

Types of Chemical Reactions

How do you recognize the main types of reaction and predict their products?

●○○ Beginner

Reactions & Stoichiometry

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Before you start: it helps to understand [Balancing Chemical Equations](#) and [Chemical Names and Formulas](#).

What is it?

Thousands of reactions fall into a few common **patterns**. Recognizing the pattern lets you predict the products and write the equation:

Type	Pattern	Example
Synthesis (combination)	$A + B \rightarrow AB$	$2 \text{Mg} + \text{O}_2 \rightarrow 2 \text{MgO}$
Decomposition	$AB \rightarrow A + B$	$\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$
Single displacement	$A + BC \rightarrow AC + B$	$\text{Zn} + \text{CuSO}_4 \rightarrow \text{ZnSO}_4 + \text{Cu}$
Double displacement	$AB + CD \rightarrow AD + CB$	$\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3$
Combustion	$\text{fuel} + \text{O}_2 \rightarrow \text{oxides}$	$\text{CH}_4 + 2 \text{O}_2 \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O}$

KEY IDEA

Look at the **reactants**: two substances joining, one substance breaking apart, an element plus a compound, two compounds swapping partners, or something burning in oxygen. The pattern tells you what the products will be; then balance the equation.

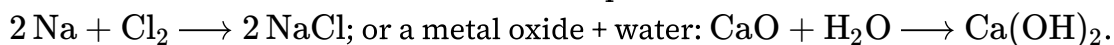
Why does it matter?

- **Predicting products.** You can write the equation for a reaction you have never seen.
- **Everyday chemistry.** Burning fuels (combustion), making lime from limestone (decomposition), extracting metals (displacement) and treating indigestion (neutralization, a double displacement).
- **It leads to deeper ideas.** Displacement and combustion are **redox** reactions; many double displacements are **precipitation** or **acid-base** reactions.

How does it work?

1. Synthesis

Two or more substances combine into one product. Often an element + element:



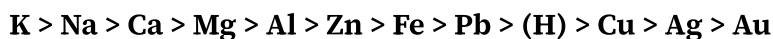
2. Decomposition

One compound breaks into simpler substances, usually when heated or by electricity:

- metal carbonates $\rightarrow$ metal oxide + carbon dioxide: $\text{CaCO}_3 \longrightarrow \text{CaO} + \text{CO}_2$
- electrolysis of water: $2\text{H}_2\text{O} \longrightarrow 2\text{H}_2 + \text{O}_2$

3. Single displacement and the activity series

A more reactive element **displaces** a less reactive one from its compound. For metals, use the **activity series** (most reactive first):



- A metal displaces any metal **below** it from a solution of its salt. Zinc displaces copper: $\text{Zn} + \text{CuSO}_4 \longrightarrow \text{ZnSO}_4 + \text{Cu}$. Copper does **not** displace zinc: no reaction.
- Metals above hydrogen displace hydrogen from acids: $\text{Mg} + 2\text{HCl} \longrightarrow \text{MgCl}_2 + \text{H}_2$.
- Halogens: a more reactive halogen displaces a less reactive one ($\text{F} > \text{Cl} > \text{Br} > \text{I}$): $\text{Cl}_2 + 2\text{KBr} \longrightarrow 2\text{KCl} + \text{Br}_2$.

4. Double displacement

Two ionic compounds **swap partners**. A reaction happens if a **precipitate** (insoluble solid), **water** or a **gas** forms:

- precipitation: $\text{AgNO}_3(\text{aq}) + \text{NaCl}(\text{aq}) \longrightarrow \text{AgCl}(\text{s}) + \text{NaNO}_3(\text{aq})$
- neutralization: $\text{HCl} + \text{NaOH} \longrightarrow \text{NaCl} + \text{H}_2\text{O}$
- gas formation: $\text{Na}_2\text{CO}_3 + 2\text{HCl} \longrightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$

5. Combustion

A substance reacts rapidly with **oxygen**, releasing heat and light. Hydrocarbons burning completely give **carbon dioxide and water**: $\text{C}_3\text{H}_8 + 5\text{O}_2 \longrightarrow 3\text{CO}_2 + 4\text{H}_2\text{O}$. With too little oxygen, combustion is **incomplete**, producing poisonous carbon monoxide (CO) or soot (C).

∞ THINK OF IT LIKE THIS

The patterns are like dance moves. In synthesis, two dancers pair up. In decomposition, a couple splits. In single displacement, a newcomer cuts in and takes someone's partner (but only if they are "more attractive": higher in the activity series). In double displacement, two couples swap partners.

🔍 MORE PRECISELY

These categories overlap and are not the only ones. Single displacement and combustion are always **redox** reactions; many synthesis and decomposition reactions are too. Double displacement reactions are not redox: no oxidation states change. A more fundamental classification uses the **driving force**: electron transfer (redox), proton transfer (acid-base) or the formation of an insoluble solid (precipitation).

Visualise it

Four reaction patterns

Each ball is an element or group of atoms.

Synthesis



Decomposition



Single displacement



Double displacement



The four basic patterns. Combustion is a special case in which one reactant is oxygen.

Worked example

WORKED EXAMPLE: Classifying reactions

Question: Classify: (a) $2 \text{KClO}_3 \longrightarrow 2 \text{KCl} + 3 \text{O}_2$ (b) $\text{Fe} + \text{CuCl}_2 \longrightarrow \text{FeCl}_2 + \text{Cu}$
(c) $\text{Pb}(\text{NO}_3)_2 + 2 \text{KI} \longrightarrow \text{PbI}_2 + 2 \text{KNO}_3$ (d) $4 \text{Al} + 3 \text{O}_2 \longrightarrow 2 \text{Al}_2\text{O}_3$

Step 1 (a) One reactant $\rightarrow$ two products: **decomposition**.

Step 2 (b) Element + compound, element swapped: **single displacement**.

Step 3 (c) Two compounds swap partners: **double displacement** (PbI_2 precipitates).

Step 4 (d) Two elements $\rightarrow$ one compound: **synthesis** (also a combustion of aluminium).

WORKED EXAMPLE: Will it react?

Question: Predict whether each reaction happens: (a) $\text{Zn} + \text{CuSO}_4$ (b) $\text{Cu} + \text{ZnSO}_4$
(c) $\text{Ag} + \text{HCl}$

Step 1 (a) Zinc is above copper: **yes**, $\text{Zn} + \text{CuSO}_4 \longrightarrow \text{ZnSO}_4 + \text{Cu}$.

Step 2 (b) Copper is below zinc: **no reaction**.

Step 3 (c) Silver is below hydrogen: **no reaction**.

WORKED EXAMPLE: Mass from a decomposition

Question: 10.0 g of calcium carbonate is heated until it fully decomposes:
 $\text{CaCO}_3 \longrightarrow \text{CaO} + \text{CO}_2$. What mass of carbon dioxide is released?

$$\begin{aligned} & 10.0 \text{ g } \text{CaCO}_3 \\ & \times \frac{1 \text{ mol } \text{CaCO}_3}{100.09 \text{ g } \text{CaCO}_3} \\ & \times \frac{1 \text{ mol } \text{CO}_2}{1 \text{ mol } \text{CaCO}_3} \\ & \times \frac{44.01 \text{ g } \text{CO}_2}{1 \text{ mol } \text{CO}_2} \\ & = 4.40 \text{ g } \text{CO}_2 \end{aligned}$$

 WORKED EXAMPLE: Writing a combustion equation

Question: Write the balanced equation for the complete combustion of propane, C_3H_8 .

Step 1 Products of complete combustion: CO_2 and H_2O .

Step 2 Balance C (3 CO_2), then H ($4 \text{ H}_2\text{O}$), then O: $3 \times 2 + 4 \times 1 = 10$ O atoms, so 5 O_2 .

Step 3 $\text{C}_3\text{H}_8 + 5 \text{ O}_2 \longrightarrow 3 \text{ CO}_2 + 4 \text{ H}_2\text{O}$

Common mistake

 COMMON MISTAKE: Predicting a displacement that can't happen

A metal only displaces a metal **below** it in the activity series. $\text{Cu} + \text{FeSO}_4$ gives no reaction, however long you wait.

 COMMON MISTAKE: Assuming every double displacement happens

Mixing $\text{KNO}_3(\text{aq})$ and $\text{NaCl}(\text{aq})$ gives no reaction: all four possible products are soluble, so no precipitate, water or gas forms. The ions just stay in solution.

 COMMON MISTAKE: Writing diatomic elements as single atoms

Oxygen, hydrogen, nitrogen and the halogens are diatomic: O_2 , H_2 , N_2 , Cl_2 . " $\text{Mg} + \text{O} \rightarrow \text{MgO}$ " is not a correct equation.

 NOTATION NOTE

- State symbols: (s) solid, (l) liquid, (g) gas, (aq) dissolved in water.
- " Δ " or "heat" written over the arrow shows that a reaction needs heating.

Remember this

 REMEMBER THIS

- Synthesis $\text{A} + \text{B} \rightarrow \text{AB}$; decomposition $\text{AB} \rightarrow \text{A} + \text{B}$.
- Single displacement $\text{A} + \text{BC} \rightarrow \text{AC} + \text{B}$: only if A is more reactive (activity series).
- Double displacement $\text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB}$: only if a precipitate, water or gas forms.
- Complete combustion of a hydrocarbon gives $\text{CO}_2 + \text{H}_2\text{O}$.
- Classify, predict the products, then balance.

References

1. Brown, T. L.; LeMay, H. E., Jr.; Bursten, B. E.; Murphy, C. J.; Woodward, P. M.; Stoltzfus, M. W. Chemistry: The Central Science, 15th ed.; Pearson, 2022.

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