06 Chemical Formulae and Equations

1 Chemical Formulae

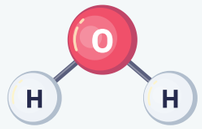
1.1 What a formula tells you

A **chemical formula** shows the elements in a substance and the _____ of their atoms.



carbon dioxide, CO_2

1 carbon atom, 2 oxygen atoms



water, H_2O

2 hydrogen atoms, 1 oxygen atom

- The _____ show which elements are present. The _____ show how many atoms of each.
- CO_2: one carbon atom and two oxygen atoms. H_2O: two hydrogen atoms and one oxygen atom.
- The prefix **di-** means _____. Carbon **di**oxide has two oxygen atoms.

1.2 Formulae of elements

Monoatomic

Single, _____ atoms. The Group 18 elements, such as neon (Ne) and argon (Ar), have _____ outer shells.

Diatomic

_____ atoms joined: H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2.

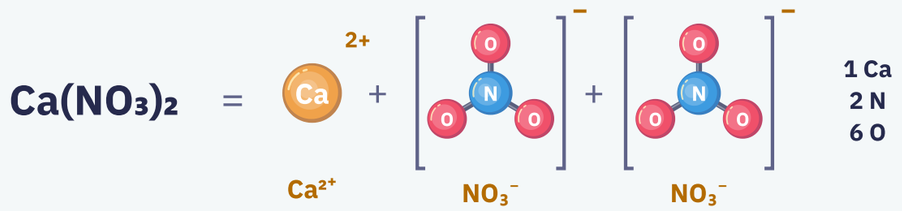
Polyatomic

Three or more atoms joined, such as phosphorus and ozone (O_3).

1 Chemical Formulae (continued)

1.3 Formulae of compounds

- A subscript outside **brackets** multiplies _____ inside them. $Ca(NO_3)_2$ has 1 calcium, _____ nitrogen and _____ oxygen atoms.



2 Constructing Formulae

2.1 Valency

Valency is the number of electrons an atom must lose, gain or share to get a noble gas configuration. The valency of an ion is its charge _____.

Group	1	2	13	14	15	16	17
Examples	Li, Na, K	Be, Mg, Ca	B, Al	C, Si	N, P	O, S	F, Cl, Br, I
Valency	1	2	_____	_____	_____	_____	1

NOTE Transition metals can form more than one ion. A _____ shows the valency: iron(II) is Fe^{2+}, iron(III) is Fe^{3+}, copper(II) is Cu^{2+}, copper(I) is Cu^{+}. Zinc (Zn^{2+}) and silver (Ag^{+}) have only one common ion.

2.2 Polyatomic ions

Name	Formula	Valency	Name	Formula	Valency
ammonium ★	NH_4^+	1	**sulfate** ★	SO_4^{2-}	2
hydroxide ★	OH^-	1	**carbonate** ★	CO_3^{2-}	2
nitrate ★	NO_3^-	1	phosphate	PO_4^{3-}	3

NOTE A polyatomic ion stays together as one unit. Put it in brackets when more than one is needed, e.g. $Mg(NO_3)_2$.

2 Constructing Formulae (continued)

2.3 The crossing method



1. write the valencies, then cross them over: C_2O_4
2. simplify 2 : 4 to 1 : 2

1. Write the symbols and their valencies below.
2. _____ the valencies: each valency becomes the _____ of the other element.
3. _____ the ratio if possible. C_2O_4 becomes CO_2.

2.4 Worked examples

WORKED EXAMPLE Write the formula of sodium phosphate.

Sodium has valency 1 (Na^+). Phosphate is a polyatomic ion with valency 3 (PO_4^{3-}).
Three Na^+ are needed to cancel one PO_4^{3-}.
The formula is **Na_3PO_4**.

WORKED EXAMPLE Write the formula of magnesium nitrate.

Magnesium has valency 2 (Mg^{2+}). Nitrate has valency 1 (NO_3^-).
Two NO_3^- are needed. Put the polyatomic ion in _____ before the subscript 2.
The formula is **$Mg(NO_3)_2$**.

2.5 Finding a charge from a formula

WORKED EXAMPLE Find the charge on the Al ion in $KAl(SO_4)_2$.

The compound is neutral, so the total charge is 0.
Let the charge on Al be x: 0 = (+1) + x + 2(−2).
So x = **+3**.

2 Constructing Formulae (continued)

2.6 Practice with formulae

Compound	Ions and valencies	Formula
calcium chloride	Ca^{2+} (2) and Cl^- (1)	**$CaCl_2$**
silver phosphate	Ag^+ (1) and PO_4^{3-} (3)	_____
iron(III) sulfate	Fe^{3+} (3) and SO_4^{2-} (2)	**$Fe_2(SO_4)_3$**
aluminium oxide	Al^{3+} (3) and O^{2-} (2)	_____

3 Chemical Equations

3.1 Word and chemical equations

sodium + chlorine → sodium chloride
$2Na(s) + Cl_2(g) \rightarrow 2NaCl(s)$



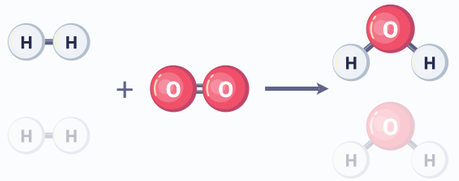
- _____ go on the left of the arrow and _____ on the right.
- The number in front of a formula is the number of units reacting or formed.
- **State symbols** show the physical state: (s) solid, (l) liquid, (g) gas, (aq) aqueous, which means _____.

NOTE The same substance can have a different state in different reactions. Sodium chloride is (s) when it forms from sodium and chlorine, but (aq) when it forms in a solution.

3.2 Balancing an equation



$H_2 + O_2 \rightarrow H_2O$: 2 O on the left, 1 O on the right



$2H_2 + O_2 \rightarrow 2H_2O$: 4 H and 2 O on each side

1. From the word equation (hydrogen + oxygen → water), write the correct formulae for reactants and products.
2. Count the atoms of each element on both sides.
3. Add numbers _____ formulae to balance. Never change a _____.
4. Add the state symbols: $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$.

3 Chemical Equations (continued)

3.3 Balancing with a solid and a gas

WORKED EXAMPLE Iron(III) oxide reacts with carbon monoxide to form iron and carbon dioxide. Write the balanced equation with state symbols.

Formulae: $Fe_2O_3 + CO \rightarrow Fe + CO_2$.

Two iron atoms on the left need **2Fe**. Three oxygen atoms in Fe_2O_3 are removed as CO_2, so use **3CO** and **3CO_2**.

$Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(s) + 3CO_2(g)$

3.4 A harder equation

WORKED EXAMPLE Aqueous iron(III) sulfate reacts with aqueous barium nitrate to form aqueous iron(III) nitrate and solid barium sulfate. Write the equation with state symbols.

Formulae: $Fe_2(SO_4)_3 + Ba(NO_3)_2 \rightarrow Fe(NO_3)_3 + BaSO_4$.

Balance the **ions**. Two Fe^{3+} need $2Fe(NO_3)_3$. Three SO_4^{2-} need $3BaSO_4$, so $3Ba(NO_3)_2$.

$Fe_2(SO_4)_3(aq) + 3Ba(NO_3)_2(aq) \rightarrow 2Fe(NO_3)_3(aq) + 3BaSO_4(s)$

3.5 Ionic equations

1. Write the balanced equation with state symbols.
   $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$
2. _____ the aqueous substances into ions.
   $Na^+ + OH^- + H^+ + Cl^- \rightarrow Na^+ + Cl^- + H_2O(l)$
3. **Cancel** the _____, which appear _____ on both sides.
4. What remains is the ionic equation: **$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$**



spectator ions Na^+ and Cl^- are unchanged, so they cancel

- _____, gases and liquids such as water are **not** split into ions.
- Write the quantity in front of an ion: $H_2SO_4(aq)$ splits into $2H^+(aq) + SO_4^{2-}(aq)$.
- Aqueous covalent substances such as aqueous chlorine are not split: $Cl_2(g) + 2I^-(aq) \rightarrow 2Cl^-(aq) + I_2(aq)$.

3 Chemical Equations (continued)

3.6 An ionic equation with a solid and a gas

WORKED EXAMPLE Write the ionic equation for $ZnCO_3(s) + 2HNO_3(aq) \rightarrow Zn(NO_3)_2(aq) + CO_2(g) + H_2O(l)$.

Split only the aqueous substances: $2H^+ + 2NO_3^-$ and $Zn^{2+} + 2NO_3^-$. Keep $ZnCO_3(s)$, $CO_2(g)$ and $H_2O(l)$ whole.

Cancel the spectator ions, $2NO_3^-(aq)$.

$ZnCO_3(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + CO_2(g) + H_2O(l)$

3.7 A precipitation reaction

WORKED EXAMPLE Write the ionic equation for $AgNO_3(aq) + HCl(aq) \rightarrow AgCl(s) + HNO_3(aq)$.

Split the aqueous substances: $Ag^+ + NO_3^- + H^+ + Cl^- \rightarrow AgCl(s) + H^+ + NO_3^-$.

Cancel the spectator ions, H^+ and NO_3^-. The solid AgCl stays whole.

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

3.8 Common mistakes to avoid

- Changing a subscript to balance an equation. Subscripts belong to the formula of the substance, so only change the number in **front**.
- Forgetting the brackets in a formula such as $Mg(NO_3)_2$.
- Writing hydrogen as H instead of H_2. The diatomic elements are H_2, N_2, O_2, F_2, Cl_2, Br_2 and I_2.
- Splitting a solid, a gas or water into ions in an ionic equation.
- Leaving the state symbols out when the question asks for them.

EXAM TIP After you balance, count the atoms of every element one last time. Check the charges too in an ionic equation.