Cambridge IGCSE · Chemistry 0620 · Notes

Formulae and equations

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Read first: **Ionic and metallic bonding**

What you need to know

By the end of this topic you should be able to:

1. **Write the formula of every element and compound named in the syllabus**, such as O_2, H_2O, CO_2, NaCl, H_2SO_4, $CaCO_3$ and CH_4.
2. **Define molecular formula**: the number and type of different atoms in one molecule of a compound.
3. **Deduce the formula of a simple compound** by counting the atoms in a model or a diagram of it.
4. **Write word equations and symbol equations**, including **state symbols**, to show how reactants turn into products.
5. **Extended only:** define **empirical formula**: the simplest whole-number ratio of the different atoms or ions in a compound.
6. **Extended only:** deduce the formula of an ionic compound from the numbers of each ion in a model or diagram, or from the charges on its ions.
7. **Extended only:** write symbol equations with state symbols, including **ionic equations**.
8. **Extended only:** work out the symbol equation, with state symbols, for a reaction you have not met before, from the information you are given.

Understand it

What a formula tells you

A chemical formula uses symbols from the Periodic Table to say **which elements** a substance contains and **how many atoms** (or ions) of each there are. The small number written **after** a symbol, the **subscript**, counts the atom just before it:

- H_2O: 2 hydrogen atoms and 1 oxygen atom (a "1" is never written).
- CO_2: 1 carbon atom and 2 oxygen atoms. Compare CO, carbon monoxide: a different substance.
- A subscript after a **bracket** multiplies everything inside it. $Ca(NO_3)_2$ has 1 Ca, 2 N and $2 \times 3 = 6$ O. $(NH_4)_2SO_4$ has 2 N, 8 H, 1 S and 4 O: 15 atoms in all.

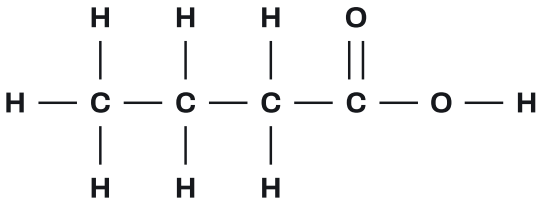
A subscript is part of the substance's identity. **You can never change a subscript** to make an equation balance, because that changes the substance.

Formulae of elements

- **Metals, carbon and silicon** are written as the symbol alone: Na, Fe, Cu, C.
- **Noble gases** exist as single atoms: He, Ne, Ar (never He_2).
- These elements exist as **diatomic molecules** (two atoms): **H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2**. In an equation, "oxygen" or "chlorine" as a reactant or product is always O_2 or Cl_2, never O or Cl.

Molecular formulae

A **molecular formula** gives the **number and type of different atoms in one molecule**. To get it from a displayed formula (a drawing showing every atom and every bond), **count each kind of atom** and write the totals, carbon first, then hydrogen, then the others.



each line is a bond; = is a double bond

count the atoms

C: 4, H: 8, O: 2

molecular formula

$C_4H_8O_2$

empirical formula

C_2H_4O (÷ 2)

Butanoic acid is sometimes written $CH_3CH_2CH_2COOH$ or C_3H_7COOH. Those show how the atoms are grouped, but they are **not** molecular formulae. Its molecular formula is **$C_4H_8O_2$**. Count every atom, including the H on the O–H group.

Empirical formulae

Extended only. The **empirical formula** is the **simplest whole-number ratio** of the atoms (or ions) in a compound. Divide every subscript in the molecular formula by the largest number that goes into all of them:

Compound	Molecular formula	Divide by	Empirical formula
ethene	C_2H_4	2	CH_2
butanoic acid	$C_4H_8O_2$	2	C_2H_4O
ethanoic acid	$C_2H_4O_2$	2	CH_2O
glucose	$C_6H_{12}O_6$	6	CH_2O
pentane	C_5H_{12}	1	C_5H_{12} (the same)

Different compounds can share an empirical formula (ethanoic acid and glucose are both CH_2O). If nothing divides all the subscripts, as in C_5H_{12} or C_2H_6O, the empirical and molecular formulae are the **same**. Ionic compounds have no molecules, so their formula (NaCl, Al_2O_3) is always the empirical formula.

Formulae of ionic compounds

An ionic compound has **no overall charge**, so its positive and negative charges must add up to zero. You learned the charges of simple ions in the note on ionic bonding. Some ions are **groups of atoms** that stay together; learn these:

Positive ions	Charge	Negative ions	Charge
Na^+, K^+, Li^+, Ag^+, H^+, ammonium NH_4^+	$1+$	Cl^-, Br^-, I^-, F^-, hydroxide OH^-, nitrate NO_3^-	$1-$
Mg^{2+}, Ca^{2+}, Ba^{2+}, Zn^{2+}, Pb^{2+}, Cu^{2+}, Fe^{2+}	$2+$	O^{2-}, S^{2-}, sulfate SO_4^{2-}, carbonate CO_3^{2-}	$2-$
Al^{3+}, Fe^{3+}	$3+$	N^{3-}, phosphate PO_4^{3-}	$3-$

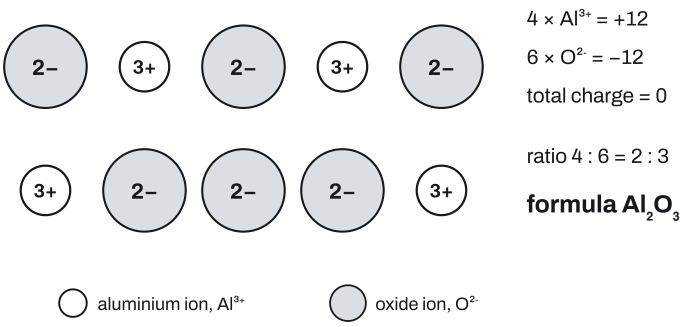
A **Roman numeral** in a name gives the charge on the metal ion: iron(II) is Fe^{2+}, iron(III) is Fe^{3+}, copper(II) is Cu^{2+}. The name's ending tells you the negative ion: **-ide** is the element alone (chloride Cl^-, oxide O^{2-}), while **-ate** contains oxygen too (sulfate, nitrate, carbonate).

To write the formula, take enough of each ion for the charges to cancel, and put a group ion in **brackets** if you need more than one of it:

Name	Ions	Charges	Formula
calcium chloride	Ca^{2+}, Cl^-	$(+2) + 2(-1) = 0$	$CaCl_2$
magnesium hydroxide	Mg^{2+}, OH^-	$(+2) + 2(-1) = 0$	$Mg(OH)_2$
aluminium sulfate	Al^{3+}, SO_4^{2-}	$2(+3) + 3(-2) = 0$	$Al_2(SO_4)_3$
ammonium sulfate	NH_4^+, SO_4^{2-}	$2(+1) + (-2) = 0$	$(NH_4)_2SO_4$
ammonium nitrate	NH_4^+, NO_3^-	$(+1) + (-1) = 0$	NH_4NO_3
iron(III) chloride	Fe^{3+}, Cl^-	$(+3) + 3(-1) = 0$	$FeCl_3$

$Mg(OH)_2$ is not $MgOH_2$: without the bracket the 2 would apply only to the H.

From a model or diagram, count the particles of each kind and simplify the ratio. For ions (**Extended only**), check that the charges cancel:



Word equations and symbol equations

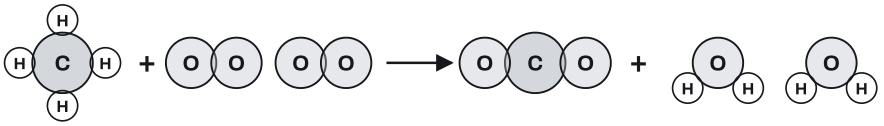
An equation shows **reactants** (on the left) turning into **products** (on the right). A **word equation** uses names:

zinc + hydrochloric acid → zinc chloride + hydrogen

A **symbol equation** uses formulae. In a reaction, atoms are **not created or destroyed**, only rearranged, so there must be the **same number of each kind of atom on both sides**. When that is true, the equation is **balanced**. You balance it by putting **numbers in front of formulae** (coefficients), which multiply the whole formula:

$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

Here 2HCl means two HCl units: 2 H and 2 Cl.



$CH_4 + 2O_2$
C: 1, H: 4, O: 4

$CO_2 + 2H_2O$
C: 1, H: 4, O: 4

same atoms on both sides: they are only rearranged

To balance methane burning in oxygen:

1. Write the correct formulae: $CH_4 + O_2 \rightarrow CO_2 + H_2O$. Count: left C 1, H 4, O 2; right C 1, H 2, O 3.
2. Carbon is already balanced. Balance hydrogen: 4 H on the left needs **2**H_2O on the right. Now the right has O $2 + 2 = 4$.
3. Balance oxygen last: 4 O needs **2**O_2 on the left.
4. Check every element: $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ has C 1, H 4, O 4 on each side.

State symbols

State symbols go in brackets after each formula to show its physical state:

Symbol	Meaning	Typical examples
(s)	solid	metals, a solid reactant, a **precipitate** (an insoluble solid that forms in a solution)
(l)	liquid	**water**, a molten substance, a liquid such as bromine at room temperature
(g)	gas	O_2, H_2, CO_2, Cl_2 given off
(aq)	aqueous: dissolved in water	**dilute acids**, alkalis, solutions of soluble salts

For example: $Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$.

Two to watch: a dilute acid is **(aq)**, not (l), because it is a solution; water itself is **(l)**, not (aq). Whether a product is (aq) or (s) depends on whether it dissolves: sodium, potassium and ammonium salts and all nitrates are soluble; most carbonates, and silver and lead chlorides, are not.

Ionic equations

Extended only. In a solution, a soluble ionic compound is split into its separate ions. Some of those ions take no part in the reaction: they are in the solution at the start and still there, unchanged, at the end. They are **spectator ions**. An **ionic equation** leaves them out and shows only the particles that change.

To write one:

1. Write the balanced symbol equation with state symbols.
2. Split every **(aq)** ionic compound into its ions. Leave solids, liquids, gases and molecules (such as H_2O) as they are.
3. Cross out the ions that appear, unchanged, on both sides.
4. Check that the **atoms** and the **charges** balance.

For hydrochloric acid neutralised by sodium hydroxide:

$$\mathrm{H^+}(aq) + \mathrm{Cl^-}(aq) + \mathrm{Na^+}(aq) + \mathrm{OH^-}(aq) \rightarrow \mathrm{Na^+}(aq) + \mathrm{Cl^-}(aq) + \mathrm{H_2O}(l)$$

Na^+ and Cl^- are spectators, so the ionic equation is $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$. Every neutralisation of an acid by an alkali has this same ionic equation. Two more patterns:

- **Precipitation**: barium chloride and sodium sulfate solutions give $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$.
- **A metal displacing another metal**: magnesium in copper(II) sulfate solution gives $Mg(s) + Cu^{2+}(aq) \rightarrow Mg^{2+}(aq) + Cu(s)$. The sulfate ion is the spectator.

In each one the total charge is the same on both sides: $(+1) + (-1) = 0$; $(+2) + (-2) = 0$; $0 + (+2) = (+2) + 0$.

Key facts and formulas

The only help printed in the exam is the **Periodic Table**, which gives the symbols of the elements. Everything else is **Learn it**.

Formula	Status
Symbols of the elements (Periodic Table)	Given
Diatomic elements: H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2; noble gases are single atoms	Learn it
Group ions: NH_4^+, OH^-, NO_3^-, SO_4^{2-}, CO_3^{2-}, PO_4^{3-}	Learn it
Roman numeral = charge on the metal ion: Fe^{2+} iron(II), Fe^{3+} iron(III), Cu^{2+} copper(II)	Learn it
Ionic formula: total positive charge + total negative charge $= 0$	Learn it
Molecular formula = number and type of different atoms in one molecule	Learn it
Extended only: empirical formula = simplest whole-number ratio of the different atoms or ions	Learn it
Balanced equation: the same number of each kind of atom on both sides; change coefficients, never subscripts	Learn it
State symbols: (s) solid, (l) liquid, (g) gas, (aq) dissolved in water	Learn it
Extended only: ionic equation: leave out spectator ions; atoms and charges both balance	Learn it
Extended only: neutralisation: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$	Learn it

Common formulae to know by heart: water H_2O, carbon dioxide CO_2, carbon monoxide CO, methane CH_4, ammonia NH_3, sulfur dioxide SO_2, hydrochloric acid HCl, sulfuric acid H_2SO_4, nitric acid HNO_3, sodium hydroxide NaOH, calcium carbonate $CaCO_3$, calcium hydroxide $Ca(OH)_2$, calcium oxide CaO.

How to do it

In the questions we have tagged for this topic (82 questions, 2021–2025, on Papers 1–4), the types came up this often. 5 of the 82 questions mix types, so the counts add up to more than 82.

Question type	Questions
Choosing or balancing a symbol equation	30

Question type	Questions
Formulae of named compounds, and ion charges	15
Molecular formulae from structures, and the definition	15
State symbols	9
Writing or completing equations in written answers	9
Empirical formulae	7
Ionic equations	2

1. Choosing or balancing a symbol equation (30 questions)

Mostly multiple choice: "which equation represents ...?", or "which values of x and y balance the equation?".

1. **Work out the formula of every reactant and product** from the names in the question. Cross out any option with a wrong formula (CaOH for calcium hydroxide, O instead of O_2, Na_2 for sodium).
2. **Check the products are the right substances**, for example CO_2 and H_2O for complete combustion, but CO (or C) and H_2O for incomplete combustion.
3. **Count each kind of atom on both sides** of what is left. The balanced one is the answer.

To balance an equation yourself, balance one element at a time, leaving elements that appear on their own (such as O_2 or H_2) until last, and recount everything at the end. For example, aluminium burning: Al + O_2 → Al_2O_3. Oxygen needs a common multiple of 2 and 3, so $3O_2$ and $2Al_2O_3$ (6 O each side), then 4Al: $4Al + 3O_2 \rightarrow 2Al_2O_3$.

Variations you will meet:

- **Every option balances.** Examiners often give four balanced equations, and only one has the right products. Check step 2 before counting.
- **Find the coefficients x and y.** Put each option's numbers in and count, or balance it yourself. With an unknown in front of O_2, balance C and H first, then count the O on the right and halve it: in $C_2H_4 + zO_2 \rightarrow 2CO_2 + 2H_2O$ the right has $4 + 2 = 6$ O, so $z = 3$.
- **An unknown formula** such as C_xH_y burning: count the atoms in the products. If $C_xH_y + 5O_2 \rightarrow 3CO_2 + 4H_2O$, then $x = 3$ and $y = 2 \times 4 = 8$, so it is C_3H_8 (and $3 \times 2 + 4 = 10$ O matches $5O_2$).
- **Combustion.** Complete: hydrocarbon + oxygen → CO_2 + H_2O. Incomplete (limited oxygen): CO or C with H_2O. For example, $2C_2H_6 + 5O_2 \rightarrow 4CO + 6H_2O$. An odd number of O atoms on the right means doubling everything.
- **Standard reactions to know:** metal + acid → salt + hydrogen ($2Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2$); carbonate + acid → salt + water + carbon dioxide ($CuCO_3 + 2HCl \rightarrow CuCl_2 + H_2O + CO_2$); acid + alkali → salt + water; metal + water → hydroxide + hydrogen ($2Na + 2H_2O \rightarrow 2NaOH + H_2$); metal oxide reduced by carbon ($2PbO + C \rightarrow 2Pb + CO_2$).
- **Decomposition** of one compound into several products, such as a nitrate giving an oxide, NO_2 and O_2: balance the metal and N first and the O_2 last, doubling if you need an even number.

- **"Which equations are balanced?"** Count every element in each one; a single mismatch rules it out.
- **The Group of a metal decides its formulae.** A Group II metal X forms X^{2+}, so its sulfate is XSO_4 and its oxide XO.

2. Formulae of named compounds, and ion charges (15 questions)

1. **Split the name into its ions**: the metal (or ammonium) first, then the negative ion. Get each charge from the group, the Roman numeral or the group-ion table.
2. **Balance the charges** to zero and write the formula, with brackets around a group ion you need more than one of.

Variations you will meet:

- **"Which formula is correct?"** Check each option: iron(III) oxide is Fe_2O_3 (not FeO or Fe_3O_4); cobalt is Co, copper is Cu; noble gases and metals are single atoms; sodium carbonate is Na_2CO_3; ammonium sulfate is $(NH_4)_2SO_4$ (not NH_4SO_4 or $(NH_3)_2SO_4$); lead(II) bromide is $PbBr_2$.
- **Covalent compounds from their names**: the prefixes count atoms, as in sulfur **di**oxide SO_2 and carbon **mon**oxide CO.
- **The charge on a metal ion from its formula.** Work backwards from the negative ions: in V_2O_5 the oxide ions give $5 \times (-2) = -10$, shared by 2 vanadium ions, so each is V^{5+}. In $Fe_2(SO_4)_3$ the sulfates give -6, so each iron is Fe^{3+}.
- **A compound with three kinds of ion**: the charges still add to zero. A compound of K^+, Al^{3+} and SO_4^{2-} with one K^+ and one Al^{3+} needs two sulfates: $(+1) + (+3) + 2(-2) = 0$, so $KAl(SO_4)_2$.
- **A metal with two kinds of ion in one compound**, such as a lead oxide containing both Pb^{2+} and Pb^{4+}: add up the positive charges of the ions you are told about and balance them with oxide ions. Two Pb^{2+} with one Pb^{4+} give $+8$, balanced by four O^{2-}: Pb_3O_4.

3. Molecular formulae from structures, and the definition (15 questions)

1. **Count each kind of atom** in the displayed formula or model. Tick them off as you go, and remember the H on every O–H and N–H.
2. Write the totals as one formula, **C first, then H, then the others**: $C_4H_8O_2$, not C_2H_4O + C_2H_4O or $CH_3COOC_2H_5$.

Variations you will meet:

- **The definition**: the **number and type of different atoms in one molecule**. Reject options that say "the arrangement of atoms" (that is a displayed or structural formula), "the total number of atoms" alone, or "the number of elements".
- **Comparing several structures**: find each molecular formula. Molecules with different arrangements can have the same molecular formula.
- **Statements about a formula** such as C_2H_5Cl: it has $2 + 5 + 1 = 8$ atoms but only 3 different elements.
- **Counting elements** (not atoms): $C_3H_7O_2N$ contains 4 elements but 13 atoms.

4. State symbols (9 questions)

1. **Solids** (a metal, a solid reactant, a precipitate or an insoluble product): **(s)**.
2. **Water**, and anything molten or a liquid at room temperature: **(l)**.
3. **Gases** (H_2, O_2, CO_2, Cl_2, and any substance that is a gas at the temperature given): **(g)**.
4. **Dilute acids, alkalis and dissolved salts**: **(aq)**.

Variations you will meet:

- **Choose the row of state symbols** for an equation: the dilute acid is (aq), the soluble salt formed is (aq), water is (l), and an insoluble product such as $BaSO_4$ or $CaCO_3$ is (s).
- **"At room temperature and pressure (r.t.p.)"**: use what each substance is at about 25 °C. A substance the question describes as a liquid is (l), even if you might have guessed (g).
- **The options mix formula errors with state errors**: check both. For marble chips in dilute nitric acid: $CaCO_3(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$.

5. Writing or completing equations in written answers (9 questions)

1. **Write every formula correctly first**, using the question's information (a given formula such as Li_3N or Zn_3P_2 must be copied exactly). Diatomic elements go in as molecules (N_2, O_2, Cl_2); other elements as single atoms (Mg, P, S).
2. **Balance**, then **check** every element.
3. Add state symbols only if the question asks for them.

For example, magnesium burning in nitrogen to make Mg_3N_2: $3Mg + N_2 \rightarrow Mg_3N_2$. Phosphorus with chlorine to make PCl_3: $2P + 3Cl_2 \rightarrow 2PCl_3$.

Variations you will meet:

- **"Complete the equation"** with some formulae already there: fill in the missing formulae and all the numbers; the mark scheme usually gives one mark for each correct coefficient or formula.
- **"Write a chemical equation"** means a **balanced symbol equation**, not a word equation.
- **"Complete the word equation"**: names only, no numbers and no formulae. Chlorine displacing iodide: chlorine + potassium iodide → potassium chloride + iodine.
- **Organic reactions**, such as propan-1-ol burning: $2C_3H_7OH + 9O_2 \rightarrow 6CO_2 + 8H_2O$. Count the O in the alcohol too: $2 + 18 = 20$ O on the left, $12 + 8 = 20$ on the right.

6. Empirical formulae (7 questions)

Extended only.

1. Get the **molecular formula** (count the atoms if you are given a structure).
2. **Divide every subscript** by the largest whole number that divides them all.
3. If none does, the empirical formula is the same as the molecular formula.

Variations you will meet:

- **"Which formula is an empirical formula?"** One that cannot be simplified: C_2H_4O can't be divided further, but $C_4H_8O_2$ can. Structural-style formulae such as C_3H_7COOH are not empirical formulae.
- **"Which compounds have the same empirical formula?"** Simplify each and compare: ethene C_2H_4 and butene C_4H_8 are both CH_2.
- **"Which molecular formulae are also empirical formulae?"** Those whose subscripts share no common factor: C_2H_6O and C_5H_{12} yes; C_4H_{10} (C_2H_5) and C_2H_4 (CH_2) no.
- **Working out an empirical formula from masses** needs moles and is in the topic on the mole.

7. Ionic equations (2 questions)

Extended only.

1. Write the full equation with state symbols.
2. Split the (aq) ionic compounds into ions; keep precipitates, water, gases and metals as they are.
3. Remove the spectator ions and check atoms and charges.

Variations you will meet:

- **A precipitate forms**: the ionic equation is just the ions that make the solid, for example $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$ when a copper(II) salt meets sodium hydroxide.
- **A metal displacing a less reactive metal**: metal atom + metal ion → metal ion + metal atom. If the metal added is **less** reactive, there is no reaction.
- **Neutralisation**: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

(a) Write the formulae of: magnesium nitrate; ammonium carbonate; iron(III) hydroxide; copper(II) sulfate. **[4]**

(b) **Extended.** Cobalt forms an oxide with the formula Co_2O_3, and nickel forms a hydroxide with the formula $Ni(OH)_2$. Deduce the charge on the metal ion in each. **[2]**

(a) Mg^{2+} with NO_3^-: two nitrates, **$Mg(NO_3)_2$**. **B1** NH_4^+ with CO_3^{2-}: two ammoniums, **$(NH_4)_2CO_3$**. **B1** Fe^{3+} with OH^-: three hydroxides, **$Fe(OH)_3$**. **B1** Cu^{2+} with SO_4^{2-}: **$CuSO_4$**. **B1**

(b) In Co_2O_3 the oxide ions give $3 \times (-2) = -6$, shared by 2 cobalt ions: **Co^{3+}**. **B1** In $Ni(OH)_2$ the hydroxide ions give $2 \times (-1) = -2$: **Ni^{2+}**. **B1**

Example 2

Aluminium powder reacts with dilute hydrochloric acid. The products are aqueous aluminium chloride, $AlCl_3$, and hydrogen gas.

(a) Write the word equation for the reaction. **[1]**

(b) Write the balanced symbol equation, including state symbols. **[3]**

(a) aluminium + hydrochloric acid → aluminium chloride + hydrogen **B1**

(b) Formulae: $Al + HCl \rightarrow AlCl_3 + H_2$. **M1** for all four correct formulae.

$AlCl_3$ has 3 Cl, so 3HCl, which gives 3 H: an odd number, but H_2 needs an even number. Double: 6HCl, then $2AlCl_3$, $3H_2$ and 2Al.

$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

A1 for balancing (Al 2, H 6, Cl 6 on each side), **B1** for all four state symbols.

Example 3

Extended. Aqueous silver nitrate is added to aqueous calcium chloride. A white precipitate of silver chloride forms.

(a) Write the symbol equation for the reaction, including state symbols. **[2]**

(b) Write the ionic equation for the reaction. **[2]**

(c) Zinc powder is added to aqueous copper(II) sulfate. Write the ionic equation for the reaction, and name the spectator ion. **[2]**

(a) Calcium chloride is $CaCl_2$, so it needs two $AgNO_3$, making 2AgCl and $Ca(NO_3)_2$:

$2AgNO_3(aq) + CaCl_2(aq) \rightarrow 2AgCl(s) + Ca(NO_3)_2(aq)$

M1 for the formulae balanced, **A1** for the state symbols, with the precipitate (s).

(b) Ca^{2+} and NO_3^- are unchanged, so leave them out:

$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

M1 for the correct species, **A1** for the state symbols. The charges balance: $(+1) + (-1) = 0$.

(c) $Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)$ **B1**. The spectator ion is **sulfate, SO_4^{2-}**. **B1**

Example 4

Extended. Hexane, C_6H_{14}, is a liquid alkane at room temperature and pressure.

(a) Give the empirical formula of hexane. **[1]**

(b) Write the balanced equation for the complete combustion of hexane at room temperature and pressure, including state symbols. **[3]**

(c) In a limited supply of air, hexane burns to form carbon monoxide and water. Write the balanced equation for this reaction. **[2]**

(a) 6 and 14 are both divisible by 2: **C_3H_7**. **B1**

(b) Products CO_2 and H_2O. **M1** Balance C and H: $C_6H_{14} + O_2 \rightarrow 6CO_2 + 7H_2O$, with $12 + 7 = 19$ O on the right: an odd number, so double everything:

$2C_6H_{14}(l) + 19O_2(g) \rightarrow 12CO_2(g) + 14H_2O(l)$

A1 for balancing: C 12, H 28 and O 38 on each side. **B1** for the state symbols (hexane and water are liquids at r.t.p.).

(c) $2C_6H_{14} + 13O_2 \rightarrow 12CO + 14H_2O$. **M1** for CO and H_2O as the products, **A1** for balancing: the right has $12 + 14 = 26$ O, which is $13O_2$.

Common mistakes

- **Changing a subscript to balance.** Writing H_2O_2 or Na_2O_2 to make the oxygen fit changes the substance. Only put numbers in front of formulae.
- **Writing the numbers wrongly.** Examiners see $2(H_2O)$ and 2(HCl), or big numbers such as 4 and 6 where 2 and 3 would do. Write $2H_2O$ and use the smallest whole numbers.
- **Forgetting that some elements are diatomic.** Chlorine, oxygen, nitrogen and fluorine go into an equation as Cl_2, O_2, N_2, F_2. Common slips are balancing chlorine with too few Cl_2 molecules ($2P + 5Cl_2 \rightarrow 2PCl_5$, not $3Cl_2$), or writing N or 2N instead of N_2.
- **Leaving the equation unbalanced** after getting all the formulae right, which throws away the balancing mark. Always recount every element at the end.
- **Wrong formulae for ions**: CaOH instead of $Ca(OH)_2$, $NaSO_4$ instead of Na_2SO_4, NH_3 instead of NH_4 in ammonium salts, or PbI instead of PbI_2. Balance the charges before writing.
- **HCl(l) and H_2O(aq).** A dilute acid is aqueous, (aq); water is a liquid, (l). These are the commonest state-symbol errors examiners report. Also, give state symbols for **every** substance when asked, not just some.
- **Writing a word equation when a chemical equation is asked for**, or putting numbers ("two sodium") or formulae in a word equation.

- **Confusing molecular, structural and displayed formulae.** C_3H_7COOH and $CH_3CH_2CH_2COOH$ are not molecular formulae; the molecular formula is $C_4H_8O_2$. Don't draw arrows or bonds when a formula is asked for.
- **Mixing up molecular and empirical formulae**, for example giving $C_4H_6O_4$ when the empirical formula ($C_2H_3O_2$) is asked for.
- **Leaving spectator ions in an ionic equation**, or writing the full equation instead. Also make sure the charges balance, not just the atoms.

How to get the marks

- **Equations are usually marked in parts**: one mark for the correct formulae (the "species") and one for balancing, or one mark for each correct number when you complete a given equation. Correct formulae that are not balanced can still earn the first mark.
- **Multiples are usually accepted** ($4Al + 6Cl_2 \rightarrow 4AlCl_3$ would still be balanced), but the smallest whole numbers are what you should aim for.
- **State symbols** earn a mark only when the question asks for them, and then usually need to be right for every substance.
- **"Write a chemical equation" / "write a symbol equation"** means a balanced equation with formulae. **"Word equation"** means names only.
- **"Deduce"** means use the information given: the formula printed in the question, the charges, or the states "at r.t.p.". Copy given formulae exactly.
- **"State the formula"** needs correct capital and small letters (Co is cobalt, CO is carbon monoxide; write a clear capital N in Na) and subscripts written low and small.
- **Definitions are marked on key words.** Molecular formula: "number and type of (different) atoms" + "in one molecule". Empirical formula: "simplest whole-number ratio" + "of atoms (or ions)".
- **Multiple-choice equations** often hinge on one detail: a wrong formula, a wrong product, a wrong state symbol, or a count that is off by one. Check all three: formulae, products, balance.

Quick check

1. Write the formulae of calcium hydroxide, sodium sulfate, ammonium chloride and iron(II) nitrate.
2. Balance these equations: (a) $Fe + Cl_2 \rightarrow FeCl_3$ (b) $C_4H_8 + O_2 \rightarrow CO_2 + H_2O$ (c) $Al + O_2 \rightarrow Al_2O_3$
3. Zinc carbonate powder is added to dilute sulfuric acid. The products are zinc sulfate solution, water and carbon dioxide. Write the symbol equation with state symbols.
4. **Extended.** Give the empirical formulae of C_6H_{12}, C_2H_6O, N_2O_4 and C_8H_{18}.
5. **Extended.** Aqueous sodium hydroxide is added to aqueous iron(II) sulfate, and a green precipitate of iron(II) hydroxide forms. Write the ionic equation for the reaction.

Answers

1. Ca^{2+} and $2OH^-$: **$Ca(OH)_2$**. $2Na^+$ and SO_4^{2-}: **Na_2SO_4**. NH_4^+ and Cl^-: **NH_4Cl**. Fe^{2+} and $2NO_3^-$: **$Fe(NO_3)_2$**.
2. (a) **$2Fe + 3Cl_2 \rightarrow 2FeCl_3$** (Fe 2, Cl 6 on each side). (b) **$C_4H_8 + 6O_2 \rightarrow 4CO_2 + 4H_2O$** (the right has $8 + 4 = 12$ O). (c) **$4Al + 3O_2 \rightarrow 2Al_2O_3$** (Al 4, O 6).
3. **$ZnCO_3(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2O(l) + CO_2(g)$**. It is already balanced: Zn 1, C 1, H 2, S 1, O 7 on each side.
4. $C_6H_{12} \rightarrow$ **CH_2** ($\div 6$); $C_2H_6O \rightarrow$ **C_2H_6O** (no common factor, so the same); $N_2O_4 \rightarrow$ **NO_2** ($\div 2$); $C_8H_{18} \rightarrow$ **C_4H_9** ($\div 2$).
5. **$Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$**. Na^+ and SO_4^{2-} are spectator ions. Charges: $(+2) + 2(-1) = 0$ on the left, 0 on the right.

Past questions to try

- **0620/21/O/N/23 Q6**: deciding which of four equations are balanced.
- **0620/22/F/M/24 Q10**: the formula of a compound from the charges of its ions.
- **0620/41/M/J/22 Q4**: writing and balancing equations for the stages of a process.
- **0620/43/O/N/21 Q3**: writing equations from a description, and ionic equations for displacement.