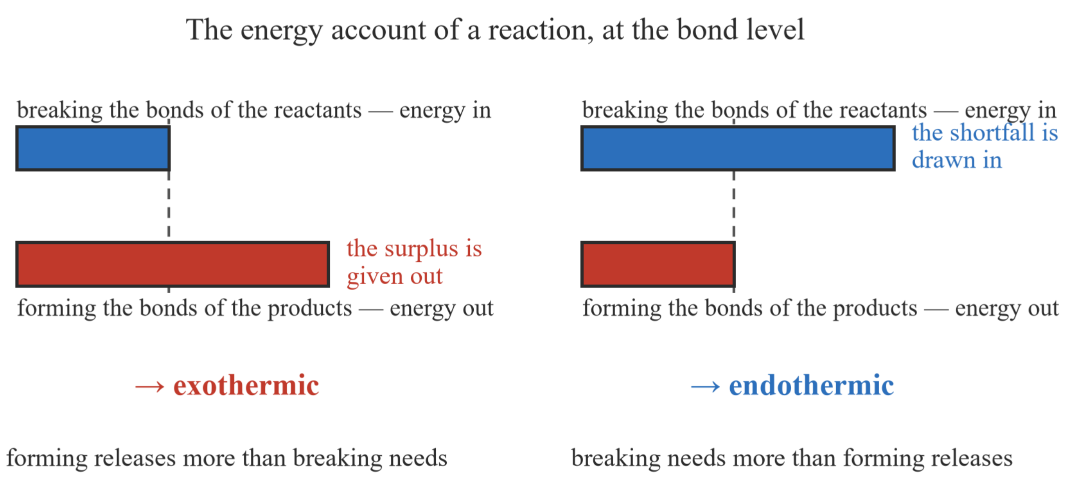
The energy picture. Because energy is conserved, the energy a reaction releases or takes in shows up as a difference between the reactants and the products:

- In an **exothermic** reaction, the products store **less** energy than the reactants did. The difference between the two is the energy released to the surroundings.
- In an **endothermic** reaction, the products store **more** energy than the reactants did. The extra amount is the energy that had to be drawn in from the surroundings during the reaction.



Energy level diagrams with no numbers. In the exothermic panel the products bar sits below the reactants bar, and a downward arrow shows the energy released to the surroundings. In the endothermic panel the products bar sits above the reactants bar, and an upward arrow shows the energy taken in from the surroundings.

At the bond level, the same idea explains where the energy goes. Breaking the bonds in the reactant molecules needs an input of energy; forming the new bonds of the products releases energy. A reaction is exothermic when the energy released by forming the new bonds is greater than the energy needed to break the old ones, so there is a surplus to give out. A reaction is endothermic when the bond-breaking needs more energy than the bond-forming gives back, so the shortfall has to be drawn in from the surroundings. This book keeps that account qualitative — no bond energies are calculated here.



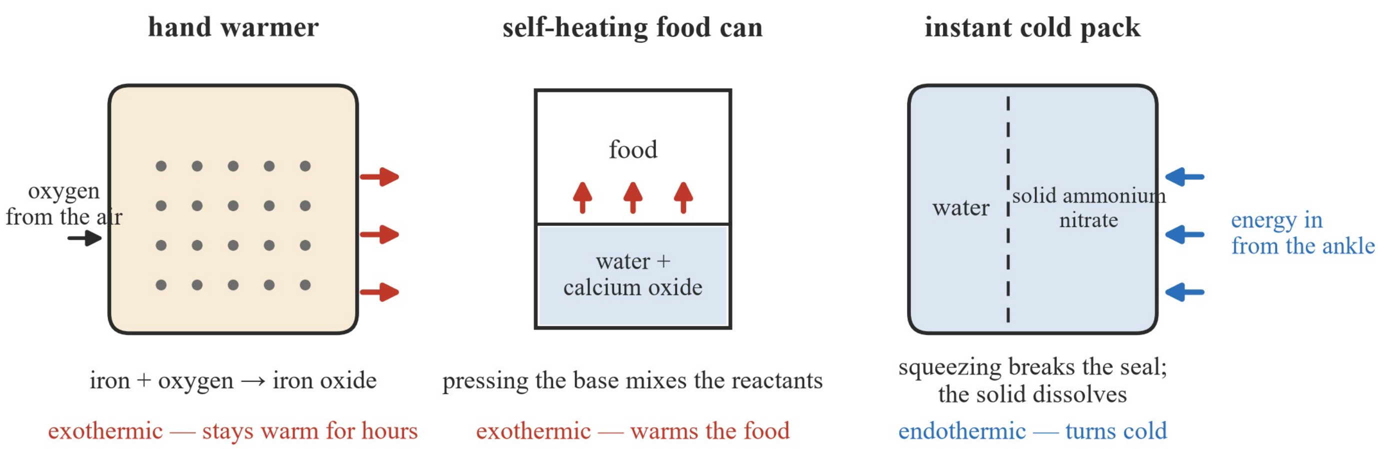
Bar charts comparing the energy needed to break the bonds of the reactants with the energy released when the bonds of the products form. In the exothermic panel the forming bonds release more than the breaking bonds need, so the surplus is given out. In the endothermic panel the breaking bonds need more than the forming bonds release, so the shortfall is drawn in.

One useful consequence: if a reaction is exothermic in one direction, the reverse change is endothermic. Burning hydrogen in oxygen releases energy and forms water; splitting water back into hydrogen and oxygen needs the same energy put back in.

Hot packs and cold packs (elaboration `VC2S10U09.E04`). The energy flow of exothermic and endothermic changes is exactly what hot packs and cold packs are built around.

- A **hand warmer** sold for cold-weather sport contains iron powder, water, salt and charcoal sealed in a breathable pouch. When opened, oxygen from the air reaches the iron, and the iron slowly reacts to form iron oxide. The reaction is exothermic, so the pouch releases energy steadily and stays warm for hours.
- **Self-heating food cans** keep the reactants apart until needed. When the base is pressed, water mixes with calcium oxide (quicklime), forming calcium hydroxide in a strongly exothermic reaction that warms the food above it without any flame.
- An **instant cold pack** for sports injuries holds water in one compartment and a solid such as ammonium nitrate in another. Squeezing the pack breaks the seal; the solid dissolves, taking in energy from the pack's contents and from whatever the pack is pressed against — an injured ankle — so the pack turns cold within a minute. Dissolving is a change of state rather than the making of a new substance, but the energy flow is the same endothermic direction; some cold packs instead mix two chemicals in an endothermic reaction.

Hot packs and cold packs — the same two directions of energy flow



Three labelled sketches. A hand warmer gives out energy as iron reacts slowly with oxygen from the air. A self-heating food can gives out energy when water mixes with calcium oxide below the food. An instant cold pack takes in energy when solid ammonium nitrate dissolves in water.

In each case the design question is the same: how much does the temperature change, how long does it last, and is it safe against skin? Those are measurable quantities, which is why packs are tested before sale rather than judged by feel.

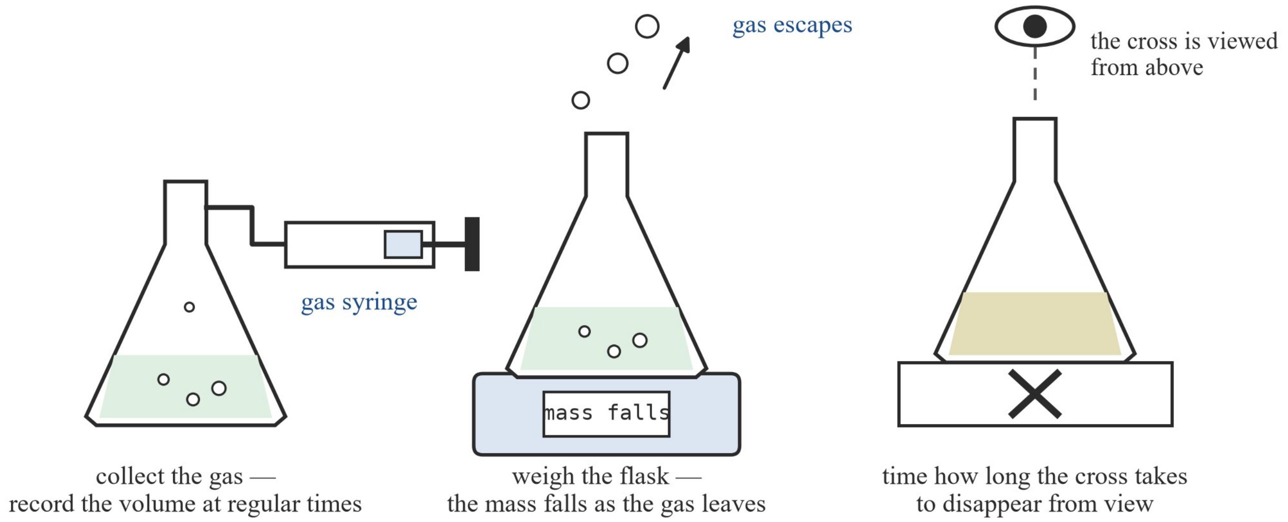
How fast do reactions go? Reactions happen at wildly different speeds. A firework burst is over in a fraction of a second; magnesium fizzes away in dilute acid in a few minutes; an iron gate takes months to rust; the weathering of rock takes centuries and more (a slow carbon process, met in Subtopic 12B). The **rate of reaction** is how fast a reaction goes — how quickly the reactants are used up, or how quickly the products form.

Rate is measured as an amount divided by a time. If you know how much product formed and how long it took, the average rate is

average rate = amount of product formed ÷ time taken with units such as cm³/s for a gas volume or g/min for a mass. The same reaction can be followed in any of three common ways:

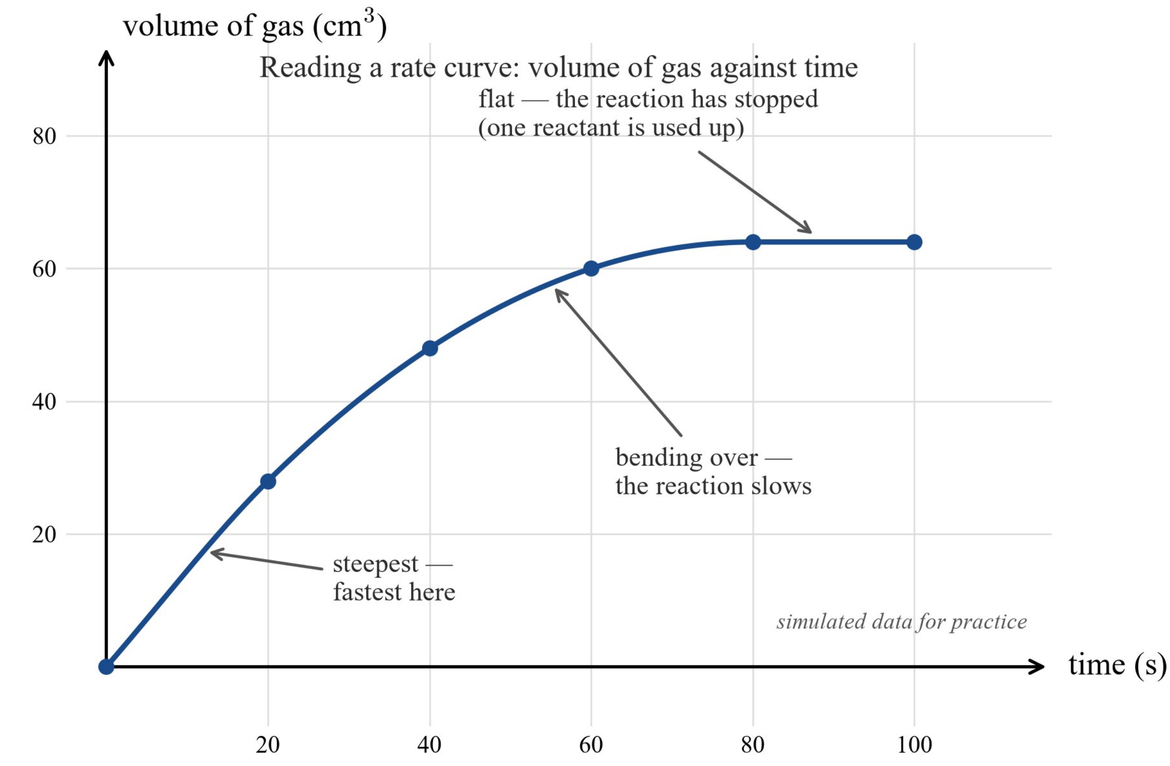
1. **Collect the gas.** If the reaction gives off a gas, collect it in a gas syringe, or in an inverted measuring cylinder standing in water, and record the volume at regular times.
2. **Weigh the flask.** If a gas escapes from a flask standing on a balance, the mass falls as the gas leaves; record the mass at regular times.
3. **Time a visible change.** The reaction between sodium thiosulfate and dilute hydrochloric acid slowly fills the liquid with a cloudiness of solid sulfur. Stand the flask on paper marked with a cross and time how long the cross takes to disappear from view.

Three ways to follow the rate of a reaction



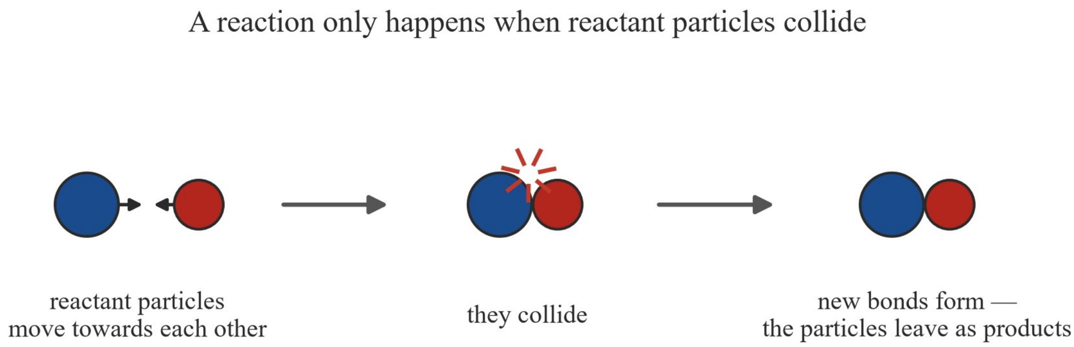
Three labelled sketches. A flask is joined by a tube to a gas syringe that collects the gas. A flask stands on a balance, and the reading falls as gas escapes. A flask of cloudy liquid stands on paper marked with a cross, viewed from above until the cross disappears.

Whichever method is used, a graph of amount against time tells the story of the reaction. Such a curve is steep at the start, becomes less steep, and finally runs flat. Read it in three parts: the steepest part is where the reaction is fastest; the curve bending over means the reaction is slowing; the flat line means the reaction has stopped, because one of the reactants has been used up. At the very start the reactant particles are at their most crowded, so the rate is greatest there, and as reactants are used the rate falls.



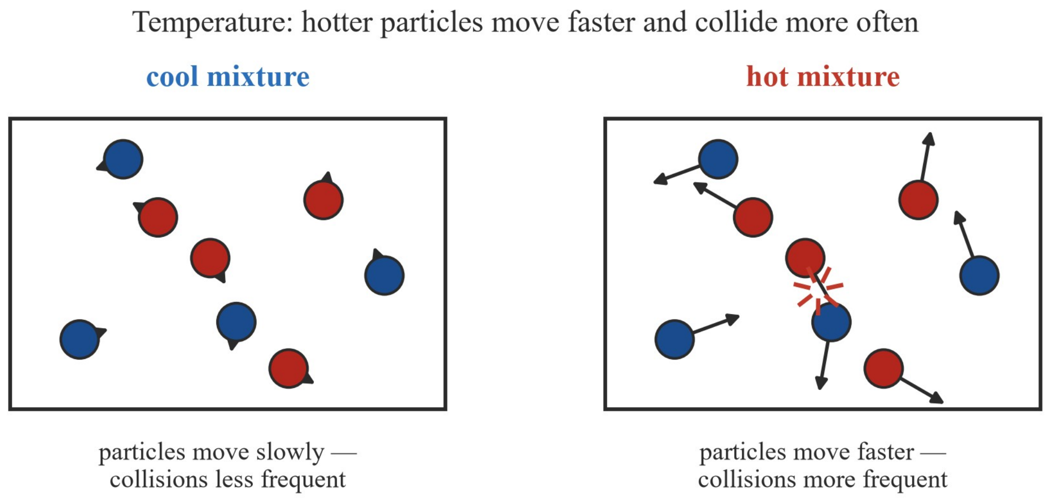
A graph of volume of gas against time, plotted from the simulated data of the worked example. The curve is steepest at the start where the reaction is fastest, bends over as the reaction slows, and runs flat at 64 cubic centimetres once a reactant is used up.

Why anything changes the rate — particles must collide. For reactants to turn into products, their particles have to run into each other. Before any reaction can happen, the reactant particles must **collide**. Every factor in the second half of this subtopic works through this one idea: anything that makes collisions happen more often makes the reaction go faster; anything that makes collisions happen less often slows it down.



Three stages. Two reactant particles move towards each other, they collide, and new bonds form so the particles leave as a product.

Factor 1 — temperature. Heat a reaction mixture and its particles move faster. Faster particles collide more often, so the reaction goes faster. Cool the mixture and the particles move more slowly, collisions become less frequent, and the reaction slows.

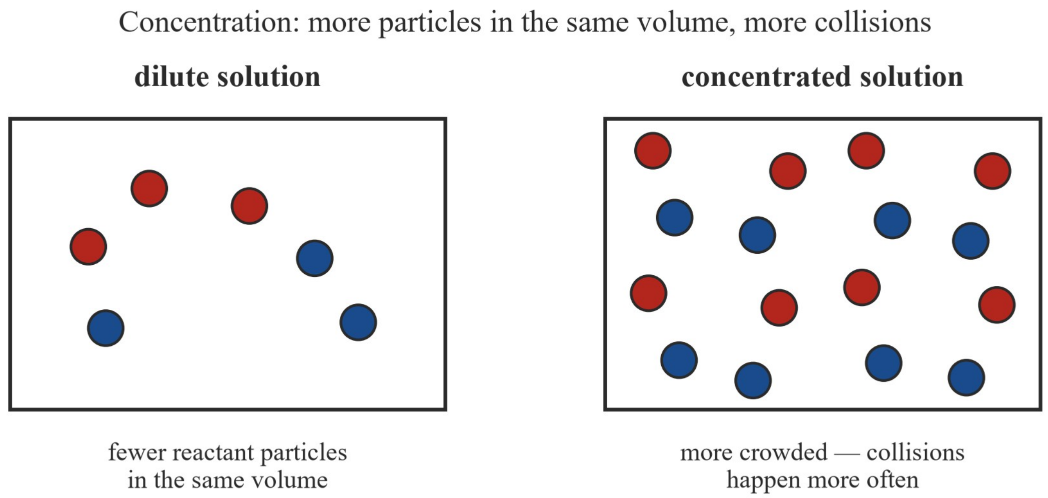


Two boxes of reactant particles. In the cool box the particles have short arrows and move slowly. In the hot box the same particles have longer arrows and move faster, and two of them collide.

Everyday life is full of this factor. Food goes off because of slow chemical changes; a refrigerator lowers the temperature so those changes happen more slowly, and a freezer slows them more again. Cooking works the other way: raising the temperature makes the changes in food happen faster. A rough pattern holds for many reactions: raising the temperature by 10 °C roughly doubles the rate. That is a rule of thumb, not a law — you test it with data in Activity 2.

Factor 2 — concentration. A **solution** forms when one substance, the **solute**, dissolves in a liquid, the **solvent**. The **concentration** of a solution says how much solute is dissolved in a given volume of solution: a **concentrated** solution has more solute dissolved in the same volume than a **dilute** one. (This book keeps concentration qualitative — no concentration calculations are needed here.)

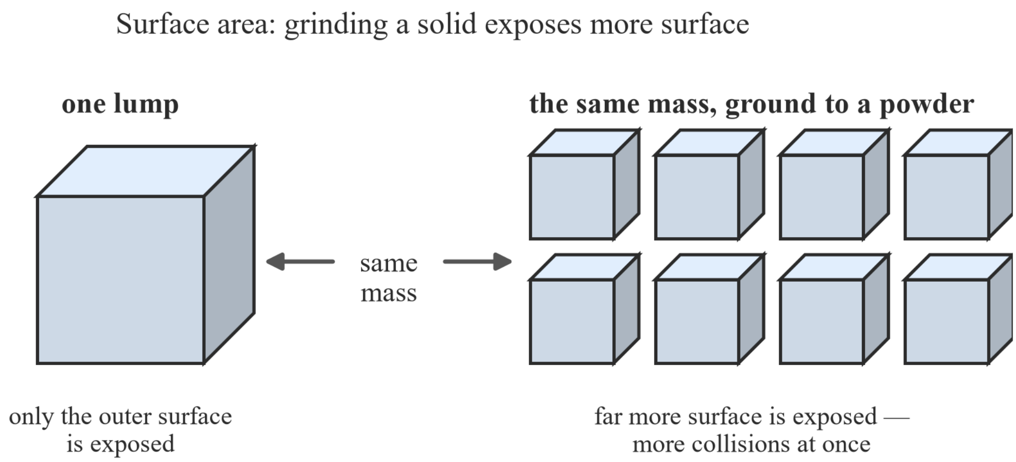
In a more concentrated solution the reactant particles are more crowded together, so they collide more often, and the reaction is faster. The same idea applies to reactions between gases: squeezing a gas mixture into a smaller volume pushes the particles closer together, which is why raising the pressure of a gas mixture has the same effect as raising the concentration of a solution.



Two boxes of the same size. The dilute box holds a few reactant particles. The concentrated box holds many more in the same volume, so the particles are more crowded and collide more often.

Factor 3 — surface area of solid reactants. A solid can only react where another substance can touch it — at its surface. Take a single lump of marble and grind it to powder: the mass is unchanged, but the powder exposes far more surface than the lump did. With more surface open to the other reactant, more collisions can happen at once, and the reaction is faster. That is why:

- marble powder fizzes away in dilute hydrochloric acid much faster than the same mass of marble chips;
- wood shavings catch fire easily while a log of the same wood needs a strong, sustained flame — the shavings expose far more surface to the oxygen;
- flour mills must guard against dust explosions: a bag of flour burns slowly, but the same flour hanging in the air as fine dust exposes so much surface that it can burn almost all at once.



The same mass of a solid drawn as one lump on the left and as eight small cubes on the right. The small cubes expose far more surface, so more collisions can happen at once.

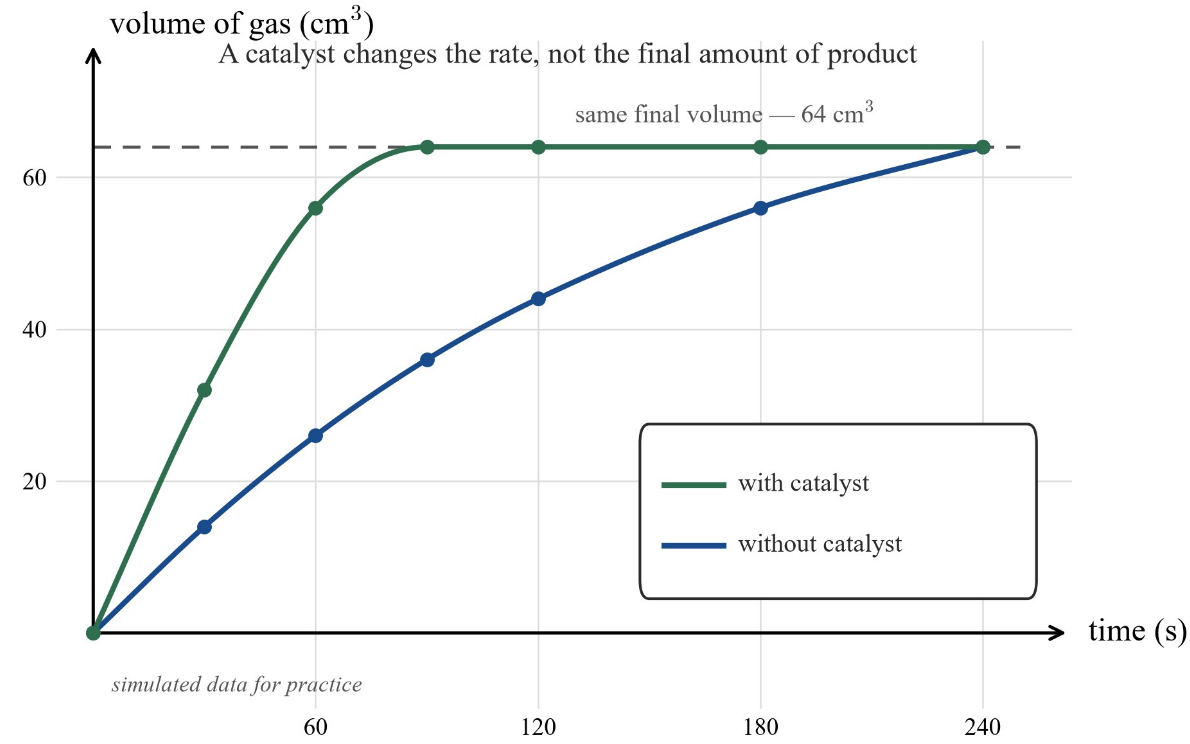
Factor 4 — catalysts. A **catalyst** is a substance that speeds up a reaction without being used up by it. At the end of the reaction the catalyst is still there, unchanged in mass, and can work again. In this subtopic, *catalyst* means exactly that: a speed-changer that is not consumed.

Catalysts matter everywhere:

- In the laboratory, a little manganese(IV) oxide speeds up the decomposition of hydrogen peroxide into water and oxygen — a reaction you met in Subtopic 11C. Without the catalyst the decomposition is too slow to notice at room temperature; with it, oxygen is given off briskly.
- In living things, **enzymes** are the catalysts that speed up the reactions that keep cells alive. Biological washing powders borrow the idea: they contain enzymes that speed up the breaking-down of food stains, which is why the powders work in cool water.
- In cars, the **catalytic converter** in the exhaust passes hot waste gases over catalyst metals such as platinum, which speed up the change of harmful gases into less harmful ones before they leave the tailpipe.

Industries value catalysts because a catalyst can let a reaction run fast at a lower temperature, which saves the fuel that heating would need.

Three things a catalyst does **not** do, which exams like to test: it does not change how much product a given amount of reactant can make; it does not turn an endothermic reaction into an exothermic one; and it does not change how much energy the reaction releases or takes in. A catalyst only changes how fast the reaction gets where it was going anyway.



A graph of volume of gas against time for the same reaction run twice, plotted from simulated data. Both runs end at the same final volume of 64 cubic centimetres, but the run with the catalyst reaches it much sooner.

Activities

Activity 1 — Energy in, energy out (elaboration `VC2S10U09.E04`). In a foam cup — which slows energy transfer to the bench, so the temperature change is easier to see — record the starting temperature of each mixture, then the temperature one minute after mixing. (i) Mix solutions of citric acid and sodium hydrogen carbonate; (ii) mix dilute hydrochloric acid with dilute sodium hydroxide solution. For each, state whether the change is exothermic or endothermic, the direction of the energy flow, and how the surroundings of the cup are affected. Then watch a teacher demonstration of a commercial instant cold pack and a hand warmer, record both temperature changes, and match each pack to its class. Wear eye protection; dilute acids and alkalis are irritants, and the teacher should prepare all solutions following Science ASSIST (ASTA) safety guidance.

Activity 2 — Temperature and rate (elaboration `VC2S10U09.E05`). Use the disappearing cross: stand a flask of sodium thiosulfate solution on a marked cross, add dilute hydrochloric acid, and time how long the cross takes to vanish. Repeat with the same volumes and concentrations at four temperatures — for example 20, 30, 40 and 50 °C — and record each time. Write the investigable question and identify the independent, dependent and controlled variables (skills from Subtopics 2A and 3A), tabulate and graph your results (Subtopic 4A), and describe the trend (Subtopic 4C). Work in a well-ventilated room, because the reaction gives off a small amount of sulfur dioxide, an irritating gas; students with asthma should check with the teacher first. Wear eye protection, and follow Science ASSIST (ASTA) guidance for the dilute acid.

Activity 3 — Surface area and concentration (elaboration `VC2S10U09.E05`). Collect the carbon dioxide from marble and dilute hydrochloric acid in an inverted measuring cylinder over water, and record the volume every 20 seconds. Run the investigation twice more, changing only one thing each time: first replace the marble chips with the same mass of marble powder, then return to chips but use a more dilute acid. For each run, state the factor being tested, the variables held constant (Subtopic 3A), and the comparison the results support. Explain each result in terms of particles and collisions, and say which single change — powder or stronger acid — made the bigger difference to the rate in your runs. Wear eye protection; keep the acid away from skin and clothing.

Activity 4 — A catalyst at work (elaboration `VC2S10U09.E05`). Half-fill two test tubes with the same hydrogen peroxide solution. To one, add a small amount of manganese(IV) oxide; leave the other as the control (what a control is for — Subtopic 3A). Observe both tubes, and test any gas with a glowing splint: a splint that relights shows oxygen. State what the catalyst changed, what it did not change, and how you know from this simple test that the manganese(IV) oxide was not consumed. Wear eye protection; hydrogen peroxide solutions irritate skin and eyes, and oxygen supports burning, so keep all other flames away. The teacher should prepare and dispense the solutions following Science ASSIST (ASTA) guidance.

Worked examples

Example 1 — scaffolded

A student mixes two colourless solutions in a foam cup. The temperature of the mixture falls from 21.5 °C to 17.0 °C. (a) Classify the reaction as exothermic or endothermic, giving the reason. (b) State the direction of the energy flow. (c) State what happens to the temperature of the surroundings of the cup. (d) Write the word-equation form for this reaction, showing where the energy term belongs.

Working	Comment
Temperature fell: 21.5 °C → 17.0 °C	The thermometer reading is the classification test.
Falling temperature → energy left the surroundings and entered the mixture	Energy is conserved, so a falling mixture temperature means energy moved in.
Classification: **endothermic**	An endothermic reaction takes in energy from the surroundings.
Surroundings cool down	The cup, the air and anything touching the cup lose energy to the mixture.

(d) reactants + energy (taken in) → products. The energy term is written on the reactant side, because energy must be supplied for the reaction to happen.

Example 2 — scaffolded

Marble chips react with excess dilute hydrochloric acid, giving off carbon dioxide. The table is **simulated data for practice**, recorded with a gas syringe.

Time (s)	0	20	40	60	80	100
Volume of gas (cm^3)	0	28	48	60	64	64

(a) Calculate the average rate of reaction over the first 20 s.

(b) Calculate the average rate over the first 60 s.
(c) State when the reaction finished, and how the data show it.
(d) Explain why the rate over the first 20 s is greater than the rate over the first 60 s.

Working	Comment
(a) average rate = amount ÷ time = 28 ÷ 20	Volume formed divided by time taken.
= **1.4 cm³/s**	Units are cm³ per second.
(b) average rate = 60 ÷ 60 = **1.0 cm³/s**	Same formula over the longer interval.
(c) finished by 80 s	The volume is 64 cm³ at 80 s and still 64 cm³ at 100 s — no more gas forms.

(d) At the start the reactant particles are at their most crowded, so collisions are most frequent and the rate is greatest. As reactants are used up, collisions become less frequent and the rate falls — which is exactly what the comparison 1.4 cm³/s against 1.0 cm³/s shows.

Example 3 — unscaffolded

A sports trainer activates an instant cold pack by squeezing it until an inner seal breaks, mixing water with the solid ammonium nitrate inside. Within a minute the pack is cold enough to hold against an injury. (a) Classify the change in the pack as exothermic or endothermic. (b) State the direction of the energy flow while the pack is getting cold. (c) Explain why the pack feels cold against the skin. (d) A teammate wants to design a hot pack instead. State the class of energy change a hot pack needs, and name one reaction used in real hot packs.

(a) Endothermic — the pack's contents take in energy as the change happens, so their temperature falls.
(b) Energy flows from the surroundings into the chemicals in the pack.
(c) The pack is colder than the skin, and energy moves from the warmer skin into the colder pack. The skin loses energy, so its temperature drops and it feels cold.
(d) A hot pack needs an exothermic change — one that releases energy. The slow reaction of iron powder with oxygen in a hand warmer is one example; calcium oxide reacting with water is another.

Example 4 — unscaffolded

Zinc powder reacts with dilute hydrochloric acid, producing hydrogen gas. Two runs use the same mass of zinc and the same volume and concentration of acid. Run A is at 20 °C; run B is at 35 °C. (a) State which run is faster and explain why, in terms of particles. (b) In a third run, the zinc powder is replaced by a single lump of zinc of the same mass. Predict how the rate compares with run A, and explain. (c) A student claims that adding a catalyst to run A would make it produce more hydrogen in total. Evaluate the claim.

(a) Run B. At the higher temperature the particles move faster, so the zinc and acid particles collide more often, and the reaction goes faster.
(b) Slower. A reaction at a solid happens only at its surface, and a single lump exposes far less surface than the same mass of powder. Fewer collisions can happen at once, so the rate is lower.
(c) The claim is wrong. A catalyst changes how fast the reaction goes, not how much product forms — the total hydrogen is fixed by the amounts of zinc and acid used. A catalyst would make run A reach its final volume sooner, but the final volume would be the same.

Practice questions

Scaffolded questions

Question 1 Definitions first. (a) Define an exothermic reaction and an endothermic reaction, in terms of energy flow. (b) State what a thermometer in the reaction mixture would show during each type. (c) State what happens to the temperature of the surroundings in each case.

Question 2 Energy terms in word equations. (a) Methane burns in oxygen: methane + oxygen → carbon dioxide + water. State on which side of the arrow the energy term belongs, and classify the reaction. (b) Calcium carbonate decomposes when strongly heated: calcium carbonate → calcium oxide + carbon dioxide. State on which side the energy term belongs, and classify the reaction.

Question 3 The energy picture. (a) In an exothermic reaction, do the products store more or less energy than the reactants? Where does the difference go? (b) In an endothermic reaction, do the products store more or less energy than the reactants? Where does the difference come from? (c) Burning hydrogen in oxygen is exothermic. State whether splitting water back into hydrogen and oxygen is exothermic or endothermic, and why.

Question 4 Packs on the shelf. (a) State the class of energy change that a hand warmer relies on. (b) Name the reaction inside an iron-powder hand warmer. (c) State the class of energy change in an instant cold pack, and describe what happens when the pack is activated. (d) Give one reason the reactants in a self-heating food can are kept apart until needed.

Question 5 Measuring rate. (a) State what the rate of reaction means. (b) Describe two ways to follow a reaction that gives off a gas. (c) A reaction produces 45 cm^3 of gas in 30 s. Calculate the average rate, with units. (d) A flask on a balance loses 0.8 g in 40 s as gas escapes. Calculate the average rate.

Question 6 The four factors, one line each. For each change — raising the temperature, raising the concentration of a solution, grinding a solid to a powder, adding a catalyst — state the effect on the rate of reaction and give the one-line collision reason.

Unscaffolded questions

Question 7 Bond breaking and bond making. Use the ideas of energy needed to break bonds and energy released when bonds form to explain why one reaction can be exothermic while another is endothermic.

Question 8 Reading the curve. The table is **simulated data for practice**: the volume of gas collected when hydrogen peroxide decomposes, with and without a manganese(IV) oxide catalyst.

Time (s)	0	30	60	90	120	180	240
Volume without catalyst (cm^3)	0	14	26	36	44	56	64
Volume with catalyst (cm^3)	0	32	56	64	64	64	64

(a) Describe the shape of each curve, using the words *steep* and *flat*.
(b) State the final volume in each run and explain why both runs end at the same volume.
(c) Use the data to state what the catalyst changed.
(d) Compare the average rate in the first 30 s of each run with a calculation.

Question 9 Kitchen chemistry. Food goes off through slow chemical changes. (a) Explain, in terms of particles, why food keeps longer in a refrigerator than on the bench. (b) Explain why a freezer keeps food longer than a refrigerator. (c) Cooking raises the temperature of food. Explain what that does to the rate of the chemical changes involved.

Question 10 The flour-mill hazard. A bag of flour is hard to set alight, but flour dust hanging in the air of a mill can burn so fast that it explodes. Explain the difference in terms of surface area and collisions.

Question 11 Catalysts. (a) Define a catalyst. (b) Describe what is observed when manganese(IV) oxide is added to hydrogen peroxide solution, and how the gas is tested. (c) Explain how the definition in (a) tells you the manganese(IV) oxide could be filtered off and used again. (d) Give one example of a catalyst in a living thing and one example in a car, and state what each speeds up.

Question 12 The disappearing cross, again. A group measures how long the cross takes to disappear when sodium thiosulfate solution and dilute hydrochloric acid are mixed at different temperatures. The table is **simulated data for practice**.

Temperature (°C)	20	30	40	50
Time for cross to disappear (s)	210	105	190	26

(a) Describe the trend the group expected.
(b) Identify the result that does not fit the trend and suggest one thing that could have gone wrong in that run.
(c) Using the trend, estimate the time the group would have expected at 25 °C.
(d) Explain, in terms of particles, why the time is shorter at the higher temperatures.

Question 13 Concentration and safety. (a) Explain, in terms of particles, why magnesium ribbon reacts faster with concentrated hydrochloric acid than with dilute acid of the same volume. (b) School laboratories use dilute rather than concentrated acids wherever possible. Use your answer to (a) to explain one safety benefit of that choice.

Question 14 Planning an investigation. You are asked to find out how the concentration of hydrochloric acid affects the rate of its reaction with magnesium ribbon. (a) Write an investigable question for this task. (b) Identify the independent variable, the dependent variable, and two variables that must be kept the same. (c) Describe what you would measure, and how you would use your measurements to compare rates. (d) State one safety precaution for this investigation and why it is needed.

Question 15 The catalytic converter. A car's catalytic converter passes hot exhaust gases through a honeycomb of ceramic channels coated with catalyst metals such as platinum. (a) State what the catalyst does to the reactions that change the harmful gases. (b) Explain why the gases pass over the catalyst while they are hot. (c) The honeycomb gives the coating a very large surface exposed to the gas. Explain why that matters, using the surface-area idea from this subtopic.

Question 16 Two claims to evaluate. (a) A student writes: "An endothermic reaction warms up the surroundings, because the reaction takes in energy." Find the error and correct it. (b) Another student claims: "Adding a catalyst to an endothermic reaction makes it start releasing energy instead." Evaluate the claim, using what a catalyst does and does not do.

Answers

Question 1 (a) exothermic — releases energy to the surroundings; endothermic — takes in energy from the surroundings; (b) rises / falls; (c) surroundings warm / surroundings cool. **Question 2** (a) energy on the product side, exothermic; (b) energy on the reactant side, endothermic. **Question 3** (a) less; released to the surroundings; (b) more; drawn in from the surroundings; (c) endothermic — the reverse change needs the same energy put back in. **Question 4** (a) exothermic; (b) iron reacting with oxygen to form iron oxide; (c) endothermic; see solution; (d) see solution. **Question 5** (a) how fast reactants are used up or products form; (b) see solution; (c) 1.5 cm^3/s; (d) 0.02 g/s. **Question 6** faster, faster, faster, faster — see solution for the collision reasons. **Question 7** see solution (energy released in bond making against energy needed for bond breaking). **Question 8** (a) see solution; (b) 64 cm^3; see solution; (c) the rate, only; (d) about 0.47 cm^3/s against about 1.07 cm^3/s. **Question 9** (a)–(c) see solution (lower temperature, slower particles, fewer collisions). **Question 10** see solution (dust exposes far more surface; many collisions at once). **Question 11** (a) see solution; (b) brisk fizzing; glowing splint relights; (c) see solution; (d) see solution. **Question 12** (a) time falls as temperature rises; (b) 190 s at 40 °C; see solution; (c) about 150 s (accept roughly 130–180 s); (d) see solution. **Question 13** (a) see solution; (b) see solution. **Question 14** (a)–(d) see solution. **Question 15** (a) speeds them up; (b) see solution; (c) see solution. **Question 16** (a) see solution (endothermic cools the surroundings); (b) see solution (a catalyst changes rate only).

Fully-worked solutions

Question 1 (a) An **exothermic** reaction releases energy from the reaction mixture into the surroundings; an **endothermic** reaction takes in energy from the surroundings into the reaction mixture. (b) A thermometer in the mixture **rises** during an exothermic reaction and **falls** during an endothermic one. (c) The surroundings **warm up** around an exothermic reaction and **cool down** around an endothermic one, because that is where the energy is coming from or going to.

Question 2 (a) Burning methane releases energy, so the energy term belongs on the **product side**: methane + oxygen → carbon dioxide + water (energy released). The reaction is **exothermic**. (b) Decomposing calcium carbonate needs a continuous input of heat, so the energy term belongs on the **reactant side**: calcium carbonate + energy → calcium oxide + carbon dioxide. The reaction is **endothermic**.

Question 3 (a) The products store **less** energy than the reactants. The difference is the energy **released to the surroundings**. (b) The products store **more** energy than the reactants. The difference is the energy **drawn in from the surroundings** during the reaction. (c) **Endothermic.** If forming water from hydrogen and oxygen releases energy, the reverse change — splitting water into hydrogen and oxygen — needs that same energy putting back in.

Question 4 (a) **Exothermic** — the pack must release energy to warm the hands around it. (b) The slow reaction of **iron with oxygen to form iron oxide** (rusting, run fast enough to feel because the powder exposes a large surface). (c) **Endothermic.** When the pack is activated the solid (such as ammonium nitrate) mixes with the water and takes in energy as it dissolves, so the pack's temperature falls and it feels cold against the skin. (d) So the reaction cannot start — and release its energy — until the moment the heat is wanted. Keeping the water and calcium oxide apart stores the reactants safely; mixing them is the switch.

Question 5 (a) The rate of reaction is **how fast a reaction goes** — how quickly the reactants are used up, or how quickly the products form. (b) Any two of: collect the gas in a gas syringe or an inverted measuring cylinder over water and record the volume at regular times; stand the flask on a balance and record the falling mass as the gas escapes; time how long a visible change (such as a cloudiness hiding a marked cross) takes to appear. (c) average rate = 45 ÷ 30 = **1.5 cm^3/s**. (d) average rate = 0.8 ÷ 40 = **0.02 g/s**.

Question 6 - **Raising the temperature** — faster: particles move faster and collide more often. - **Raising the concentration** — faster: more reactant particles in the same volume, so collisions are more frequent. - **Grinding a solid to a powder** — faster: more surface is exposed, so more collisions can happen at once. - **Adding a catalyst** — faster: the catalyst speeds the reaction without being consumed.

Question 7 Breaking the bonds of the reactants needs an input of energy; forming the new bonds of the products releases energy. If the energy released when the new bonds form is greater than the energy needed to break the old ones, there is a surplus, and the reaction gives that surplus out — it is **exothermic**. If the bond-breaking needs more energy than the bond-forming gives back, the reaction must draw in the shortfall from the surroundings — it is **endothermic**. The balance between those two amounts decides which class a reaction belongs to.

Question 8 (a) Both curves are **steep at the start** (the reaction is fastest then), bend over, and finish **flat** once no more gas forms. The curve with the catalyst reaches the flat part much sooner than the curve without. (b) Both runs end at **64 cm³**, because both started with the same amounts of hydrogen peroxide. A catalyst changes how fast the reaction goes, not how much product the reactants can make, so the final volume is the same. (c) The catalyst changed **the rate, and nothing else**: the same final volume was reached in about 90 s with the catalyst, but only at about 240 s without it. (d) First 30 s without catalyst: 14 ÷ 30 ≈ **0.47 cm³/s**. First 30 s with catalyst: 32 ÷ 30 ≈ **1.07 cm³/s**. The run with the catalyst is more than twice as fast over that interval.

Question 9 (a) Going off depends on slow chemical changes whose rate falls with temperature. In a refrigerator the particles of the reacting substances move more slowly than on the bench, so they collide less often, and the changes happen more slowly — the food keeps longer. (b) A freezer is colder still. The lower the temperature, the slower the particles move and the fewer the collisions, so the changes slow again — which is why frozen food keeps longer than refrigerated food. (c) Cooking raises the temperature, so the particles move faster and collide more often, and the chemical changes that turn raw food into cooked food happen faster.

Question 10 Burning needs the fuel's surface to meet oxygen. In a bag of flour, most grains are buried inside and only the outer surface is exposed, so the reaction with oxygen is slow. As dust hanging in air, the same mass of flour exposes an enormous total surface — every grain is surrounded by oxygen — so a great many collisions can happen at once and the burning can sweep through the whole cloud almost instantly. That is why mills treat dust as an explosion hazard.

Question 11 (a) A catalyst is a substance that **speeds up a reaction without being used up** by it — at the end it is still present, unchanged in mass. (b) Bubbles of gas are given off briskly. Test the gas with a glowing splint: oxygen makes the splint relight. (c) Because a catalyst is not consumed, the manganese(IV) oxide remains as a solid when the reaction finishes. Filtering it off leaves it ready to speed up another batch. (d) In living things, **enzymes** speed up the reactions that keep cells alive. In a car, the **catalytic converter** uses catalyst metals such as platinum to speed up the change of harmful exhaust gases into less harmful ones.

Question 12 (a) The higher the temperature, the shorter the time for the cross to disappear — the reaction is faster at higher temperatures. (b) The **190 s result at 40 °C** does not fit: it sits above the 30 °C time, against the trend. Possible causes include the mixture being cooler than recorded, the cross being judged by a different person, or the solutions measured with the wrong volumes in that run. (c) At 25 °C, halfway in temperature between 20 and 30 °C, the time should sit between 210 s and 105 s — **about 150 s** is a reasonable estimate. (d) At higher temperatures the particles move faster, so the reactant particles collide more often, and the cloudiness that hides the cross forms sooner.

Question 13 (a) In concentrated acid there are more acid particles in the same volume, so the acid particles are more crowded around the magnesium ribbon. Collisions between acid particles and the metal surface happen more often, so the reaction is faster. (b) A dilute acid reacts more slowly for exactly that reason, which gives more time to respond to a spill or splash and makes any reaction easier to control. Diluting is a simple way to reduce risk while still showing the reaction — alongside eye protection and careful handling, as recommended by Science ASSIST (ASTA) guidance.

Question 14 (a) For example: *How does the concentration of hydrochloric acid affect the rate of its reaction with magnesium ribbon?* The question names both the variable being changed and the response being measured. (b) Independent variable: the concentration of the acid. Dependent variable: the rate of reaction. Variables kept the same (any two): volume of acid, length and mass of the magnesium ribbon, temperature, and the surface condition of the ribbon. (c) Collect the hydrogen in a gas syringe and record the volume at regular times, or time how long the ribbon takes to disappear. To compare rates, compare the volumes of gas after a fixed time, or calculate average rate as volume formed ÷ time taken for each concentration. (d) Wear **eye protection**, because hydrochloric acid is an irritant and the reaction can spit. Keep flames away, because the gas produced is hydrogen, which is flammable.

Question 15 (a) It **speeds up** the reactions that change the harmful gases into less harmful ones. (b) Hot gas particles move faster, so they collide with the catalyst surface more often — temperature is still a rate factor even with a catalyst present, and exhaust gases are hot already, so the converter uses that heat rather than wasting it. (c) A larger exposed surface lets more gas particles touch the catalyst at once, so more collisions with the catalyst can happen at the same time and the gases are cleaned faster during the short time they spend in the exhaust.

Question 16 (a) The error is the direction. An endothermic reaction takes in energy **from** the surroundings, so energy leaves the surroundings and the surroundings **cool down**, not warm up. Taking energy in is exactly why an endothermic change feels cold. (b) The claim is wrong. A catalyst changes **only how fast** a reaction goes — it does not change the class of the energy change, and it does not change how much energy is released or taken in. An endothermic reaction with a catalyst is still endothermic: it simply takes in its energy faster.

Where this leads: the rate factors and the exothermic/endothermic classification taught here are the starting point for VCE Chemistry Unit 3, Area of Study 2 (“How can the rate and yield of chemical reactions be optimised?”), reference-only for this book. VCE re-teaches the collision idea as a formal collision theory with an energy barrier and adds equilibrium; those extensions, including energy-profile diagrams with a barrier, sit above this book’s ceiling and are not taught here (TOC D9). This subtopic also hands two tools forward inside the book: the energy-flow classification connects to the conservation treatment in Subtopic 14C, and the investigation skills practised in Activities 2–4 feed directly into SIT-2, the full investigation report that follows this chapter and draws its contexts from Chapters 7–11. Subtopic 11C delivers the other limb of `VC2S10U09` — synthesis, decomposition and displacement — and Subtopics 11A and 11B supply the conservation-of-mass picture and the equations used throughout.

Test A

Topic test 4 — Chemical sciences: atoms, isotopes, the periodic table and chemical reactions

Science understanding and science inquiry · Chapters 10–11 · Subtopics 10A, 10B, 10C, 11A, 11B, 11C and 11D · Codes VC2S10U06, VC2S10U07, VC2S10U08 and VC2S10U09

Total: 40 marks · Section A (multiple choice): 10 marks · Section B (short/structured response): 30 marks

6 of the 40 marks are science inquiry marks, attached to the practical work of Chapters 10–11 (Section B, Q16 and Q17).

Planned for about 50 minutes. This paper is untimed — there is no time to beat.

This is a school-designed paper. It is not a VCAA instrument. Achievement at Levels 9 and 10 is reported against the Victorian Curriculum achievement standard on teacher judgement; the marks here are one source of evidence towards that judgement.

Conditions

- Completion is **untimed**. The 50 minutes is planning guidance only; take as long as you need.
- **Reading support** is permitted. Your teacher may read any question out to you if you need it. Reading is not what is being looked at, and your teacher will not help with the answer.
- **A scientific calculator is permitted.** Only the half-life calculation in Q12 needs arithmetic, and it can also be done by repeated halving. No formula sheet. No reading time.
- Answer every question. For multiple-choice questions, circle the letter of the best answer. There is only one best answer for each question.

In this test you will:

- describe how the model of the atom changed as new evidence arrived, and work with subatomic particles and isotopes (Q1, Q2, Q11)
- identify how an unstable isotope decays to form a stable atom (Q9)
- use half-life to calculate how a radioactive sample changes with time (Q12)
- use groups and periods to describe patterns and trends in the periodic table (Q3, Q4, Q13)
- apply the Law of Conservation of Mass, and write and balance symbol equations (Q5, Q6, Q14, Q15)
- classify reactions as synthesis, decomposition or displacement, and predict their products (Q7, Q10, Q16)
- classify an energy change as exothermic or endothermic (Q8)
- read observations, identify variables and explain a pattern from the practical work of Chapters 10–11 (Q16, Q17)

Section A — Multiple choice (10 marks)

Each question is worth 1 mark. Circle the letter of the best answer.

Q1 *(1 mark · VC2S10U06)* Which subatomic particle has a positive charge?

A. Electron B. Proton C. Neutron D. Photon

Q2 *(1 mark · VC2S10U06)* Carbon-12 and Carbon-14 are isotopes because they have:

A. Same neutrons, different protons B. Different electrons only C. Same mass D. Same protons, different neutrons

Q3 *(1 mark · VC2S10U07)* Elements in the same GROUP of the periodic table have:

A. Similar chemical properties (same outer electrons) B. The same atomic mass C. The same density at room temperature D. The same number of neutrons

Q4 *(1 mark · VC2S10U07)* Why are noble gases (Group 18) generally UN-reactive?

A. They have an empty outer electron shell B. They have only one electron in their outer shell C. Full outer electron shell — energetically stable D. They are too heavy to react with other elements

Q5 *(1 mark · VC2S10U08)* In '$2H_2 + O_2 \rightarrow 2H_2O$', what are the REACTANTS?

A. H_2O B. H_2 and O_2 C. H_2 only D. O_2 only

Q6 *(1 mark · VC2S10U08)* Balance: $H_2 + Cl_2 \rightarrow HCl$. Coefficient of HCl?

A. 1 B. 3 C. 2 D. 4

Q7 *(1 mark · VC2S10U09)* Heating $CaCO_3$ produces $CaO + CO_2$. This is:

A. Decomposition B. Synthesis C. Displacement D. Combustion

Q8 *(1 mark · VC2S10U09)* A student mixes citric acid and sodium hydrogen carbonate in water. The temperature of the mixture falls. This reaction is classified as:

A. exothermic, because the reaction releases energy to the surroundings B. exothermic, because the reaction takes in energy from the surroundings C. endothermic, because the reaction releases energy to the surroundings D. endothermic, because the reaction takes in energy from the surroundings

Q9 *(1 mark · VC2S10U06)* Iodine-131 decays to form the stable atom xenon-131. Which type of radiation is emitted in this decay?

A. Alpha radiation B. Beta radiation C. Gamma radiation D. No radiation is emitted — the atom simply splits in two

Q10 *(1 mark · VC2S10U09)* Why does Cu NOT displace Fe from $FeSO_4$ (no reaction)?

A. Cu and Fe have equal reactivity B. SO_4 only bonds with copper, not iron C. Cu is less reactive than Fe in the reactivity series D. Cu atoms are too large to enter the solution

Section B — Short/structured response (30 marks)

Q11 *(4 marks · VC2S10U06)* In 1897 J. J. Thomson passed a cathode ray between two electric plates and saw the ray bend towards the positive plate. In 1909 Geiger and Marsden, working under Ernest Rutherford, fired alpha particles at a thin sheet of gold foil and watched where they went on a zinc sulfide screen.

(a) Name the particle Thomson discovered, and state its charge. *(1 mark)*
(b) In the gold foil experiment, most of the alpha particles passed straight through the foil, but about 1 in 8 000 bounced straight back. State what each of these two observations showed about the structure of the atom. *(2 marks)*
(c) In 1932 James Chadwick fired alpha particles at beryllium and found a new particle. Name the particle, and state where it sits in the atom. *(1 mark)*

Q12 *(5 marks · VC2S10U06)* Iodine-131 is an unstable isotope used in hospitals to treat some thyroid conditions. Its half-life is 8.0 days. A sample arrives at a hospital giving a corrected count rate of 8 000 counts/min. *(Simulated data for practice.)*

(a) Define the half-life of a radioactive isotope. *(1 mark)*
(b) Calculate the corrected count rate of the sample after 16 days. Show your working. *(2 marks)*
(c) Calculate how many days it takes for the corrected count rate to fall to 1 000 counts/min. *(1 mark)*
(d) The count rate a Geiger-Müller counter measures includes the background count. State why the background count rate is subtracted before the sample's count rate is used. *(1 mark)*

Q13 *(4 marks · VC2S10U07)* An atom of element X has the electron arrangement 2,8,7.

(a) State the group and the period element X sits in, and say how each number follows from the electron arrangement. *(2 marks)*
(b) State whether element X is a metal or a non-metal, and name the region of the periodic table where it sits. *(1 mark)*

(c) Fluorine sits at the top of Group 17, in Period 2. Predict whether element X is more or less reactive than fluorine, and give the reason from the Group 17 trend. *(1 mark)*

Q14 *(5 marks · VC2S10U08)* A class mixes vinegar and sodium hydrogen carbonate. *(All readings are simulated data for practice.)* In run 1 the reaction happens inside a sealed plastic bag: the total mass is 152.4 g before mixing and 152.4 g after. In run 2 the same amounts are mixed in an open cup: the mass falls from 152.4 g to 151.8 g.

(a) State the Law of Conservation of Mass. *(1 mark)*
(b) Explain why the mass did not change in run 1, even though a gas was produced. *(1 mark)*
(c) Explain the fall of 0.6 g in run 2. Name the substance that left. *(2 marks)*
(d) Steel wool heated in air gains mass: 5.0 g of wool becomes 6.4 g of dark product. Explain why a gain of mass does not break the law. *(1 mark)*

Q15 *(6 marks · VC2S10U08)* Balance each equation. Put coefficients (numbers in front) only — never change the small numbers inside a formula.

(a) $Mg + O_2 \rightarrow MgO$ *(1 mark)*
(b) $CH_4 + O_2 \rightarrow CO_2 + H_2O$ *(1 mark)*
(c) $Al + O_2 \rightarrow Al_2O_3$ *(1 mark)*
(d) $H_2O_2 \rightarrow H_2O + O_2$ *(1 mark)*
(e) Write the word equation for the reaction of zinc with dilute hydrochloric acid. *(1 mark)*
(f) Balance the symbol equation for the same reaction: $Zn + HCl \rightarrow ZnCl_2 + H_2$. *(1 mark)*

Q16 *(3 marks · VC2S10U09 · inquiry)* In Subtopic 11C, Activity 2, a class places a clean iron nail in a beaker of blue copper sulfate solution, records what they see, and leaves it for several days. The class wears eye protection, because copper sulfate solution is an irritant and is harmful to the environment. Iron is more reactive than copper.

(a) State two observations recorded at the end that show a reaction has happened. *(1 mark)*
(b) Name the two products of the reaction. *(1 mark)*
(c) Identify the family of the reaction — synthesis, decomposition or displacement — and state the question from the identification key that decides the sorting. *(1 mark)*

Q17 *(3 marks · VC2S10U09 · inquiry)* In Subtopic 11D, Activity 2, a class uses the disappearing cross to investigate how temperature affects the rate of the reaction between sodium thiosulfate solution and dilute hydrochloric acid. The class works in a well-ventilated room and wears eye protection. *(All times are simulated data for practice.)*

Temperature (°C)	20	30	40	50
Time for the cross to disappear (s)	210	105	52	26

(a) State (i) the variable the class changed and (ii) the variable the class measured. *(1 mark)*
(b) Describe the pattern the results show. *(1 mark)*
(c) Use the idea of colliding particles to explain why the cross disappears sooner at the higher temperatures. *(1 mark)*

Test B

Topic test 4 — Chemical sciences: atoms, isotopes, the periodic table and chemical reactions

Science understanding and science inquiry · Chapters 10–11 · Subtopics 10A, 10B, 10C, 11A, 11B, 11C and 11D · Codes VC2S10U06, VC2S10U07, VC2S10U08 and VC2S10U09

Total: 40 marks · Section A (multiple choice): 10 marks · Section B (short/structured response): 30 marks

6 of the 40 marks are science inquiry marks, attached to the practical work of Chapters 10–11 (Section B, Q16 and Q17).

Planned for about 50 minutes. This paper is untimed — there is no time to beat.

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- **A scientific calculator is permitted.** Only the half-life calculation in Q12 needs arithmetic, and it can also be done by repeated halving. No formula sheet. No reading time.
- Answer every question. For multiple-choice questions, circle the letter of the best answer. There is only one best answer for each question.

In this test you will:

- work with subatomic particles, describe how the model of the atom changed as new evidence arrived, and identify how unstable isotopes decay to form stable atoms (Q1, Q11)
- use half-life to calculate how a radioactive sample changes with time (Q12)
- classify an energy change as exothermic or endothermic (Q9)
- describe the reactivity trend of Group 1 and the flame colours that identify elements (Q3, Q4, Q10, Q13)
- apply the Law of Conservation of Mass to closed and open systems, and balance symbol equations (Q5, Q6, Q14, Q15)
- classify reactions as synthesis, decomposition or displacement, and predict their products (Q7, Q8)
- read observations, identify variables and explain a pattern from the practical work of Chapters 10–11 (Q16, Q17)

Section A — Multiple choice (10 marks)

Each question is worth 1 mark. Circle the letter of the best answer.

Q1 *(1 mark · VC2S10U06)* Which particle has the SMALLEST mass?

A. Proton B. Neutron C. Electron D. Nucleus

Q2 *(1 mark · VC2S10U06)* Isotopes of an element differ in:

A. Number of neutrons B. Number of protons C. Charge D. Element identity

Q3 *(1 mark · VC2S10U07)* Going across a period from left to right, the number of:

A. Protons decreases B. Electron shells increases C. Outer electrons stays the same D. Outer electrons increases

Q4 *(1 mark · VC2S10U07)* Which Group 1 metal is MOST reactive with water?

A. Lithium B. Caesium (heaviest in group) C. Sodium D. Potassium

Q5 *(1 mark · VC2S10U08)* In the equation $2H_2 + O_2 \rightarrow 2H_2O$, the PRODUCT is:

A. H_2O B. H_2 C. O_2 D. H^+

Q6 *(1 mark · VC2S10U08)* If a balanced equation has 2 oxygen atoms on the LEFT, the RIGHT side must have:

A. 1 oxygen atom B. 4 oxygen atoms C. 2 oxygen atoms D. Any number of oxygen atoms

Q7 *(1 mark · VC2S10U09)* $Zn + 2HCl \rightarrow ZnCl_2 + H_2$ is a:

A. Synthesis B. Single displacement C. Decomposition D. Combustion

Q8 *(1 mark · VC2S10U09)* Predict the product of $CuSO_4 + Fe \rightarrow$

A. Cu + S B. $CuFe_2$ C. $FeSO_4$ + Fe D. $FeSO_4$ + Cu

Q9 *(1 mark · VC2S10U09)* A hand warmer uses the reaction of iron with oxygen in the air. The temperature of the pack rises. This reaction is classified as:

A. exothermic, because the reaction releases energy to the surroundings B. exothermic, because the reaction takes in energy from the surroundings C. endothermic, because the reaction releases energy to the surroundings D. endothermic, because the reaction takes in energy from the surroundings

Q10 *(1 mark · VC2S10U07)* Why do Group 1 (alkali) metals react strongly with water?

A. They have a full outer shell of electrons B. They are very dense metals C. They have seven outer electrons to share D. Their single outer electron is readily lost

Section B — Short/structured response (30 marks)

Q11 *(4 marks · VC2S10U06)* The model of the atom changed as new evidence arrived.

(a) In the early 1800s John Dalton proposed a model of the atom. State what Dalton proposed. *(1 mark)*
(b) In 1897 J. J. Thomson discovered the electron. State what this discovery showed about Dalton's model. *(1 mark)*
(c) In Rutherford's gold foil experiment, about 1 in 8 000 alpha particles bounced straight back. State what this showed about where the atom's positive charge sits. *(1 mark)*
(d) Radon-222 is an unstable isotope. It decays to polonium-218. State the type of radiation emitted in this decay. *(1 mark)*

Q12 *(5 marks · VC2S10U06)* Technetium-99m is a radioactive isotope used in medical imaging: it is put into the body, and the gamma rays that escape are detected by a camera. Its half-life is 6.0 hours. A freshly prepared sample gives a corrected count rate of 4 800 counts/min. *(Simulated data for practice.)*

(a) State what the half-life of 6.0 hours tells you about this sample. *(1 mark)*
(b) Calculate the corrected count rate 12 hours after the sample is prepared. Show your working. *(2 marks)*
(c) Calculate how many hours it takes for the corrected count rate to fall to 600 counts/min. *(1 mark)*
(d) State one reason a hospital chooses an isotope with a half-life measured in hours, not years, for a scan inside the body. *(1 mark)*

Q13 *(4 marks · VC2S10U07)* A teacher demonstrates the reactions of lithium, sodium and potassium with water. These metals are stored under oil, because they react with the air and with water.

(a) State two observations a student records when a small piece of sodium is placed on water. *(1 mark)*
(b) State the trend in reactivity going down Group 1, and give the reason for the trend from the electron shells of the atoms. *(2 marks)*
(c) Potassium catches fire during its reaction. State the colour of the flame, and state the name of the pattern of light each element gives off, which acts like a fingerprint. *(1 mark)*

Q14 *(5 marks · VC2S10U08)* A student burns a 2.0 kg log of wood on an open fire and finds only about 0.1 kg of ash left. Another student heats 4.8 g of magnesium in a sealed crucible; the magnesium combines with 3.2 g of oxygen from the air trapped inside. *(All readings are simulated data for practice.)*

(a) Explain why the ash is so much lighter than the log, and name the two substances that carry most of the log's mass away. *(2 marks)*
(b) Calculate the mass of magnesium oxide formed in the sealed crucible, and explain how your answer shows the Law of Conservation of Mass. *(2 marks)*
(c) A student writes: "The log lost mass, so mass is not conserved when wood burns." Evaluate the claim. *(1 mark)*

Q15 *(6 marks · VC2S10U08)* Balance each equation. Put coefficients (numbers in front) only — never change the small numbers inside a formula.

(a) $N_2 + H_2 \rightarrow NH_3$ *(1 mark)*
(b) $C_3H_8 + O_2 \rightarrow CO_2 + H_2O$ *(1 mark)*
(c) $Na + Cl_2 \rightarrow NaCl$ *(1 mark)*
(d) $Fe + O_2 \rightarrow Fe_2O_3$ *(1 mark)*
(e) Write the word equation for the burning of methane in oxygen. *(1 mark)*
(f) A student writes $CuCO_3 \rightarrow CuO + CO_2$. State whether the equation is already balanced, and show the atom count that supports your answer. *(1 mark)*

Q16 *(3 marks · VC2S10U09 · inquiry)* In Chapter 11, Activity 3 of Subtopic 11B, a class heats a small spatula measure of green copper(II) carbonate in a test tube fitted with a delivery tube whose end stands in limewater. The class wears eye protection, and leaves the glass to cool before touching it, because the glass stays hot.

(a) State two observations that show a reaction is happening — one of the solid, one of the limewater. *(1 mark)*
(b) Name the gas given off, and state what the limewater result shows. *(1 mark)*
(c) Identify the family of the reaction — synthesis, decomposition or displacement — and state the question from the identification key that decides the sorting. *(1 mark)*

Q17 *(3 marks · VC2S10U09 · inquiry)* In Subtopic 11D, Activity 4, a class half-fills two test tubes with the same hydrogen peroxide solution. To one tube they add a small amount of black manganese(IV) oxide powder; the other tube is left as the control. The class wears eye protection and keeps flames away, because the gas given off supports burning.

(a) State what is observed in the tube with the manganese(IV) oxide, and what is observed in the control tube. *(1 mark)*
(b) Name the gas given off, and state the test that identifies it. *(1 mark)*
(c) State what the word *catalyst* means, and state how the class could show that the manganese(IV) oxide was not consumed. *(1 mark)*

Marking guide

This guide is written for a teacher marker — no specialist science background beyond Chapters 10–11 of this book is needed. Award a mark when the student's answer matches an acceptable response below or says the same idea in other words. Do not award half marks. The marks are a record that evidence was seen; they are not used to rank students.

Test A — Section A — Multiple choice

Q	Answer	Code	Source
Q1	**B**	`VC2S10U06`	bank item `VC2S10U06.E01.S01.D1.V01`
Q2	**D**	`VC2S10U06`	bank item `VC2S10U06.E02.S01.D2.V01`
Q3	**A**	`VC2S10U07`	bank item `VC2S10U07.E01.S01.D1.V01`
Q4	**C**	`VC2S10U07`	bank item `VC2S10U07.E02.S01.D3.V01`
Q5	**B**	`VC2S10U08`	bank item `VC2S10U08.E01.S01.D1.V01`
Q6	**C**	`VC2S10U08`	bank item `VC2S10U08.E02.S01.D2.V01`
Q7	**A**	`VC2S10U09`	bank item `VC2S10U09.E01.S01.D2.V01`
Q8	**D**	`VC2S10U09`	new item authored against `VC2S10U09.E04`
Q9	**B**	`VC2S10U06`	new item authored against `VC2S10U06.E03`
Q10	**C**	`VC2S10U09`	bank item `VC2S10U09.E02.S01.D3.V01`

Eight of the ten items are drawn from the MCQ bank under the codes assessed on this paper; none is drawn from a neighbouring code. Q8 and Q9 are newly authored against their own codes: the bank's `VC2S10U09` items cover only reaction types (`.E01`) and product prediction (`.E02`), and cannot supply an exothermic/endothermic item at any difficulty (the energy limb sits with elaboration `VC2S10U09.E04`), and the bank's `VC2S10U06` items cover only subatomic particles (`.E01`) and isotopes (`.E02`), and cannot supply an item on how unstable isotopes decay (elaboration `VC2S10U06.E03`). Items mix easy (D1), medium (D2) and hard (D3) difficulties. Items are printed with their stem and options word for word; only the positions of the options have changed for this paper, so that the correct answers are spread across A, B, C and D (the printed positions are A × 2, B × 3, C × 3, D × 2). Formulas are printed with true subscripts and the bank's `->` as →, per the book's typography.

Why each answer is correct, in brief:

- **Q1 B** — the proton carries a positive charge (+1); the electron is negative, the neutron has no charge, and a photon is not one of the atom's subatomic particles.
- **Q2 D** — isotopes of the one element have the same number of protons and differ only in their number of neutrons.
- **Q3 A** — elements in the same group have the same number of outer electrons, and the outer electrons drive the chemical behaviour.
- **Q4 C** — the noble gases have a full outer electron shell, which is energetically stable, so they have no need to gain, lose or share electrons.

- **Q5 B** — the reactants are the starting substances, written on the left of the arrow: H_2 and O_2. H_2O is the product.
- **Q6 C** — $H_2 + Cl_2 \rightarrow 2HCl$ gives two hydrogens and two chlorines on each side; the coefficient of HCl is 2.
- **Q7 A** — one reactant ($CaCO_3$) splitting into two products (CaO and CO_2) is the decomposition pattern.
- **Q8 D** — the temperature of the mixture falls, so the reaction takes in energy from the surroundings: endothermic. Citric acid with sodium hydrogen carbonate is one of the endothermic examples taught in Subtopic 11D.
- **Q9 B** — iodine-131 decays to xenon-131 by emitting a beta particle, as taught in Subtopic 10B; alpha decay changes the atom's mass, and gamma emission alone does not change one element into another.
- **Q10 C** — a displacement happens only when the element coming in is more reactive than the element it would push out; copper sits below iron in the reactivity series, so no reaction occurs.

Test A — Section B — Short/structured response

Q11 *(4 marks · VC2S10U06)* (a) the electron; its charge is negative (−1). *1 mark* The name and the charge must both be there. (b) most alpha particles passed straight through → the atom is mostly empty space. *1 mark* About 1 in 8 000 bounced straight back → the atom's mass and positive charge are concentrated in a tiny central nucleus. *1 mark* (c) the neutron; it sits in the nucleus. *1 mark* Both parts needed. Marker note: this item assesses the changing model of the atom as new evidence arrived (elaboration `VC2S10U06.E01`), taught in Subtopic 10A. No dates or names beyond those given in the stem are required.

Q12 *(5 marks · VC2S10U06)* (a) the time it takes for half of the unstable atoms in a sample to decay. *1 mark* Accept "for the count rate to halve". (b) 16 days ÷ 8.0 days = 2 half-lives. *1 mark* 8 000 → 4 000 → 2 000 counts/min. *1 mark* (c) 8 000 → 4 000 → 2 000 → 1 000 is 3 halvings, so 3 half-lives; 3 × 8.0 = 24 days. *1 mark* (d) background radiation is always present (from rocks in the ground, cosmic rays, building materials); unless it is subtracted, every reading carries that extra count and the sample's true count rate is overestimated. *1 mark* Accept any wording that says the background adds to the measured count. Marker note: this is the half-life calculation §7 requires on this paper; it uses the repeated-halving method of Subtopic 10B (elaboration `VC2S10U06.E04`). Corrected count rate = measured count rate − background count rate is the relationship taught in 10B.

Q13 *(4 marks · VC2S10U07)* (a) Group 17 — the atom has 7 outer electrons. *1 mark* Period 3 — the atom has 3 shells occupied. *1 mark* Each number must follow from the given arrangement. (b) a non-metal; the right-hand side of the periodic table. *1 mark* Both parts needed. (c) less reactive; reactivity decreases going down Group 17, and element X sits below fluorine. *1 mark* Marker note: naming element X as chlorine is not required, and is neither rewarded nor penalised.

Q14 *(5 marks · VC2S10U08)* (a) the total mass of the products equals the total mass of the reactants; atoms are rearranged, never made or destroyed. *1 mark* (b) the sealed bag is a closed system — the carbon dioxide made stays inside the bag, so its mass is still on the balance. *1 mark* (c) the open cup is an open system. *1 mark* 0.6 g of carbon dioxide escaped into the room. *1 mark* (d) the extra mass is oxygen from the air that joined the iron while it was heated: 5.0 g of iron + 1.4 g of oxygen = 6.4 g of product, so the total is still conserved. *1 mark* Marker note: the readings are the simulated data for practice taught in Subtopic 11A (elaboration `VC2S10U08.E03`).

Q15 *(6 marks · VC2S10U08)* (a) $2Mg + O_2 \rightarrow 2MgO$. *1 mark* (b) $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$. *1 mark* (c) $4Al + 3O_2 \rightarrow 2Al_2O_3$. *1 mark* (d) $2H_2O_2 \rightarrow 2H_2O + O_2$. *1 mark* (e) zinc + hydrochloric acid → zinc chloride + hydrogen. *1 mark* (f) $Zn + 2HCl \rightarrow ZnCl_2 + H_2$. *1 mark* Award each balancing mark only for the fully balanced equation; a coefficient of 1 may be left unwritten. A changed formula (for example MgO_2 in place of MgO) loses the mark — the stem says coefficients only. Marker note: this is the equation balancing §7 requires on this paper. Every formula appears in the provided table of Subtopic 11B (elaboration `VC2S10U08.E04`); the zinc–acid reaction itself is taught in Subtopic 11C.

Q16 *(3 marks · VC2S10U09 · inquiry)* (a) any two of: the nail is coated with an orange-brown layer; the blue solution fades towards pale green. *1 mark* (b) copper and iron sulfate. *1 mark* (c) displacement, with the deciding question: does an element take the place of another in a compound? Yes — iron takes copper's place. *1 mark* The family and the key question must both be there. Marker note: the inquiry marks attach to the chapter's own practical work (D7): this item is the iron-nail displacement of Subtopic 11C, Activity 2 (elaboration `VC2S10U09.E03`).

Q17 *(3 marks · VC2S10U09 · inquiry)* (a) (i) the temperature of the mixture; (ii) the time for the cross to disappear. *1 mark* Both needed. (b) the higher the temperature, the shorter the time — the reaction is faster at higher temperatures. *1 mark* (c) at higher temperatures the particles move faster, so the reactant particles collide more often and the cloudiness forms sooner. *1 mark* Marker note: this item is the disappearing-cross rate investigation of Subtopic 11D, Activity 2 (elaboration `VC2S10U09.E05`), with fresh data. Identifying variables uses the method taught in Chapters 2–3.

Test B — Section A — Multiple choice

Q	Answer	Code	Source
Q1	**C**	`VC2S10U06`	bank item `VC2S10U06.E01.S01.D2.V01`
Q2	**A**	`VC2S10U06`	bank item `VC2S10U06.E02.S01.D1.V01`
Q3	**D**	`VC2S10U07`	bank item `VC2S10U07.E01.S01.D2.V01`
Q4	**B**	`VC2S10U07`	bank item `VC2S10U07.E02.S01.D1.V01`
Q5	**A**	`VC2S10U08`	bank item `VC2S10U08.E01.S01.D2.V01`
Q6	**C**	`VC2S10U08`	bank item `VC2S10U08.E02.S01.D1.V01`
Q7	**B**	`VC2S10U09`	bank item `VC2S10U09.E01.S01.D3.V01`
Q8	**D**	`VC2S10U09`	bank item `VC2S10U09.E02.S01.D2.V01`
Q9	**A**	`VC2S10U09`	new item authored against `VC2S10U09.E04`
Q10	**D**	`VC2S10U07`	bank item `VC2S10U07.E01.S01.D3.V01`

Nine of the ten items are drawn from the MCQ bank under the codes assessed on this paper; none is drawn from a neighbouring code. Q9 is newly authored against the same code: the bank's `VC2S10U09` items cover only reaction types (`.E01`) and product prediction (`.E02`), and cannot supply an exothermic/endothermic item at any difficulty (the energy limb sits with elaboration `VC2S10U09.E04`). Items mix easy (D1), medium (D2) and hard (D3) difficulties. Items are printed with their stem and options word for word; only the positions of the options have changed for this paper, so that the correct answers are spread across A, B, C and D (the printed positions are A × 3, B × 2, C × 2, D × 3). Formulas are printed with true subscripts and the bank's `->` as →, per the book's typography.

Why each answer is correct, in brief:

- **Q1 C** — the electron is about 1/1836 as heavy as a proton or a neutron; nearly all of the atom's mass sits in the nucleus.
- **Q2 A** — isotopes differ only in their number of neutrons; the number of protons fixes the element, so it cannot change.
- **Q3 D** — going left to right across a period, each element has one more outer electron; the number of shells stays the same across a period.
- **Q4 B** — reactivity increases going down Group 1, so caesium, the heaviest of the four, reacts most strongly with water.
- **Q5 A** — the product is the substance formed, written on the right of the arrow: H_2O.

- **Q6 C** — atoms are neither made nor destroyed, so the right side must hold the same 2 oxygen atoms as the left.
- **Q7 B** — zinc, the more reactive element, takes the place of hydrogen in the compound: the displacement pattern.
- **Q8 D** — iron is more reactive than copper, so iron displaces copper: $FeSO_4$ + Cu.
- **Q9 A** — the temperature of the pack rises, so the reaction releases energy to the surroundings: exothermic. The hand warmer that uses the reaction of iron with oxygen is taught in Subtopic 11D.
- **Q10 D** — a Group 1 atom holds a single outer electron that is readily lost in a reaction; the further down the group, the more easily it is lost.

Test B — Section B — Short/structured response

Q11 *(4 marks · VC2S10U06)* (a) all matter is made of tiny particles called atoms, which cannot be divided into anything smaller (solid spheres). *1 mark* (b) the atom is divisible — it contains smaller particles (electrons), so Dalton's indivisible sphere cannot be the whole story. *1 mark* (c) the positive charge (and most of the mass) is concentrated in a tiny central nucleus. *1 mark* (d) alpha radiation (an alpha particle). *1 mark* Marker note: the changing model of the atom is taught in Subtopic 10A (elaboration `VC2S10U06.E01`); the radon-222 decay is taught in Subtopic 10B (elaboration `VC2S10U06.E03`). No dates or names beyond those given in the stem are required.

Q12 *(5 marks · VC2S10U06)* (a) every 6.0 hours, half of the unstable atoms in the sample decay — the count rate halves. *1 mark* (b) 12 hours ÷ 6.0 hours = 2 half-lives. *1 mark* 4 800 → 2 400 → 1 200 counts/min. *1 mark* (c) 4 800 → 2 400 → 1 200 → 600 is 3 halvings, so 3 half-lives; 3 × 6.0 = 18 hours. *1 mark* (d) any one of: the isotope's activity falls away quickly after the scan, so the patient is not exposed for long; an isotope with a half-life of years would keep the patient radioactive long after the scan is over. *1 mark* Marker note: this is the half-life calculation §7 requires on this paper; the medical-imaging context is the tracer application taught in Subtopic 10B, and the calculation is the repeated-halving method of elaboration `VC2S10U06.E04`.

Q13 *(4 marks · VC2S10U07)* (a) any two of: fizzes; melts into a ball; darts around on the surface. *1 mark* (b) reactivity increases going down Group 1. *1 mark* The outer electron sits in a higher shell, further from the nucleus, so it is held less tightly and is lost more easily. *1 mark* (c) lilac; the emission spectrum. *1 mark* Both parts needed. Marker note: the demonstration and its explanation are taught in Subtopic 10C (elaborations `VC2S10U07.E02` and `VC2S10U07.E06`).

Q14 *(5 marks · VC2S10U08)* (a) the fire is an open system, so most of the log's mass leaves as gases. *1 mark* Carbon dioxide and water vapour. *1 mark* (b) 4.8 + 3.2 = 8.0 g. *1 mark* The mass of the product equals the total mass of the reactants (magnesium and oxygen together), which is what the law says. *1 mark* (c) the claim is wrong: the law holds when every reactant and every product is counted — the missing mass left as gases into the air; it was not destroyed. *1 mark* Marker note: the log and the sealed crucible are simulated data for practice in the style of Subtopic 11A (elaboration `VC2S10U08.E03`); the magnesium + oxygen → magnesium oxide masses (4.8 g + 3.2 g → 8.0 g) are the values taught in Subtopic 11A.

Q15 *(6 marks · VC2S10U08)* (a) $N_2 + 3H_2 \rightarrow 2NH_3$. *1 mark* (b) $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$. *1 mark* (c) $2Na + Cl_2 \rightarrow 2NaCl$. *1 mark* (d) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$. *1 mark* (e) methane + oxygen → carbon dioxide + water. *1 mark* (f) yes — the atoms of each element already match on both sides: Cu 1 = 1, C 1 = 1, O 3 = 3. *1 mark* The count must be shown. Award each balancing mark only for the fully balanced equation; a coefficient of 1 may be left unwritten. A changed formula loses the mark — the stem says coefficients only. Marker note: this is the equation balancing §7 requires on this paper. Every formula appears in the provided table of Subtopic 11B (elaboration `VC2S10U08.E04`); (e) is the combustion word equation taught in Subtopic 11A, and (f) is the thermal decomposition of copper(II) carbonate taught in Subtopics 11B and 11C.

Q16 *(3 marks · VC2S10U09 · inquiry)* (a) the green powder leaves a black residue; the limewater turns milky. *1 mark* Both needed. (b) carbon dioxide; the milky limewater identifies the gas. *1 mark* (c) decomposition, with the deciding question: is there only one reactant? Yes — one compound splits into two products. *1 mark* The family and the key question must both be there. Marker note: the inquiry marks attach to the chapter's own practical work (D7): this item is the heating of copper(II) carbonate, Subtopic 11B, Activity 3 (elaboration `VC2S10U08.E04`), which Subtopic 11C also draws on.

Q17 *(3 marks · VC2S10U09 · inquiry)* (a) the tube with the manganese(IV) oxide bubbles briskly — many bubbles of gas; the control tube shows no bubbles, or only very slow ones. *1 mark* Both tubes must be described. (b) oxygen; a glowing splint relights in the gas. *1 mark* (c) a catalyst is a substance that speeds up a reaction without being used up; the class could filter the mixture afterwards and show the black solid is still there, unchanged. *1 mark* The definition and the check must both be there. Marker note: this item is the catalyst activity of Subtopic 11D, Activity 4 (elaboration `VC2S10U09.E05`). The second tube is the control, as taught in Chapters 2–3 (Subtopic 3A).

Tracing the items to the achievement standard

Every item traces to the achievement-standard extract of the subtopic that owns its code (§4.1 of the plan of record). The extracts are quoted as the authority file gives them. `VC2S10U06`, `VC2S10U08` and `VC2S10U09` are split-delivered: 10A owns the changing-atomic-model limb and 10B the decay and half-life limb; 11A owns the Conservation-of-Mass limb and 11B the word and balanced symbol equations limb; 11C owns the reaction-types limb and 11D the exothermic/endothermic classification limb. `VC2S10U07` is delivered whole by 10C. The `VC2S10U09` extract names the energy classification that 11D delivers, and it is assessed directly by Test A Q8 and Test B Q9; the reaction-type and rate items trace to the same code, because 11C builds the reaction types, and 11D the rate factors, that the classification draws on.

Code	Subtopic	Achievement-standard extract	Test A items	Test B items
`VC2S10U06`	10A and 10B	"They explain how ideas about the structure of the atom have changed over time, and model natural radioactive decay to illustrate how stable atoms are formed."	Q1, Q2, Q9, Q11, Q12	Q1, Q2, Q11, Q12
`VC2S10U07`	10C	"They describe patterns and trends in the periodic table."	Q3, Q4, Q13	Q3, Q4, Q10, Q13
`VC2S10U08`	11A and 11B	"They demonstrate the Law of Conservation of Mass in chemical reactions, and write word and balanced chemical equations for these reactions."	Q5, Q6, Q14, Q15	Q5, Q6, Q14, Q15
`VC2S10U09`	11C and 11D	"They classify energy changes in chemical reactions as exothermic or endothermic."	Q7, Q8, Q10, Q16, Q17	Q7, Q8, Q9, Q16, Q17

Inquiry weighting: 6 of the 40 marks on each paper are inquiry items attached to the practical work of Chapters 10–11 (Section B Q16 and Q17) — meeting the required minimum of 6 inquiry-strand marks per topic test (D7). On Test A the items attach to the iron-nail displacement of Subtopic 11C (Activity 2) and the disappearing-cross rate investigation of Subtopic 11D (Activity 2); on Test B, to the heating of copper(II) carbonate from Subtopic 11B (Activity 3) and the catalyst activity of Subtopic 11D (Activity 4).

Mark record — Test A

Question	Code	Worth	Given
Q1 — the positively charged particle	VC2S10U06	1	
Q2 — carbon-12 and carbon-14	VC2S10U06	1	
Q3 — same group, same properties	VC2S10U07	1	
Q4 — why the noble gases stay aloof	VC2S10U07	1	
Q5 — the reactants in the water equation	VC2S10U08	1	
Q6 — balancing hydrogen and chlorine	VC2S10U08	1	
Q7 — heating calcium carbonate	VC2S10U09	1	
Q8 — an endothermic mixture	VC2S10U09	1	
Q9 — how iodine-131 decays	VC2S10U06	1	
Q10 — why copper cannot push iron out	VC2S10U09	1	
Q11 — the evidence that changed the atom	VC2S10U06	4	
Q12 — the half-life of iodine-131	VC2S10U06	5	
Q13 — element X, 2,8,7	VC2S10U07	4	
Q14 — the sealed bag and the open cup	VC2S10U08	5	
Q15 — balancing equations	VC2S10U08	6	
Q16 — the iron nail in copper sulfate (inquiry)	VC2S10U09	3	
Q17 — the disappearing cross (inquiry)	VC2S10U09	3	
Total		**40**	

Mark record — Test B

Question	Code	Worth	Given
Q1 — the lightest particle	VC2S10U06	1	
Q2 — what isotopes differ in	VC2S10U06	1	
Q3 — across a period	VC2S10U07	1	
Q4 — the most reactive Group 1 metal	VC2S10U07	1	
Q5 — the product in the water equation	VC2S10U08	1	
Q6 — oxygen atoms on both sides	VC2S10U08	1	
Q7 — zinc and hydrochloric acid	VC2S10U09	1	
Q8 — iron in copper sulfate solution	VC2S10U09	1	
Q9 — the hand warmer's energy change	VC2S10U09	1	
Q10 — why Group 1 reacts with water	VC2S10U07	1	
Q11 — how the model of the atom changed	VC2S10U06	4	
Q12 — the half-life of technetium-99m	VC2S10U06	5	
Q13 — lithium, sodium, potassium and water	VC2S10U07	4	
Q14 — the log fire and the sealed crucible	VC2S10U08	5	
Q15 — balancing equations	VC2S10U08	6	
Q16 — heating copper(II) carbonate (inquiry)	VC2S10U09	3	
Q17 — a catalyst at work (inquiry)	VC2S10U09	3	
Total		**40**	

SIT-2 Full investigation report

What this task assesses — Science inquiry strand: `VC2S10I02`, `VC2S10I03`, `VC2S10I04`, `VC2S10I05`, `VC2S10I06`, `VC2S10I07` and `VC2S10I08` (Victorian Curriculum F–10 Version 2.0, Science, Levels 9 and 10). SIT-2 is the second of the two Scientific Investigation Tasks that assess Chapter 2–6's inquiry spine (D7). Where SIT-1 reads someone else's investigation, SIT-2 runs one of your own: you choose one of three approved contexts drawn from Chapters 7–11, plan the investigation, write the risk assessment and the ethics statement, conduct it, keep the logbook, process the data, analyse it, evaluate the method and the conclusion, and report the finding to a stated audience. **Achievement-standard extracts served here (D14), as the authority file gives them:** `VC2S10I02` — *"They plan a range of valid, reproducible and safe scientific investigations and explain how they have addressed any ethical and cultural considerations when generating or using primary and secondary data."* · `VC2S10I03` — *"They select and use equipment to generate and record data, ensuring the use of suitable sample sizes and assessing the precision of multiple measurement readings."* · `VC2S10I04` — *"They select and construct a range of appropriate representations to organise, process and summarise data and information."* · `VC2S10I05` — *"They analyse and compare a variety of data and information to identify and explain qualitative and quantitative patterns, trends, relationships, assumptions and anomalies."* · `VC2S10I06` — *"They evaluate the validity and reproducibility of investigation methods including ways to improve the quality of data, and the validity of conclusions and claims."* · `VC2S10I07` — *"They provide evidence-based explanations for findings and construct logical arguments based on the evaluation of multiple sources of evidence to justify conclusions and assess claims."* · `VC2S10I08` — *"They select and use appropriate presentation formats, scientific content, vocabulary, models, conventions, formulas and other representations to achieve their purpose when communicating and justifying their ideas, findings, arguments and proposals to diverse audiences."* **The cultural-heritage and permissions check (D10 protocol limb).** Part 3 of this task is where the protocol limb of `VC2S10I02` is assessed: every student works through the Country and Place checks taught in Subtopic 3B — the *Aboriginal Heritage Act 2006* (Vic) and the *Aboriginal Heritage Regulations 2018* (Vic), Registered Aboriginal Parties, Cultural Heritage Management Plans, and the land manager's permission where none of those applies — and records the outcome for their chosen context, because the achievement standard above asks students to explain how they have addressed any ethical and cultural considerations when generating or using primary and secondary data. The instruments are named; no provision numbers are cited in this task. The second limb of the mandate — `VC2S10I07`'s ethical issues and cultural protocols when accessing, using or citing secondary data — is addressed through Part 3's secondary-data statement and the report's reference list, the way Subtopic 5B teaches. **Elaboration contexts drawn on:** `VC2S10I02.E01` (the ethical discussion before any investigation involving animals — assessed through Part 3 where relevant), `VC2S10I02.E07` (identifying the hazards of chemicals and biological materials and how they should be addressed — assessed through Part 2, and built for Context 2 by Subtopic 3B's completed marble-chips assessment), `VC2S10I03.E03` and `VC2S10I03.E05` (precision, uncertainty and how much data is enough — assessed through Part 4), `VC2S10I07.E05` (acknowledging sources and respecting cultural protocols when using or citing secondary data — assessed through Part 3 and Part 8) and `VC2S10I08.E01` (the written report — assessed through Part 8).

Scientific Investigation Task 2 — Full investigation report

Science inquiry · hosted after Chapter 11 · Codes `VC2S10I02`, `VC2S10I03`, `VC2S10I04`, `VC2S10I05`, `VC2S10I06`, `VC2S10I07` and `VC2S10I08`

Total: 40 marks · Part 1 Plan: 7 marks · Part 2 Risk assessment: 5 marks · Part 3 Ethics statement: 6 marks · Part 4 Logbook: 5 marks · Part 5 Processed data: 6 marks · Part 6 Analysis: 3 marks · Part 7 Evaluation: 4 marks · Part 8 Report: 4 marks

Planned for about three weeks of class time. This task is untimed — there is no time to beat.

This is a school-designed task. It is not a VCAA instrument. There is no external examination at Levels 9 and 10; achievement is reported against the Victorian Curriculum Levels 9 and 10 achievement standard on teacher judgement, and the marks here are one source of evidence towards that judgement.

Conditions

- Completion is **untimed**. The three weeks is planning guidance only; your teacher will set the checkpoints and the due dates.
- **Reading support** is permitted. Your teacher may read any part of this task out to you if you need it. Reading is not what is being looked at, and your teacher will not help with the answers.
- A **scientific calculator is permitted** for processing your data.
- You may work with one partner for the bench work and the data collection, but **each student keeps their own logbook and writes their own plan, risk assessment, ethics statement, analysis, evaluation and report.**
- **Write down what you actually saw**, even when it is messy. Made-up numbers are not science. A messy result you can explain is worth more than a tidy one you invented.

The task in one paragraph

Plan and run your own investigation from one of the three approved contexts below. Before any practical work starts, your teacher must approve three things: your plan (Part 1), your risk assessment (Part 2) and your ethics statement (Part 3). Then run the investigation and keep a logbook (Part 4). Process your data into a table and the right representation (Part 5), analyse it for trends and anomalies (Part 6), evaluate your method and your conclusion (Part 7), and finish with a report written for a stated audience (Part 8). The eight parts are marked separately, with the point-based marking guide at the back of this task.

Part 1 — Context and plan (7 marks)

Your investigation must stay inside one of these three contexts. You may sharpen the question, change the values you test, and choose your own equipment within the list, but the question must stay one your class can answer with standard school laboratory equipment, in class time, safely. Each context names the subtopic that gives it its science.

Context 1 — A slower catch *(Chapter 8 · Subtopic 8A — the nervous system coordinating responses to stimuli)*

Subtopic 8A teaches the pathway every coordinated response follows — stimulus → receptor → control centre → effector → response — and the ruler-drop test that times it. The distraction question is the one 8A's own activity asks: does a second task, occupying the control centre, slow the pathway down?

Seed question: How does a distraction (a phone conversation) change reaction time in the ruler-drop test?

Standard equipment: a 30 cm ruler (smallest division 1 mm), a quiet room, a table and chairs, and a results sheet with participant codes. The distance the ruler falls converts to a reaction time with Subtopic 8A's relationship (distance fallen = $\frac{1}{2} \times g \times t^2$, with $g = 9.8$ m/s²). Participants are class volunteers, recruited with informed consent the way Subtopic 3B teaches.

Context 2 — Marble chips, timed *(Chapter 11 · Subtopic 11D — the factors that change reaction rate; Subtopic 3B has already risk-assessed this exact task)*

Subtopic 11D teaches that the rate of a reaction — how fast reactants turn into products — is changed by concentration (how much acid is dissolved in the water), temperature, surface area and catalysts, and shows three ways to measure a rate: the gas collected, the mass lost, or a cross disappearing. The reaction of marble chips (calcium carbonate) with dilute hydrochloric acid makes carbon dioxide gas, and Subtopic 3B's completed risk assessment is written for exactly this task — start there, then make the assessment your own.

Seed question: How does the concentration of dilute hydrochloric acid change the rate of its reaction with marble chips?

Standard equipment: marble chips (calcium carbonate), dilute hydrochloric acid at two or three concentrations prepared by the teacher by dilution, conical flask, bung and delivery tube, gas syringe or inverted measuring cylinder in a water trough, stopwatch, electronic balance (to 0.1 g) if the mass-loss method is used, safety glasses. The rate can be the volume of gas collected ÷ time (cm³/s), or the time taken to collect a fixed volume of gas.

Context 3 — Beans and warmth *(Chapter 7 · Subtopic 7B — sexual reproduction in plants produces seeds carrying variation)*

Subtopic 7B teaches that sexual reproduction mixes the variation of two parents into their offspring, and that in plants the offspring starts as a seed. Germination — the seed sprouting and beginning to grow — needs water, oxygen and a suitable temperature.

Seed question: How does temperature change the number of bean seeds that germinate over seven days?

Standard equipment: bean seeds from one packet, paper towel or cotton wool, petri dishes or plastic cups, water, labels, a thermometer, and three teacher-approved locations at different temperatures (for example a refrigerator, the classroom bench and a warm cupboard). Seeds are living things — dormant, but alive — and Gate 2 of the ethics statement must cover how they are treated with care.

What Part 1 must contain

Write, under clear headings:

1. **Your context** — which one of the three you chose.
2. **Your question** — an investigable question (2A) inside that context. Name the two amounts it links.
3. **Your hypothesis** — a reasoned prediction with a reason attached: *I predict … because …* (2B), where the reason uses science from the named subtopic.
4. **Your variables** — the independent variable (the one you change), the dependent variable (the one you measure), and at least three controlled variables (the ones you keep the same), each with how you will keep it the same (3A).
5. **Your assumptions** — at least one thing you are taking for granted that could affect the result (3A).
6. **Your method** — numbered steps another group could follow exactly, including how many values of the independent variable you will test, how many repeat readings you will take, and how large your sample is — and why that is enough (3C). Name at least one possible source of error or bias, and the step in the method that controls it (`VC2S10I02`).

Do not start any practical work until your teacher has approved Parts 1, 2 and 3.

Part 2 — Risk assessment (5 marks)

Write a risk assessment for your method, the way 3B teaches it — the five-step routine that is always done before the work starts:

1. **Find the hazards** — anything in your method with the potential to cause harm: chemicals, glass, hot water, spills, electrical equipment, a slippery floor.
2. **Rate each risk before any controls** — likelihood (1–5) times consequence (1–5), on the 3B grid: 1–4 LOW, 5–9 MEDIUM, 10–15 HIGH, 16–25 EXTREME.
3. **Bring each risk down** with controls, working down the hierarchy of controls — eliminate, substitute, isolate, engineering controls, administrative controls, and only then personal protective equipment (PPE). Name the PPE you will wear, or say plainly that none is needed and why.
4. **Rate each risk again** with the controls in place. Every after-controls rating must be lower than the one before; a rating still sitting in the high or extreme zone means the plan does not run — it goes back for better controls.
5. **Get the sign-off** — your teacher signs and dates the risk assessment before any practical work starts. Approval comes before the work starts, never after.

Present it as a table with one row per hazard, naming who could be harmed and how.

Part 3 — Ethics statement, including the cultural-heritage and permissions check (6 marks)

Ethics asks who and what else the work touches, and holds the work to what is right and fair. Write the ethics statement as the four gates of Subtopic 3B write it:

1. **Gate 2 — living things.** Does your investigation use or affect any living thing — animals, plants, seeds, cultures of microorganisms? If yes, how will it be treated with care and respect, and kept from harm? Where

animals are involved, work through Subtopic 3B's three Rs — replace, reduce, refine — and the approval gate. If no living thing is involved, say so plainly.

2. **Gate 2 — people.** Does your investigation ask anything of people — participants in a test, a survey, data about them? If yes, show how the plan serves the five principles from 3B — informed consent, voluntary participation, privacy, no harm, and the teacher's check of the plan — and say what a participant under 18 needs as well. If no people are involved, say so.
3. **Secondary data and sources.** Will you use anyone else's data, methods or ideas — from a book, a website, this workbook, a class investigation? Name what is borrowed, and credit it in your report's reference list (5B, 6A). Where secondary data of Aboriginal or Torres Strait Islander origin is used, the citation obligations 5B teaches apply — name them. If nothing is borrowed, say so.
4. **Gate 3 — the cultural-heritage and permissions check.** Work through the Country and Place checks from 3B, question by question, and record your answer for your chosen context:
    - *Could the work touch Aboriginal cultural heritage — places, objects or ancestral remains — or take place on Country?* Your teacher checks, before the work starts, whether the area has registered Aboriginal cultural heritage and whether any conditions apply.
    - *If the work runs off the school grounds:* permission is sought from the right people — the Traditional Owners, through the Registered Aboriginal Party for that area — and every condition is followed, because conditions are part of the permission, not suggestions.
    - *If the work stays on school grounds:* the school is the land manager. Record the school's permission, and record what you checked.
    - *If anything that might be an artefact turns up:* stop, record, tell, report — the four steps from 3B, in order. Artefacts are protected under the *Aboriginal Heritage Act 2006* (Vic) and the *Aboriginal Heritage Regulations 2018* (Vic), and an artefact moved is evidence destroyed.

Part 3 is where this book checks what 3B taught. A context run entirely inside the school laboratory or classroom still gets the full check — the right answer there is not *not applicable*, it is the check itself: which questions do not apply, why, whose permission you did get, and what you would do if something that might be an artefact turned up. If your teacher approves a version of your context that runs off the school grounds, the check must name the real permissions that version needs.

Finish the statement with **Gate 4 — approvals and briefing**: who approved the plan, and that everyone involved was briefed on the rules before the work began.

Part 4 — Logbook (5 marks)

A **logbook** is the dated, written record of everything you did and observed, made at the time — not copied up afterwards. Your logbook must show:

- an entry for each session, dated;
- your raw readings, as you took them, with units, recorded to the precision the instrument supports (3C) — say what each instrument reads to, and if you record a reading to less precision than the instrument shows (because the judgement behind it is not that good), say why;
- repeat readings at every value of the independent variable, and the sample you used — how many trials, how many participants or samples — with a word on why that is enough (3C);
- honest mistakes handled the right way — a single line through the wrong reading, still legible, with a note in the margin. Never rub out, never overwrite;
- anything unexpected — a spill, a cooled beaker, a distracted participant, a seed that moulded — recorded when it happened;
- any digital tool you used — a spreadsheet, a datalogger — named, with the raw readings still visible behind it.

Part 5 — Processed data (6 marks)

Process your raw data the way Chapter 4 teaches:

1. **A processed table** — organised with the independent variable first, your repeat readings, and the mean at each value. Round each mean to the precision of the readings (4A). Units appear once, in the heading of each column, and the number and caption sit above the table (6A).
2. **The right representation** — choose the representation that fits your data from the 4A flowchart: categories of the independent variable → a bar graph; continuous values → a line graph; the distribution of many results → a histogram or dot plot. Construct it, not describe it: the independent variable on the horizontal axis, the dependent variable on the vertical axis, both labelled with the quantity and its unit, a sensible scale on each axis, and points or bars placed accurately (4A).
3. **The spread of the data** — report the uncertainty of your repeats the way 3C teaches, for example as mean ± half the range of the repeat readings (3C, 4A).
4. **Caption below the figure** — number your graph and give it its caption below (6A).
5. **Anomalies in view** — if you exclude a reading, show it, cross it out, and say why, in the table itself. Nothing disappears silently (4C).

Part 6 — Analysis (3 marks)

Read your processed data for what it shows (4C):

- state the **pattern, trend or relationship** — in words, with direction and shape, and then with the numbers that show it;
- **identify the anomalies** — readings that sit away from the rest — and give your best account of them, or a reasoned statement that there are none;
- say what your data **cannot** show — one investigation answers one question.

Part 7 — Evaluation (4 marks)

Interrogate your own method and your own conclusion (5A):

- name **two sources of error** in your method — not *human error*, but the particular thing — classify each as **random error** or **systematic error**, and say which way each would push your readings;
- return to your **assumptions** from Part 1: did each one hold? How do you know?
- judge the **validity** of the method — did it actually test what it set out to test, with only the tested factor different between conditions? — and say how much you can **trust the conclusion**, argued from the repeat readings, the sample, and the size of the trend against the scatter;
- give **one improvement** to the quality of the data, and **one question your investigation leaves unanswered**.

Part 8 — Report to a stated audience (4 marks)

Write the report in the nine-section shape of 6A — title, aim, hypothesis, background (only if your reader needs it), method, results, discussion, conclusion, references — and write it for a **stated audience**: name who the report is for, and why they would want the finding. The audience can be real (the school canteen, the road-safety committee, the principal, a Year 5 class) or clearly labelled as practice. Marks go to the fit and to the argument:

- the **conclusion answers the aim**, and is no stronger than the evidence allows — state what was tested, what was found, and where it holds (5B);
- the **argument is evidence-based**: a claim held up by the evidence from your results and the reasoning that connects them (5B);
- the **format, register and vocabulary suit the reader you named** (6B) — a reader who did not do the investigation and may not be a scientist;

- **conventions hold**: tables and figures numbered and captioned (caption above the table, below the figure), units written once in headings, past tense for what was done and found, and every borrowed thing credited in the reference list with an in-text citation beside it (6A).

What to hand in

Part	What	Marks	Code
1	Plan: context, question, hypothesis, variables, assumptions, method with sample size and an error or bias controlled	7	`VC2S10I02`
2	Risk assessment, signed by your teacher before practical work	5	`VC2S10I02`
3	Ethics statement with the cultural-heritage and permissions check	6	`VC2S10I02`
4	Logbook: dated entries, raw readings, precision, sample size, repeats	5	`VC2S10I03`
5	Processed table and representation, captioned, spread reported, anomalies in view	6	`VC2S10I04`
6	Analysis: trend, numbers, anomalies	3	`VC2S10I05`
7	Evaluation: errors classified, assumptions, validity, trust, improvement, next question	4	`VC2S10I06`
8	Report to a stated audience, nine-section shape, evidence-based, referenced	4	`VC2S10I07`, `VC2S10I08`
	Total	**40**	

Checkpoints

- **Checkpoint 1** — Parts 1, 2 and 3 approved by your teacher. No practical work before this.
- **Checkpoint 2** — practical work done, logbook kept.
- **Checkpoint 3** — Parts 5, 6 and 7 drafted and checked against the data.
- **Checkpoint 4** — Part 8 submitted.

Marking guide — SIT-2 Full investigation report

This guide is written for the classroom teacher. Award a mark when the student's response matches a descriptor below or says the same idea in other words. **Do not award half marks.** The marks are a record that evidence was seen; they are not used to rank students.

The model response that follows this guide is worked for **Context 1 — A slower catch**. It is one acceptable response of many: all three contexts are equally open, and a student's own sharpening of the seed question is expected. Judge every part against the descriptors, not against the model's numbers.

Approvals before marking. Confirm before you mark Part 4 onward that the student's Part 2 carries your own (or a colleague's) sign-off dated before the first practical session, and that the logbook entries are dated after it. Practical work that started before approval loses the Part 2 sign-off mark.

Part 1 — Plan (7 marks · `VC2S10I02`)

Descriptor	Marks
A context from the three approved, named.	1
An investigable question inside that context, linking two named amounts — one to change, one to measure. A question that is a yes/no question, or that cannot be answered with school equipment, does not earn this mark.	1
A hypothesis written as a reasoned prediction with a reason attached — *I predict … because …* — where the reason uses science from the named subtopic. A prediction with no reason earns no mark here.	1
The independent and dependent variables each named, with a unit or a scale for the one to be measured.	1
At least three controlled variables, each with *how* it will be kept the same — not just a list of things kept the same.	1
At least one assumption stated plainly.	1
A numbered method another group could follow — values of the independent variable named, repeat readings named, sample size named with a word on why it is enough — and at least one possible source of error or bias identified with the step of the method that controls it.	1

Part 2 — Risk assessment (5 marks · `VC2S10I02`)

Descriptor	Marks
The hazards of the chosen method identified — at least two real hazards of that method, each with who could be harmed and how, not a generic list.	1
Each hazard rated before controls as likelihood × consequence on the 3B grid (1–5 each; zones 1–4 low, 5–9 medium, 10–15 high, 16–25 extreme), with the zone named.	1
Controls given that work down the hierarchy of controls — eliminating, substituting or isolating the hazard where that is possible, not jumping straight to PPE.	1
The PPE named — or a reasoned statement that none is needed — and each risk re-rated with the controls in	1

Descriptor	Marks
place, lower than before, with nothing left in the high or extreme zone.	
The teacher's sign-off, dated before the first practical session.	1

Part 3 — Ethics statement (6 marks · `VC2S10I02`)

Descriptor	Marks
Gate 2, living things: the student says whether the work uses or affects any living thing, and where it does, how it is treated with care and kept from harm — or says plainly that none is involved. Where animals are used, the three Rs and the approval gate are worked through.	1
Gate 2, people: the student says who the work asks anything of, and where it does, how the five principles — informed consent, voluntary participation, privacy, no harm, teacher's check — are served, including the parent or carer signature for participants under 18 — or says plainly that no people are involved.	1
Secondary data and sources: what is borrowed is named, with credit promised in the reference list; where secondary data of Aboriginal or Torres Strait Islander origin is used, the citation obligations 5B teaches are named.	1
The cultural-heritage and permissions check worked through question by question for the chosen context — the area checked with the teacher and the land manager for registered Aboriginal cultural heritage, the permission identified (the school's, for work on school grounds; the Registered Aboriginal Party's, with its conditions, for fieldwork on Country) — with a reasoned answer at each question, not a blank.	2
The artefact rule stated for the context: if anything that might be an artefact turns up, stop, record, tell, report — or a reasoned account of why the work cannot disturb the ground at all.	1

Marking note. The full marks for the check are available to a school-based investigation whose student reaches the right conclusion by the right route: the work stays inside the school building or grounds, no registered Aboriginal cultural heritage is known there (checked with the school as land manager), the school's permission is recorded, and the artefact rule is stated. A student whose approved context runs off the school grounds must name the real permission that context needs — through the Registered Aboriginal Party for that area, with every condition recorded — and is marked against the same descriptor.

Part 4 — Logbook (5 marks · `VC2S10I03`)

Descriptor	Marks
Entries dated, written as the work happened — not a clean copy written up afterwards.	1
Raw readings recorded with units, to the precision each instrument supports, and the precision of each instrument stated somewhere the reader can find it — with a reason where a reading is recorded to less precision than the instrument shows.	1

Descriptor	Marks
Repeat readings at every value of the independent variable.	1
The sample stated and justified — how many trials, how many participants or samples, and a word on why that is enough.	1
Mistakes and surprises recorded honestly — the wrong reading crossed out with one line, still legible, noted in the margin; the unexpected event recorded at the time. A logbook with no crossing at all in a real investigation is a warning sign, not a strength.	1

Part 5 — Processed data (6 marks · `VC2S10I04`)

Descriptor	Marks
A processed table with the independent variable first, the repeat readings (or the per-participant or per-sample means where the design calls for them), and the mean at each value.	1
Each mean rounded to the precision of the readings, and units written once, in the column headings.	1
The right representation chosen from the 4A flowchart for the data's type — a bar graph where the independent variable is a set of categories, a line graph where it is continuous, a histogram or dot plot for the distribution of many results — constructed, not described.	1
Both axes labelled with the quantity and its unit, a sensible scale on each axis, and the points or bars placed accurately.	1
The spread of the repeats reported — for example as mean ± half the range, the way 3C teaches.	1
Table and figure numbered and captioned — caption above the table, below the figure — and any excluded reading shown, crossed out, with the reason; nothing disappears silently.	1

Part 6 — Analysis (3 marks · `VC2S10I05`)

Descriptor	Marks
The pattern, trend or relationship stated in words — with direction (rises, falls, stays level) and shape (steadily, all six participants, the same direction).	1
The trend carried by real numbers from the processed data.	1
Anomalies identified and given a best account, or a reasoned statement that there are none.	1

Part 7 — Evaluation (4 marks · `VC2S10I06`)

Descriptor	Marks
Two sources of error named from the student's own method — particular things, not *human error* — each classified as random error or systematic error, each with which way it would push the readings. One mark each.	2

Descriptor	Marks
The assumptions from Part 1 revisited: did each hold, and what is the evidence?	1
The validity of the method judged and the trust in the conclusion argued — from the repeat readings, the sample, and the size of the trend against the scatter — plus one real improvement to the quality of the data and one question the investigation leaves unanswered.	1

Part 8 — Report (4 marks · `VC2S10I07`, `VC2S10I08`)

Descriptor	Marks
A conclusion that answers the aim, is no stronger than the evidence allows, and is supported by visible evidence from the results — the finding, and the numbers it stands on.	1
An evidence-based argument: a claim held up by the evidence and the reasoning that connects them — not a restated opinion.	1
A stated audience, and a report shaped for that reader — format, register and vocabulary suited to someone who did not do the investigation. A report written at nobody in particular earns no mark here.	1
The nine-section shape of 6A followed; tables and figures numbered and captioned in their places; units written once; every borrowed thing credited in the reference list with an in-text citation beside it.	1

Tracing the parts to the achievement standard

Every part traces to the achievement-standard extract of the CD it serves (§4 of the plan of record). The extracts are quoted as the authority file gives them.

Code	Subtopic that teaches it	Achievement-standard extract	Parts
`VC2S10I02`	3A, 3B	"They plan a range of valid, reproducible and safe scientific investigations and explain how they have addressed any ethical and cultural considerations when generating or using primary and secondary data."	1, 2, 3
`VC2S10I03`	3C	"They select and use equipment to generate and record data, ensuring the use of suitable sample sizes and assessing the precision of multiple measurement readings."	4
`VC2S10I04`	4A, 4B	"They select and construct a range of appropriate representations to	5

Code	Subtopic that teaches it	Achievement-standard extract	Parts
		organise, process and summarise data and information.”	
VC2S10I05	4C	“They analyse and compare a variety of data and information to identify and explain qualitative and quantitative patterns, trends, relationships, assumptions and anomalies.”	6
VC2S10I06	5A	“They evaluate the validity and reproducibility of investigation methods including ways to improve the quality of data, and the validity of conclusions and claims.”	7
VC2S10I07	5B	“They provide evidence-based explanations for findings and construct logical arguments based on the evaluation of multiple sources of evidence to justify conclusions and assess claims.”	8
VC2S10I08	6A, 6B	“They select and use appropriate presentation formats, scientific content, vocabulary, models, conventions, formulas and other representations to achieve their purpose when communicating and justifying their ideas, findings, arguments and proposals to diverse audiences.”	8

Inquiry weighting: 40 of 40 marks — this task is the student-run half of the authentic assessment of Chapter 2–6’s inquiry spine (D7), and every mark is an inquiry-strand mark.

Mark record

Part	Code	Worth	Given
Part 1 — plan	VC2S10I02	7	
Part 2 — risk assessment	VC2S10I02	5	
Part 3 — ethics statement with the cultural-heritage and permissions check	VC2S10I02	6	
Part 4 — logbook	VC2S10I03	5	
Part 5 — processed data	VC2S10I04	6	

Part	Code	Worth	Given
Part 6 — analysis	`VC2S10I05`	3	
Part 7 — evaluation	`VC2S10I06`	4	
Part 8 — report to a stated audience	`VC2S10I07`, `VC2S10I08`	4	
Total		**40**	

Model response — SIT-2 Full investigation report

This is a simulated student response, written for this book. It is worked for Context 1 — A slower catch. The student, the participants, the teacher and the audience are not real people, and the data are simulated data for practice, made up to show what each part of a strong submission looks like — the dated logbook with its honest mistake, the flagged trial, the participant codes standing in for names, the means with their spread, and the report written for a named reader. It is one acceptable response, not the only one.

Part 1 — Plan

Context. Context 1 — A slower catch (Chapter 8, Subtopic 8A).

Question. How does a distraction — holding a phone conversation — affect reaction time in the ruler-drop test?

Hypothesis. I predict that reaction time will be longer (slower) with the phone distraction, because Subtopic 8A teaches that every response follows the pathway stimulus → receptor → control centre → effector → response, and the control centre — the brain — is the part that notices the falling ruler and decides to catch it. A phone conversation occupies that same control centre, so the message should take longer to process before the command reaches the fingers.

Variables.

Variable	What it is	How it is handled
Independent	Distraction during the test	Two conditions: no distraction, and a phone conversation held throughout the drops. Conditions run in that order, or reversed, by participant code — see the method
Dependent	Reaction time	Found from the distance the ruler falls, read to the nearest cm at the top of the thumb, and converted with distance fallen = ½ × g × t^2 (g = 9.8 m/s^2), from Subtopic 8A
Controlled	The ruler and the catch position	The same 30 cm ruler every time; the 0 cm end always held between the participant's thumb and first finger, which wait either side without touching
Controlled	The release	The same dropper for every participant, releasing without warning
Controlled	The setting	The same quiet room, the same table and chair, every participant seated
Controlled	Effort per trial	Five trials per condition for every participant, about 10 s apart

Assumptions. I assume the phone conversation loads the control centre but leaves the catching hand free — the phone is held at the ear with one hand while the other waits on the ruler. I also assume every participant tries equally hard in both conditions, and that the drop distance is a fair measure of reaction time because the same relationship (distance fallen = ½ × g × t^2) links the two for every trial.

Method.

1. Recruit six volunteers from the class. Give each the plain-language information sheet before they agree, and collect the consent form signed by the participant and a parent or carer (all participants are under 18). Assign codes P1–P6; no names are recorded anywhere.

2. Split the order to control order bias: P1, P3 and P5 do the no-distraction condition first; P2, P4 and P6 do the phone condition first. Doing the same condition first every time would let practice, not distraction, explain any difference.
3. Seat the participant at the table. The dropper holds the ruler vertical so the 0 cm end hangs between the participant's thumb and first finger, which wait either side of it without touching.
4. Without warning, the dropper lets go. The participant catches the ruler as quickly as they can.
5. Read the centimetre mark at the top of the thumb to the nearest cm and record it against the participant's code.
6. Repeat steps 3–5 four more times — five trials in total — about 10 s apart.
7. For the phone condition, the participant holds a phone conversation with the teacher's assistant from before the first drop until after the last.
8. Run the second condition after a two-minute rest.
9. Convert each distance to a reaction time with distance fallen = $\frac{1}{2} \times g \times t^2$, $g = 9.8\ m/s^2$ (Subtopic 8A).

The sample — six participants, five trials each, sixty readings — is the class's call on 3C's sample-size guidance: five trials per person is the number 8A's own activity uses, and six people means no single person can dominate the class mean.

Marks earned: 7 of 7 — context named; investigable question linking two named amounts; hypothesis with a reason from the Subtopic 8A pathway; both variables named with units and scales; four controlled variables each with its *how*; one assumption stated; and a numbered method another group could follow — two conditions named, five repeat trials, six participants, a word on why the sample is enough, and order bias identified with the counterbalancing step that controls it.

Part 2 — Risk assessment

Hazards are rated on the 3B grid: likelihood (1–5) × consequence (1–5); 1–4 LOW, 5–9 MEDIUM, 10–15 HIGH, 16–25 EXTREME.

Hazard	Who could be hurt	Rating before controls	Controls, working down the hierarchy	Rating with controls
Ruler dropped or knocked to the floor	Someone slips on it; a foot is struck	3 × 2 = 6, MEDIUM	The floor is cleared of bags before the session; the ruler is picked up at once whenever it falls; all work is done seated at a cleared bench	1 × 2 = 2, LOW
Participant jerks the bench or chair while distracted by the phone call	Bruised knees or shins from the chair or table edge	3 × 2 = 6, MEDIUM	The chair is set back from the walkway; the bench top is cleared of everything except the ruler and the data sheet; the conversation stays at normal speaking volume	1 × 1 = 1, LOW
Tired or sore fingers from repeated catching	Minor discomfort to the catching hand	2 × 1 = 2, LOW	Five trials per condition only, about 10 s apart, with a two-minute rest between conditions	1 × 1 = 1, LOW

PPE. None is needed for this task — there are no chemicals, no heating and no projectiles. Closed shoes are worn, per the school's ordinary laboratory rules.

Sign-off. Approved by the teacher on Wednesday 12 August 2026. Data collection ran Friday 14 August 2026 — after approval, not before.

Marks earned: 5 of 5 — three real hazards of this method, each with who could be hurt; each rated before controls with the zone named; controls work down the hierarchy (clearing the floor and the bench come before anything worn); PPE addressed with a reasoned statement that none is needed, and every risk re-rated lower, all in the low zone; sign-off dated before the first practical session.

Part 3 — Ethics statement

Gate 2 — living things. This investigation uses no living things. No animal, plant, seed or culture of microorganisms is kept, hurt or disturbed, so the three Rs do not apply — there is nothing to replace, reduce or refine.

Gate 2 — people. Six classmates took part, so the five principles from Subtopic 3B all applied:

- *Informed consent* — every participant read a plain-language information sheet saying what the test involves, how long it takes (about five minutes) and what happens to their results, before agreeing. Because every participant is under 18, a parent or carer signed as well.
- *Voluntary participation* — taking part was a choice, and anyone could stop at any time without giving a reason, with no effect on their grade. Nobody stopped.
- *Privacy* — no names were collected. Each participant was assigned a code (P1–P6) before any measurement, and only codes appear on the results sheet and in this report.
- *No harm* — the task carries no physical risk beyond ordinary classroom activity, asks no personal questions, and the two-minute rest between conditions kept fatigue low.
- *Ethics approval* — the teacher checked and approved the plan before any participant was recruited. In formal research this gate is an ethics committee; in classwork it is the teacher checking the plan first.

Secondary data and sources. The ruler-drop method and the conversion relationship (distance fallen = $\frac{1}{2} \times g \times t^2$) come from Subtopic 8A of this book, and the risk-assessment method follows Subtopic 3B, which in turn follows Science ASSIST guidance. Both are credited in the report's reference list. No Aboriginal or Torres Strait Islander data or knowledge is used in this investigation, so the citation and cultural-protocol obligations of Subtopic 5B are not triggered — but they were checked for, the way Part 3 asks. Every number in this investigation is my own.

Gate 3 — the cultural-heritage and permissions check. I worked through the Country and Place checks from Subtopic 3B:

- *Could the work touch Aboriginal cultural heritage, or take place on Country?* No. The whole investigation ran inside the school science classroom — no ground was disturbed, nothing was collected or removed, and no outdoor site was visited. Even so, the check was done, not assumed: my teacher confirmed with the school that no registered Aboriginal cultural heritage place is known on the school grounds, under the framework of the *Aboriginal Heritage Act 2006* (Vic) and the *Aboriginal Heritage Regulations 2018* (Vic).
- *Off-school-grounds permission.* Not needed — the work never left the school grounds, so no permission through a Registered Aboriginal Party applied. If any future version of this context ran outdoors — at a creek or a reserve, say — that check would come first, before any data collection, with every condition of the permission followed.
- *The land manager's permission.* The school is the land manager for this work. The teacher and the school approved the investigation on Wednesday 12 August 2026, before any participant was tested.
- *The artefact rule.* If anything that might be an artefact were ever found on the school grounds — by this investigation or by anyone else — the rule from 3B applies, in order: stop, do not touch or move it, record exactly where it is, tell the teacher straight away, and let the teacher report it to the right people so it is protected where it lies. An artefact's position is part of what it is, and an artefact moved is evidence destroyed.

Gate 4 — approvals and briefing. The plan, the risk assessment and this ethics statement were approved by the teacher on Wednesday 12 August 2026. Before the first session, the dropper, the phone assistant and I were all briefed on the method, the controls and the rules above.

Marks earned: 6 of 6 — living things and people answered plainly, with all five principles served for the participants, including the parent or carer signatures; borrowed methods named with credit promised and the 5B citation check recorded; the cultural-heritage and permissions check worked through question by question to the right conclusion for a school-based context, with the check with the land manager recorded; and the artefact rule stated in full with the approvals gate closed.

Part 4 — Logbook

Entry 1 — Wednesday 12 August 2026 (planning). Plan approved. Risk assessment signed. Ethics statement approved. Consent forms collected — six of six, each signed by the participant and a parent or carer; codes P1–P6 assigned, names kept off every sheet. Order allocation written on the sheet: P1, P3, P5 run no-distraction first; P2, P4, P6 run the phone condition first. Equipment checked: one 30 cm ruler, smallest division 1 mm — readings will be recorded to the nearest cm, because judging the mark at the top of the thumb during a fast catch is not good to a millimetre (3C). Data sheet has codes only.

Entry 2 — Friday 14 August 2026 (data collection). All six participants completed both conditions, five trials each. Raw readings below, in the order taken — fall distance in cm. One flag: P4's third no-distraction trial read 28 cm — someone laughed across the room and P4 looked away before the release, then said they were not ready. Recorded as it happened. Flagged — do not use for P4's mean.

Code	No distraction, trials 1–5 (cm)	Phone distraction, trials 1–5 (cm)	Notes
P1	15, 16, 14, 15, 17	21, 22, 20, 23, 22	No-distraction condition first
P2	18, 17, 19, 18, 18	24, 25, 23, 24, 26	Phone condition first; reported the call "hard to ignore"
P3	13, 14, 12, 14, 13	19, 18, 20, 19, 19	No-distraction condition first
P4	16, 15, ~~28~~, 16, 17	22, 21, 23, 22, 22	No-distraction condition first; trial 3 flagged — participant not ready, looked away
P5	19, 18, 20, 19, 18	25, 24, 26, 25, 25	No-distraction condition first
P6	14, 15, 15, 14, 16	20, 19, 21, 20, 20	Phone condition first

Everything else went as planned. One ruler drop to the floor at trial 2 of P5, picked up at once — no effect on the readings.

Entry 3 — Monday 17 August 2026 (processing). Processed the table in a spreadsheet, then checked every cell against this logbook by hand. Drew the bar graph. Wrote the analysis and the evaluation. Drafted the report.

Marks earned: 5 of 5 — dated entries written at the time; raw readings with units, to the nearest cm, with the ruler's 1 mm division stated and the coarser recording justified by the catching judgement; five repeat trials at both conditions for all six participants, with the sample named and justified in the plan; the bad trial crossed out with a single line, still readable, and explained in the notes column; and the one surprise — the dropped ruler — recorded when it happened.

Part 5 — Processed data

Table 1. Mean fall distance in the ruler-drop test with and without a phone distraction, from five trials per participant per condition; P4's no-distraction mean rests on four trials after the flagged trial was excluded (simulated data for practice).

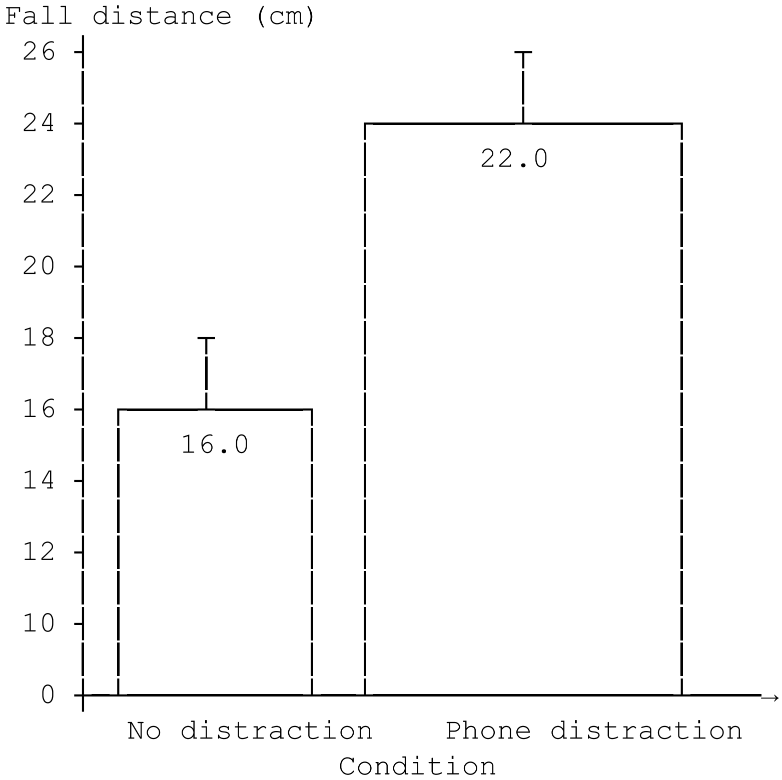
Condition	P1 (cm)	P2 (cm)	P3 (cm)	P4 (cm)	P5 (cm)	P6 (cm)	Class mean (cm)
No distraction	15.4	18.0	13.2	16.0	18.8	14.8	16.0

Condition	P1 (cm)	P2 (cm)	P3 (cm)	P4 (cm)	P5 (cm)	P6 (cm)	Class mean (cm)
Phone distraction	21.6	24.4	19.0	22.0	25.0	20.0	22.0

The readings are recorded to the nearest cm, so each participant mean keeps one decimal place and each class mean is rounded to the nearest cm: for the no-distraction condition, (15.4 + 18.0 + 13.2 + 16.0 + 18.8 + 14.8) ÷ 6 = 16.03 → 16.0 cm; for the phone condition, (21.6 + 24.4 + 19.0 + 22.0 + 25.0 + 20.0) ÷ 6 = 22.0 cm exactly. The six participant means are the repeats at each condition. The spread, as mean ± half the range of those six means (3C), is 16.0 ± 2.8 cm without distraction and 22.0 ± 3.0 cm with it. The design puts participants across the columns because every person did both conditions; each row is still one value of the independent variable with its repeats and its mean.

The class means convert to reaction times through distance fallen = ½ × g × t^2: t^2 = 2 × 0.220 ÷ 9.8 = 0.0449, so t = 0.21 s for the phone condition, and t = 0.18 s for the no-distraction condition the same way.

Figure 1. Mean fall distance with and without the phone distraction; error bars show ± half the range of the six participant means.



The independent variable is a set of two categories — no distraction, phone distraction — so the 4A flowchart sends the data to a bar graph, not a line graph: condition on the horizontal axis, mean fall distance on the vertical axis, both labelled with the quantity and its unit, bars drawn from Table 1.

Marks earned: 6 of 6 — processed table with one row per condition, the repeats and the mean at each value; means rounded to the precision of the readings, units once in the headings; a bar graph chosen from the flowchart for a categorical independent variable and constructed; both axes labelled with quantity and unit, sensible scales, bars placed accurately; the spread reported as ± half the range of the participant means; table and figure numbered and captioned — caption above the table, below the figure — with the excluded trial shown crossed out in the logbook table and its reason carried into Table 1's caption; nothing disappeared.

Part 6 — Analysis

The trend is clear and one-directional: **with the phone distraction, the fall distance was longer — the reaction was slower — for every participant.** All six participant means rose between the two conditions, from 15.4 to 21.6 cm (P1), 18.0 to 24.4 cm (P2), 13.2 to 19.0 cm (P3), 16.0 to 22.0 cm (P4), 18.8 to 25.0 cm (P5) and 14.8 to 20.0 cm (P6). The class mean rose from 16.0 to 22.0 cm — a shift of 6.0 cm, which converts to reaction times of 0.18 s without distraction and 0.21 s with it, about 0.03 s slower. The two ranges do not overlap: the slowest no-distraction mean (18.8 cm) is still quicker than the quickest phone-distraction mean (19.0 cm).

One anomaly was found and flagged at the bench: P4's third no-distraction trial read 28 cm, far from that participant's other four (15–17 cm). The logbook records why — someone laughed across the room and P4 looked away, so the reading measured a startle, not the test condition — and it was left out of P4's mean rather than quietly dropped. No other reading sits away from its participant's range, which is 2–3 cm for every participant in both conditions.

What these data cannot show: they say nothing about distractions other than a phone conversation, nothing about people outside these six students, and nothing about whether the slowdown would matter in a real crossing of a real road — the test measures a catch at a bench, not a step off a kerb.

Marks earned: 3 of 3 — trend stated with direction and shape, and with the consistency across participants; carried by the actual participant means, the class means, the converted times and the non-overlap of the ranges; the anomaly identified with its best account from the logbook.

Part 7 — Evaluation

Two sources of error.

1. **Judging the catch mark is a random error.** The ruler is moving when it is caught, and reading the mark at the top of the thumb is a judgement made in a hurry. Some trials read a little long, some a little short, with no pattern to which way — the 2–3 cm scatter inside each participant's trials is exactly that signature (5A). Repeating and averaging reduces it, which is why there were five trials per condition.
2. **The release rhythm is a systematic error.** The dropper aimed for "without warning", but after five trials the releases had a rhythm a participant could half predict, and predicting makes every catch come early. That pushes every reading in both conditions a little short — it never goes away with repeats — but because it acts on both conditions equally, it moves the two bars down together and leaves the comparison between them as it was.

The assumptions revisited. The first assumption — that the phone conversation loads the control centre but leaves the catching hand free — held: the phone was held at the ear with one hand while the other waited on the ruler, and no participant reported the phone getting in the way of the catch. The second — equal effort in both conditions — held as far as the data can show: all six participants completed both conditions, and the counterbalanced order let me check that practice alone was not doing the work: the three participants who ran the phone condition first (P2, P4, P6) showed the same shift as the three who ran it second.

Validity and trust. The method is valid for its question: only the tested factor differed between conditions — same ruler, same dropper, same room, same number of trials — and the fall distance is exactly what a reaction-time question needs measured. How far the conclusion can be trusted: the difference between conditions (6.0 cm) is about twice the scatter within a condition (± about 3 cm), the ranges do not overlap, and six out of six participants show the same direction, so the direction of the finding is solid. The exact size of the slowdown I trust less — six people is a small sample, and one of the four means behind the no-distraction class mean rests on four trials instead of five.

One improvement. Double the sample — twelve participants instead of six, five trials each — which halves the weight any one person carries in the class mean (3C), and mark the starting finger position on the table so the catch position is identical every trial.

One question left unanswered. Is a phone conversation the worst kind of distraction, or would music, or a passenger talking, slow the pathway more? The method is ready to swap the distraction and run again — that is the next investigation.

Marks earned: 4 of 4 — two particular errors, each classified (random, systematic) and each with which way it pushes the readings, including the systematic one that leaves the comparison intact; both assumptions revisited with evidence, including the order-bias check; validity judged and trust argued from the sample, the repeats and the size of the trend against the scatter, with one real improvement and one real next question.

Part 8 — Report to a stated audience

Stated audience. The report is written for the school's road-safety committee, the staff group that runs the school's road-safety program, which is deciding whether to add a "phones down near traffic" message to this year's campaign. The committee did not do this investigation and is not reading it for the method — so the report opens with the finding in plain words, and the full nine-section report follows underneath for anyone who wants to check the work.

Phones and reaction time: a report for the school road-safety committee

The finding in plain words. Being on a phone call made every student in our test slower to react — all six, none faster. On average, the catch was about 6 cm later on the falling ruler, which works out to about three-hundredths of a second of extra reaction time (0.18 s without the phone, 0.21 s with it). That sounds small, but near traffic a slower reaction means less time to stop, step back or look up. The message the data support for the campaign: phones down before you cross.

Title. How a phone conversation affects reaction time in the ruler-drop test.

Aim. To find how a distraction — holding a phone conversation — affects reaction time in the ruler-drop test.

Background. Every coordinated response follows the pathway stimulus → receptor → control centre → effector → response, and the control centre — the brain — is where a second task competes for attention (Science 9–10, Subtopic 8A [S1]).

Hypothesis. It was predicted that reaction time would be longer with the phone distraction, because the conversation occupies the same control centre that must notice the falling ruler and command the catch.

Method. Six student volunteers, recruited with informed consent signed by each participant and a parent or carer, completed five ruler-drop trials with no distraction and five while holding a phone conversation, on the same ruler, with the same dropper, in the same room (full numbered method in the plan submitted with this report). The order of the two conditions was alternated between participants to control order bias. Fall distances were read to the nearest cm and converted to reaction times with distance fallen = $\frac{1}{2} \times g \times t^2$ ($g = 9.8$ m/s^2) [S1]. The risk assessment, written to Science ASSIST guidance [S2] and signed by the teacher before any testing, kept the floor clear and the work seated.

Results. Table 1 and Figure 1 (both reproduced from the processed data section) show the mean fall distance for each condition: 16.0 ± 2.8 cm without distraction, 22.0 ± 3.0 cm with the phone, where the ± values are half the range of the six participant means. Converted, the class means are 0.18 s and 0.21 s. One trial was excluded: a no-distraction reading taken while the participant was not ready, shown crossed out in the logbook with its reason.

Discussion. The results support the hypothesis: with the phone distraction, reaction was slower for all six participants, and the class mean fall distance rose 6.0 cm, from 16.0 to 22.0 cm, about 0.03 s of extra reaction time. The two ranges do not overlap — the slowest no-distraction participant was still quicker than the quickest distracted one — which is what makes the pattern strong for a six-person sample. One outlier was recorded and excluded with its reason. Two sources of error were identified: judging the catch mark, a random error scattered both ways and reduced by the five-trial averaging, and the dropper's release rhythm, a systematic error that pushes all readings short but acts on both conditions equally, so it leaves the comparison intact. The limits: six students, one kind of distraction, a catch at a bench — the data do not yet show what a phone does at a real kerbside.

Conclusion. For the six students tested, holding a phone conversation slowed reaction time in the ruler-drop test: the mean fall distance rose from 16.0 to 22.0 cm, a shift of 6.0 cm, equivalent to about 0.03 s of extra reaction time, in the same direction for every participant. For the committee: the data support adding the "phones down near traffic" message to the campaign — distracted reactions are slower reactions, and slower reactions near traffic leave less time to respond.

References.

[S1] Science 9–10 (Victorian Curriculum F–10 Version 2.0, Levels 9 and 10), student workbook, Subtopic 8A — the nervous system coordinating responses to stimuli, including the ruler-drop test and the distance-fallen relationship.

[S2] Science ASSIST (ASTA), "Risk management", 2026. asta.edu.au — retrieved 2026-08-14.

Marks earned: 4 of 4 — the conclusion answers the aim, no stronger than the evidence allows, on visible evidence from the results; the argument is claim, evidence and reasoning, not a restated opinion; the audience is stated and the report is shaped for that reader — the finding up front in plain words, the checkable nine-section report underneath; and the nine-section shape is followed with the conventions — captions in their places, units once, past tense for what was done and found, both borrowed things credited beside their use.

Model total: 40 of 40.

Sources — SIT-2 Full investigation report

Web sources below were retrieved 2026-08-22.

- **[S1]** Victorian Curriculum and Assessment Authority, *Victorian Curriculum F–10 Version 2.0, Science, Levels 9 and 10*, content descriptions `VC2S10I02`–`VC2S10I08`, their elaborations and their achievement-standard extracts, 2026. vcaa.vic.edu.au
- **[S2]** Science ASSIST (ASTA), "Risk management", 2026. asta.edu.au
- **[S3]** State of Victoria, *Aboriginal Heritage Act 2006* (Vic), legislation.vic.gov.au/in-force/acts/aboriginal-heritage-act-2006/06-016 — retrieved 2026-08-22. *Aboriginal Heritage Regulations 2018* (Vic), legislation.vic.gov.au/in-force/statutory-rules/aboriginal-heritage-regulations-2018/018 — retrieved 2026-08-22. Named in this book's TOC §6 approved source list; named as instruments only in this task, with no provision numbers cited.

The three approved contexts are original compositions for this task, each anchored to the subtopic named beside it — 8A (the nervous-system pathway and the ruler-drop test), 11D with 3B (the factors that change reaction rate, and the completed risk assessment 3B already wrote for the marble-chips investigation), and 7B (sexual reproduction in plants, seeds and variation). Every context is achievable with standard Victorian secondary laboratory equipment. The elaboration contexts drawn on are `VC2S10I02.E01`, `VC2S10I02.E07`, `VC2S10I03.E03`, `VC2S10I03.E05`, `VC2S10I07.E05` and `VC2S10I08.E01`, assessed through Parts 2, 3, 4 and 8 as the header block sets out.

The model response is a **simulated example for practice**: the student, the participants, the teacher and the audience are not real people, the logbook dates are illustrative, and the measurements are simulated data for practice, constructed to show each part of a strong submission — including one honestly flagged trial and the participant codes standing in for names — not records of a real investigation.

Teacher-facing note — D10 protocol limb, CONTENT_POLICY alignment (not student text). Part 3 of this task delivers the protocol limb of `VC2S10I02` (and the citation limb of `VC2S10I07`), which is CD text and mandatory whatever the reviewer decides about cultural knowledge under TOC D10: it is assessed as process and law, exactly as Subtopic 3B teaches it — the *Aboriginal Heritage Act 2006* (Vic) and the *Aboriginal Heritage Regulations 2018* (Vic), Registered Aboriginal Parties, Cultural Heritage Management Plans, the permission sequence on Country and Place, and the land manager's permission where none of those applies. The instruments are named; no provision numbers, determinations, Registered Aboriginal Party names or community names are invented in this task, per TOC §6. No cultural knowledge is authored here — no stories, practices, ceremonies or knowledge claims — which is also the position of the estate's binding content policy (`S:\Files\CONTENT_POLICY.md`, Rule 1, recorded 2026-08-15): what every student must produce is the check itself — the questions asked, the permissions identified, and the artefact rule recorded for the chosen context. All three approved contexts are school-based, so every student reaches the check by the same route the model shows; a school that approves an off-grounds variant must mark it against the same Part 3 descriptors, with the real permissions named — through the Registered Aboriginal Party for that area, with every condition of the permission recorded.