

Chemical Reactions & Equations

Preparation for General Chemistry · Dr. Karmach

By the end of this unit, you can...

- Write a balanced equation with physical states from a description, changing coefficients only
- Classify a reaction as combination, decomposition, single displacement, double displacement, or combustion, and predict its products from the pattern
- Use the activity series to decide whether a single displacement runs with a metal, an acid, or water, and write no reaction when it does not
- Apply the solubility rules to predict a precipitate and write the equation with states
- Recognize a gas-forming reaction, replacing H_2CO_3 , H_2SO_3 , or NH_4OH with the gas and water
- Write molecular, complete ionic, and net ionic equations, and classify a solute as a strong, weak, or nonelectrolyte

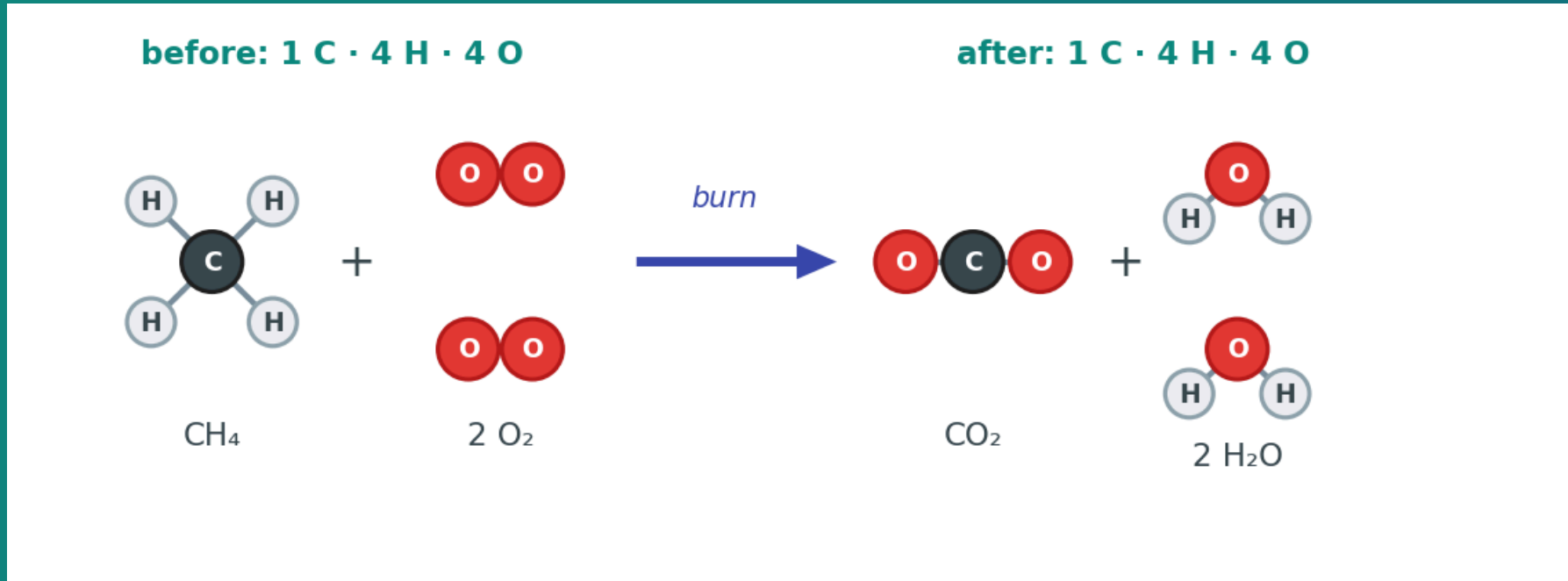
Today's route

1. **Balancing Equations**
2. **Types of Reactions**
3. **The Activity Series**
4. **Solubility Rules & Precipitation**
5. **Net Ionic Equations**
6. **Electrolytes & Dissociation**

1 • Balancing Equations

Turn any skeleton equation into a balanced one, and identify which numbers may change.

Atoms don't disappear



Burning methane makes new molecules out of the same atoms. Count them: 1 C, 4 H, 4 O before and after. Every reaction works this way.

What an equation says



reactants → products · the arrow reads "react to form" · each + reads "and"

"methane and oxygen react to form carbon dioxide and water"

(s) solid · (l) liquid · (g) gas · (aq) aqueous, dissolved in water

An equation is a sentence about substances. Formulas right, coefficients not yet chosen: that is a **skeleton equation**. Balancing supplies the coefficients; nothing else may change.

Writing an equation from words

"Solid magnesium burns in oxygen gas to form solid magnesium oxide."

the words name each substance and its state

Four things go into the equation: formulas, a state for each substance, coefficients, and any condition, such as heat, above the arrow. Oxygen gas is O₂, one of the seven diatomic elements.



"solid magnesium": Mg(s) · "oxygen gas": O₂(g) · "solid magnesium oxide": MgO(s) · coefficients
come last, from balancing

Your turn: count atoms in 3 Mg(OH)₂

Sixty seconds, straight from the naming rules: parentheses multiply, and now a coefficient multiplies the whole formula.

atom	count
Mg	$3 \times 1 = \underline{\hspace{1cm}}$
O	$3 \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}}$
H	$3 \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}}$



$$\text{Mg: } 3 \times 1 = 3 \cdot \text{O: } 3 \times 2 = 6 \cdot \text{H: } 3 \times 2 = 6$$

The coefficient 3 multiplies every atom in the formula; the subscript 2 multiplies only what the parentheses enclose.

Why every equation must balance

A reaction rearranges atoms. It never creates or destroys them. Both sides of a correct equation must show the **same number of each kind of atom**.



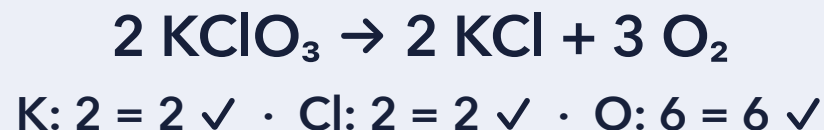
H: $4 = 4$ ✓ · O: $2 = 2$ ✓ · a possible reaction



H: $2 = 2$ ✓ · O: $2 \neq 1$ ✗ · an O atom would have to vanish

What "balanced" looks like

every atom count matches: the beam stays level



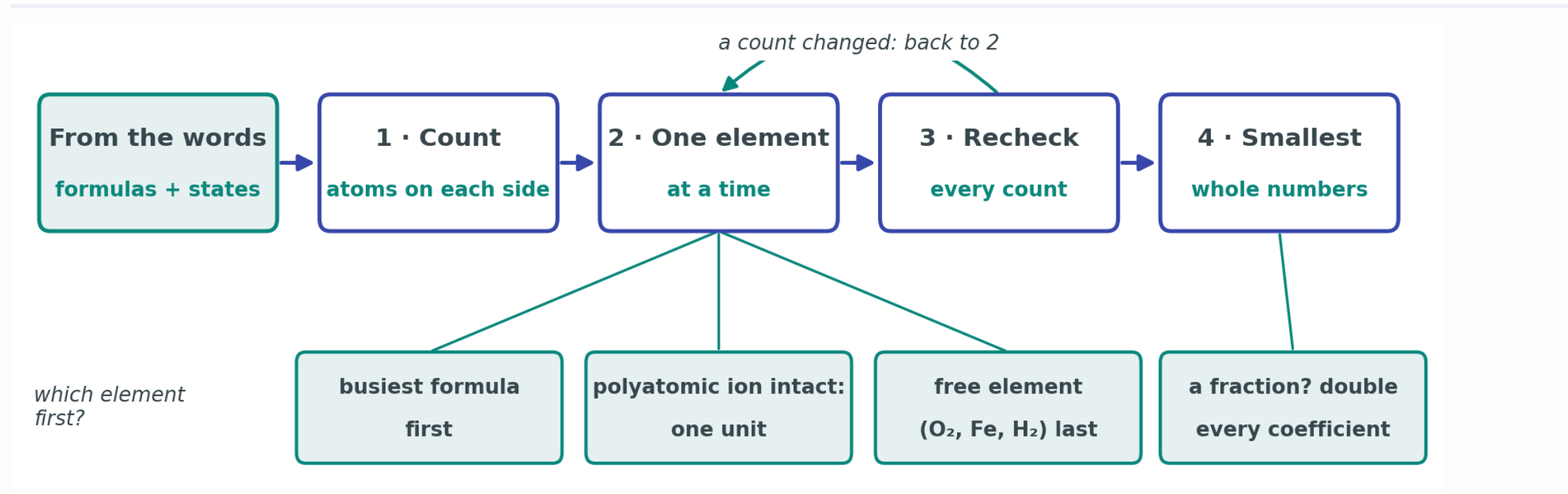
Every element's count matches. That is the complete test.



The method

1. Write the atom count for each side.
2. Balance **one element at a time**. Save any element that appears in several formulas for last.
3. **Recheck every count** after each change.
4. Finish with the smallest whole numbers.

Which element to balance first



Start with the element in the busiest formula. A polyatomic ion that crosses the arrow unchanged balances as one unit. A free element, such as O₂ or Fe, goes last: its coefficient changes nothing else.



Guided example: hydrogen chloride

"Hydrogen gas and chlorine gas combine to form hydrogen chloride gas."

given: the words · wanted: the balanced equation with states

Dissolving hydrogen chloride in water makes hydrochloric acid.

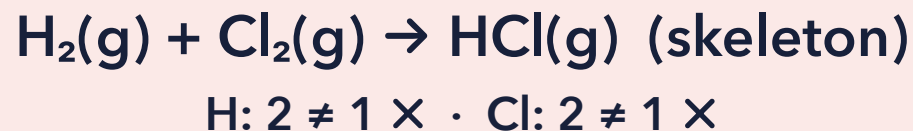
Write the balanced equation with states, one named move at a time.

✓ Guided example: solution

"Hydrogen gas and chlorine gas combine to form hydrogen chloride gas."
given: the words · wanted: the balanced equation with states

From the words · formulas and states

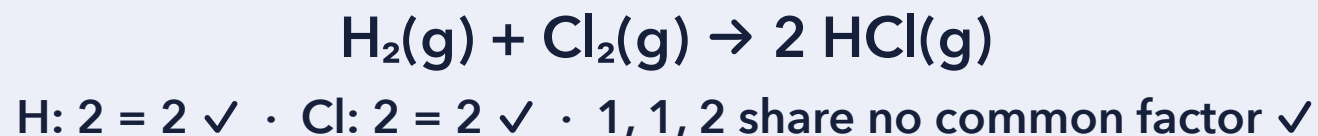
Step 1 · Write the atom count for each side



Step 2 · Balance one element at a time

Step 3 · Recheck every count

Step 4 · Finish with the smallest whole numbers

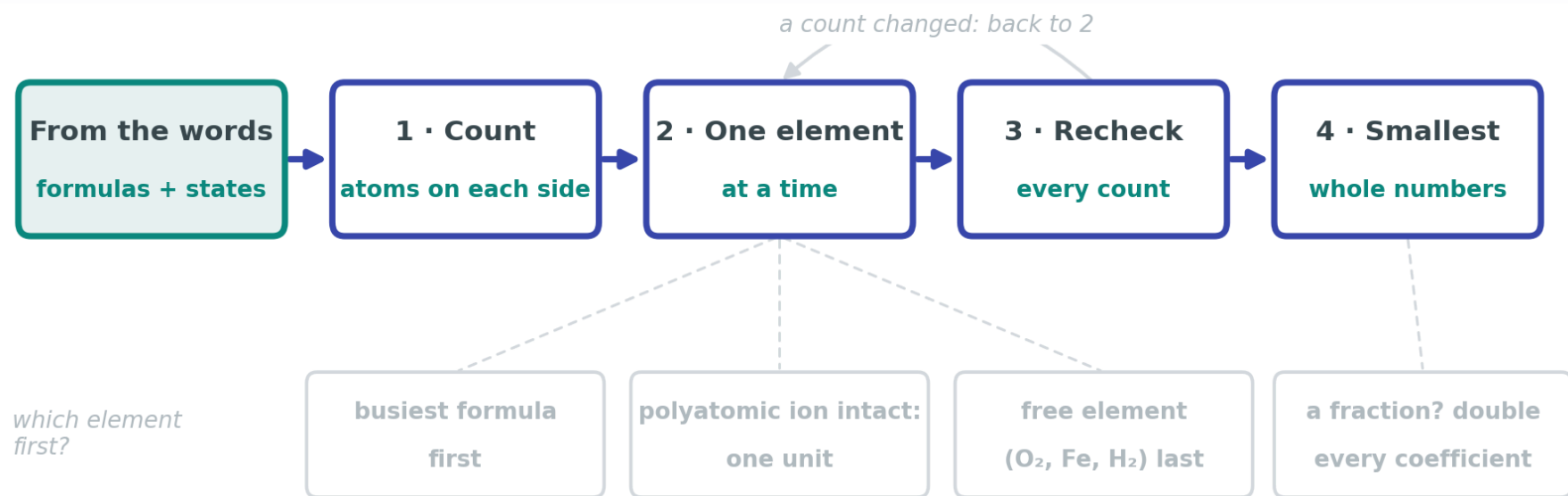


 **Sense check:** One coefficient settled both elements. The 2 counts HCl molecules; the formula never changed.

✓ Guided example: the route



given: the words · found: the balanced equation · H: $2 = 2$ ✓ · Cl: $2 = 2$ ✓



 **Sense check:** The words supplied every formula and state. Then the four method steps, straight through: no count changed after the first coefficient.



Worked example 1: splitting water

Step 1 • Write the atom count for each side



H: 2 = 2 ✓ · O: 1 ≠ 2 ✗

Electrolysis splits water into hydrogen gas and oxygen gas. Oxygen doesn't balance.

A common first attempt: change H_2O to H_2O_2 . Test it.

✓ Worked example 1: solution



H: $2 = 2$ ✓ · O: $1 \neq 2$ ✗

A common first attempt



H: $2 = 2$ ✓ · O: $2 = 2$ ✓

Step 2 · Balance one element at a time



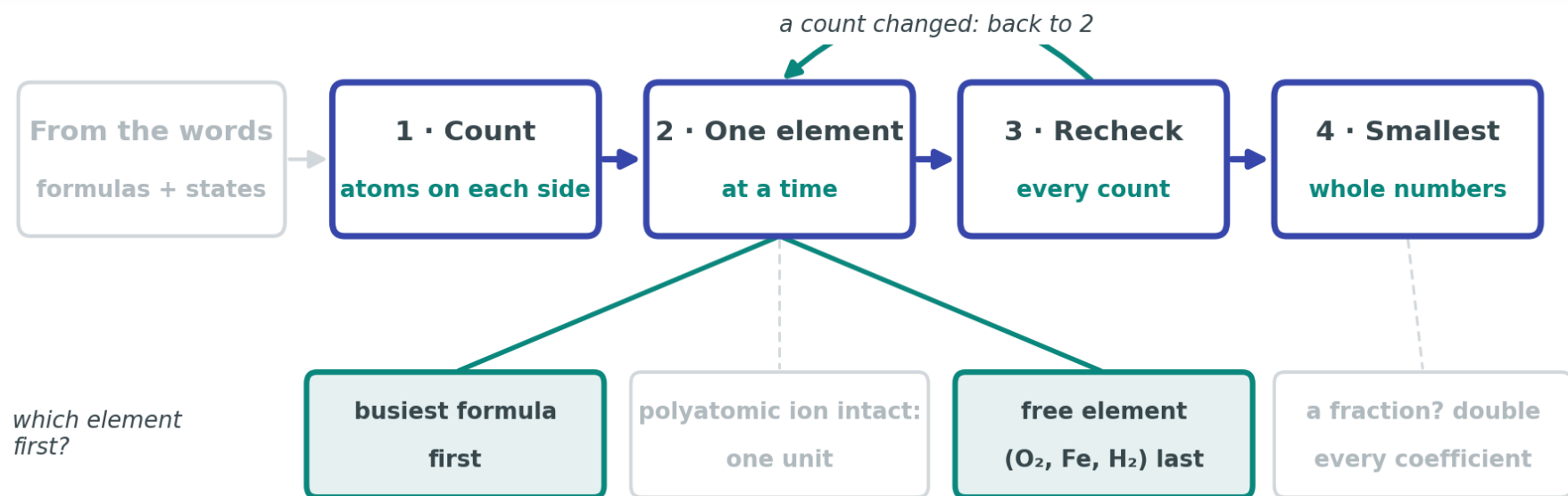
H: $4 = 4$ ✓ · O: $2 = 2$ ✓

 **Sense check:** Coefficients change the amount. Subscripts change the substance. Only coefficients may change.

✓ Worked example 1: the route



found: H: 4 = 4 ✓ · O: 2 = 2 ✓



 **Sense check:** H_2O is the only compound, so O went first: $2 \text{H}_2\text{O}$. That changed the H count, and the recheck sent it back to Step 2. H_2 , a free element, took the last coefficient.



Worked example 2: a common multiple

Rust: iron reacting with oxygen.

Step 1 • Write the atom count for each side



Fe: 1 $\neq$ 2 • O: 2 $\neq$ 3

Oxygen shows 2 on the left and 3 on the right. What is the smallest number both divide into?

✓ Worked example 2: solution



Fe: 1 $\neq$ 2 · O: 2 $\neq$ 3

Step 2 · Balance one element at a time



O: 6 = 6 ✓ · Fe: 1 $\neq$ 4 ✗

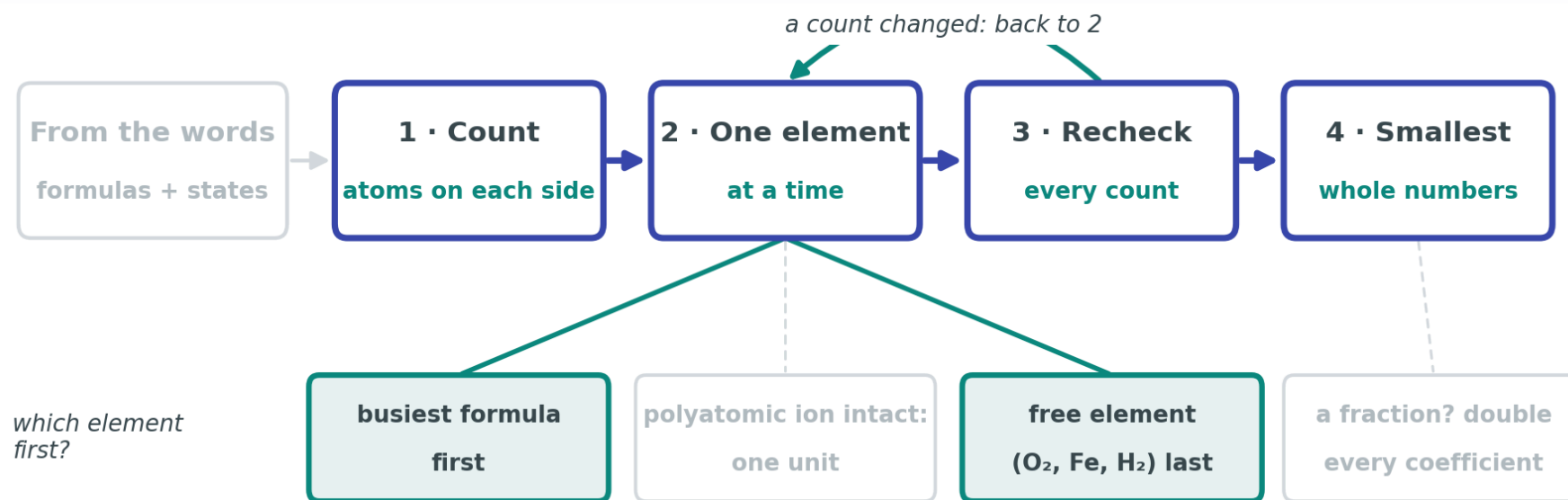
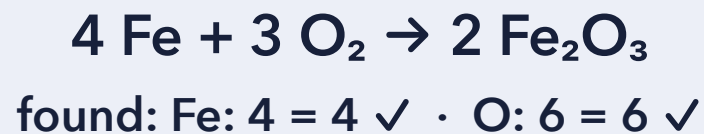
Step 3 · Recheck every count



Fe: 4 = 4 ✓ · O: 6 = 6 ✓

 **Sense check:** One change can unbalance an element already counted. Recheck every count after each change.

✓ Worked example 2: the route



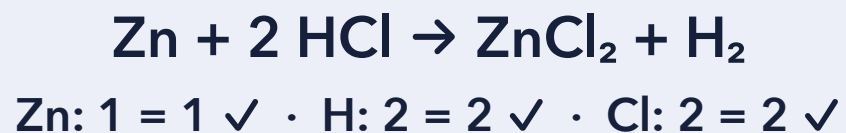
Sense check: Fe_2O_3 is the busiest formula, so O went first, with the common multiple 6. The recheck caught Fe, and the free element took the last coefficient: 4 Fe.

Your turn: zinc and hydrochloric acid



atom	left	right
Zn	1	1 ✓
H	<u> </u> × 1	2
Cl	<u> </u> × 1	2

One coefficient balances both H and Cl.



Where this goes wrong

Changing subscripts. Writing H_2O_2 balances the counts but changes the substance. If the formula changes, the chemistry changes.

Forgetting the unwritten 1. $\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2$ has coefficient sum $1 + 2 + 1 + 1 = 5$, not 4. An unwritten coefficient is still a 1.

Reading coefficients as grams. $4 \text{Fe} + 3 \text{O}_2$ does not mean "4 g and 3 g." Coefficients count particles or moles. Converting to mass requires the molar mass.

Stopping too early. $8 \text{Fe} + 6 \text{O}_2 \rightarrow 4 \text{Fe}_2\text{O}_3$ balances, but every coefficient divides by 2. Reduce to smallest whole numbers.



Practice 1



Ammonia burned over a platinum catalyst, the first step in making nitric acid for fertilizer. What does the **5** in front of O_2 mean?

- A. Each O_2 molecule contains 5 oxygen atoms.
- B. 5 molecules of O_2 react, or equally 5 moles, in proportion to the other coefficients.
- C. 5 grams of O_2 are consumed.
- D. Exactly 5 individual molecules react. The number cannot scale up to moles.

✓ Practice 1: answer B



$$5 \text{ O}_2 \rightarrow 5 \times 2 = 10 \text{ O} \cdot \text{ right side: } 4 \text{ NO} + 6 \text{ H}_2\text{O} \rightarrow 4 + 6 = 10 \text{ O} \checkmark$$

A describes a subscript's job. C: coefficients are counts, never masses. D: multiplying every coefficient by Avogadro's number leaves the ratios unchanged, so coefficients count moles as well as molecules.

🧠 **Sense check:** In 5 O_2 , the coefficient and the subscript do different jobs: $5 \times 2 = 10$ atoms of O.

Practice 2: from words, one coefficient

"Dinitrogen tetroxide gas breaks apart into nitrogen dioxide gas."

Which balanced equation, with states, matches the description?

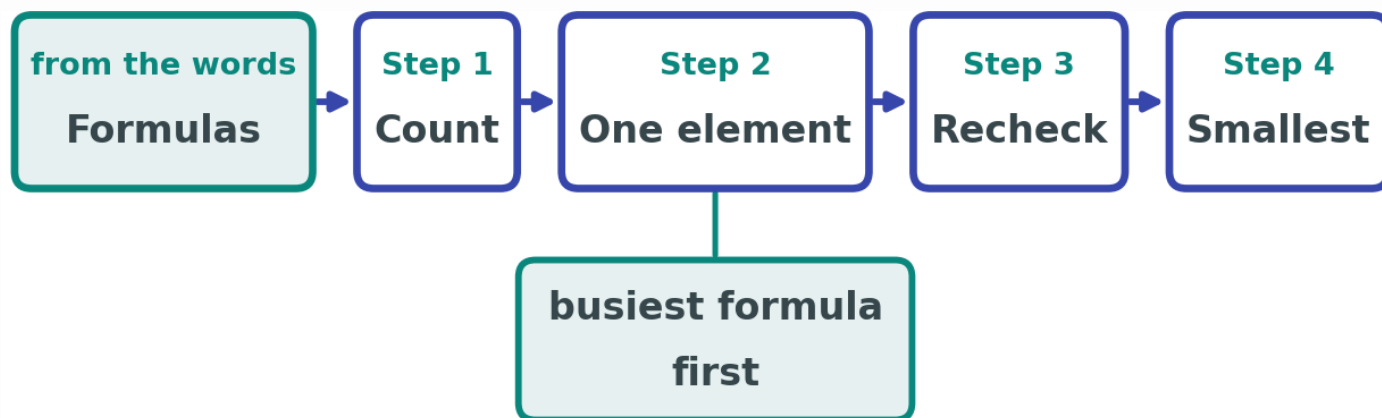
- A. $\text{N}_2\text{O}_4(\text{g}) \rightarrow \text{NO}_2(\text{g})$
- B. $\text{N}_2\text{O}_4(\text{g}) \rightarrow 2 \text{NO}(\text{g}) + \text{O}_2(\text{g})$
- C. $2 \text{N}_2\text{O}_4(\text{g}) \rightarrow 4 \text{NO}_2(\text{g})$
- D. $\text{N}_2\text{O}_4(\text{g}) \rightarrow 2 \text{NO}_2(\text{g})$

✓ Practice 2: answer D



dinitrogen tetroxide: N_2O_4 · nitrogen dioxide: NO_2 · N: $2 = 2 \checkmark$ · O: $4 = 2 \times 2 \checkmark$

A is the skeleton: N $2 \neq 1$, O $4 \neq 2$. B balances, but NO is nitrogen monoxide; the words name nitrogen dioxide. C balances, but every coefficient divides by 2.



🧠 **Sense check:** N_2O_4 is the busiest formula: its 2 N need 2 NO_2 , and O then matches, $4 = 4$. One coefficient, and the formulas the names fixed never changed.



Worked example 3: sulfate as one unit

"Solid aluminum reacts with aqueous copper(II) sulfate to form solid copper and aqueous aluminum sulfate."

given: sulfate SO_4^{2-} · wanted: the balanced equation with states

A strip of aluminum dropped into blue copper(II) sulfate solution turns red-brown as copper coats it.

Write the balanced equation with states.

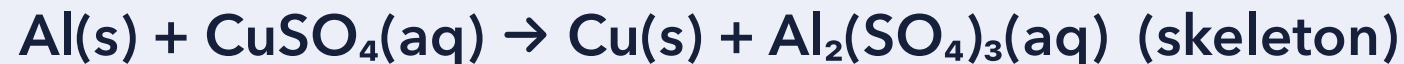
✓ Worked example 3: solution

"Solid aluminum reacts with aqueous copper(II) sulfate to form solid copper and aqueous aluminum sulfate."

given: sulfate SO_4^{2-} · wanted: the balanced equation with states

From the words · formulas and states

Step 1 · Write the atom count for each side



SO_4 crosses the arrow intact: one unit · Al: $1 \neq 2 \times$ · Cu: $1 = 1 \checkmark$ · SO_4 : $1 \neq 3 \times$

Step 2 · Balance one element at a time



SO_4 : $3 = 3 \checkmark$ · Cu: $3 \neq 1 \times$ · Al: $1 \neq 2 \times$

🧠 **Sense check:** Sulfate is settled as one unit, $3 = 3$. Fixing it changed the Cu count: the recheck comes next.

✓ Worked example 3: solution, continued



$\text{SO}_4: 3 = 3 \checkmark \cdot \text{Cu}: 3 \neq 1 \times \cdot \text{Al}: 1 \neq 2 \times$

Step 3 · Recheck every count

Step 4 · Finish with the smallest whole numbers



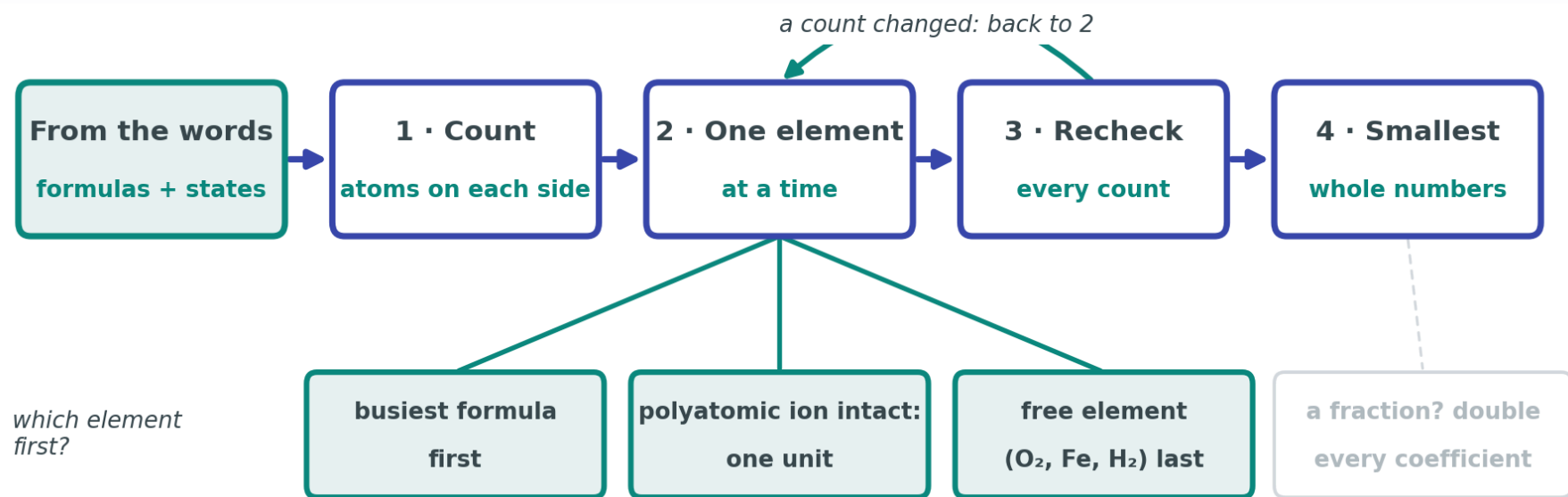
$\text{Al}: 2 = 2 \checkmark \cdot \text{Cu}: 3 = 3 \checkmark \cdot \text{SO}_4: 3 = 3 \checkmark \cdot 2, 3, 3, 1 \text{ share no factor}$

 **Sense check:** Atom by atom the answer is the same: S $3 = 3$, O $3 \times 4 = 12$ on each side $\checkmark$. One SO_4 count replaced two element counts.

✓ Worked example 3: the route



found: Al: 2 = 2 ✓ · Cu: 3 = 3 ✓ · SO₄: 3 = 3 ✓



 **Sense check:** Words to formulas, then the busiest formula set the sulfate count. The recheck sent the two free elements back to Step 2, last.

Practice 3: nitrate as one unit

"Aqueous silver nitrate and aqueous magnesium chloride react to form solid silver chloride and aqueous magnesium nitrate."

given: nitrate NO_3^-

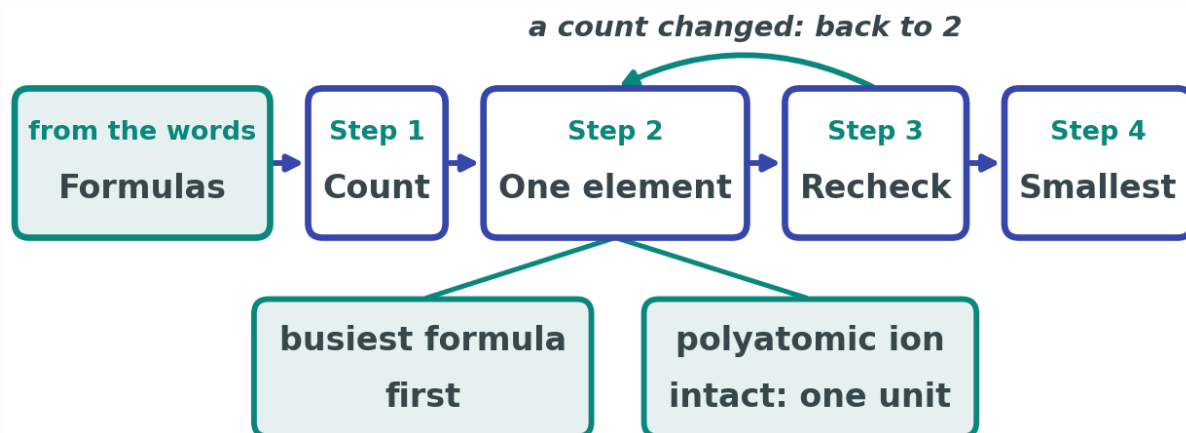
Which balanced equation, with states, matches the description?

- A. $2 \text{AgNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq}) \rightarrow 2 \text{AgCl}(\text{s}) + \text{Mg}(\text{NO}_3)_2(\text{aq})$
- B. $\text{AgNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq}) \rightarrow \text{AgCl}_2(\text{s}) + \text{MgNO}_3(\text{aq})$
- C. $\text{AgNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{Mg}(\text{NO}_3)_2(\text{aq})$
- D. $2 \text{AgNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq}) \rightarrow 2 \text{AgCl}(\text{aq}) + \text{Mg}(\text{NO}_3)_2(\text{s})$

✓ Practice 3: answer A



B edited subscripts: Ag^+ and Cl^- make AgCl ; Mg^{2+} takes two NO_3^- . C is the skeleton: $\text{Cl } 2 \neq 1$, $\text{NO}_3 \ 1 \neq 2$. D swaps the states: the words make silver chloride the solid.



🧠 **Sense check:** $\text{Mg}(\text{NO}_3)_2$ went first: its 2 NO_3 , one unit each, need 2 AgNO_3 . The recheck found $\text{Ag } 2 \neq 1$, so 2 AgCl .

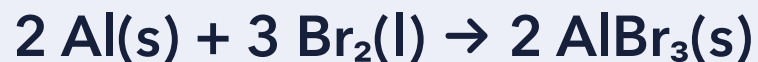
Practice 4: a common multiple from words

"Solid aluminum reacts with liquid bromine to form solid aluminum bromide."

Balance the equation in smallest whole numbers. What is the sum of all the coefficients, unwritten 1s included?

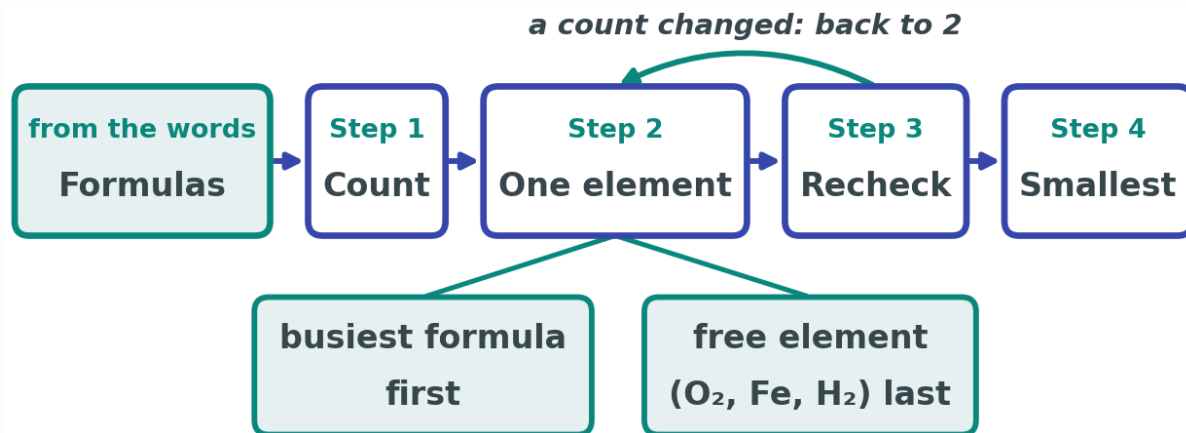
- A. 3.5
- B. 7
- C. 14
- D. 5

✓ Practice 4: answer B



$$\text{Al: } 2 = 2 \checkmark \cdot \text{Br: } 3 \times 2 = 6 = 2 \times 3 \checkmark \cdot \text{sum: } 2 + 3 + 2 = 7$$

A stopped at the fraction: $1 + 3/2 + 1 = 3.5$. C used 12 as the common multiple and never divided down: $4 + 6 + 4 = 14$. D wrote bromine as Br atoms: $\text{Al} + 3 \text{ Br} \rightarrow \text{AlBr}_3$ gives $1 + 3 + 1 = 5$, but bromine is diatomic, Br_2 .



 **Sense check:** Br went first from the busiest formula, AlBr_3 : 2 and 3 meet at 6. Al, the free element, came last: 2 Al.

Worked example 4: combustion

Stove gas is methane, and burning it makes carbon dioxide and water. The skeleton:

Step 1 • Write the atom count for each side



C: 1 = 1 ✓ · H: 4 ≠ 2 · O: 2 ≠ 3

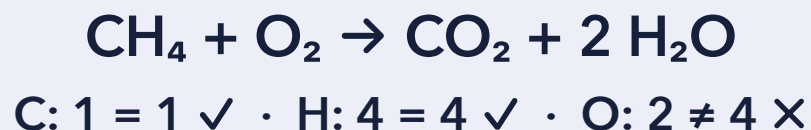
For combustion, balance **C first, H second, O last**. O₂ contains only one element, so its coefficient can be set last without disturbing the others.

Balance it.

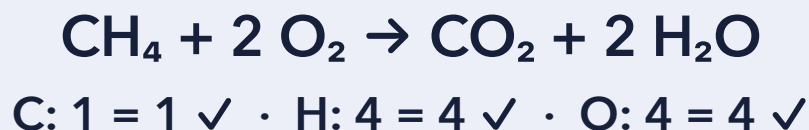
✓ Worked example 4: solution



Step 2 • Balance one element at a time

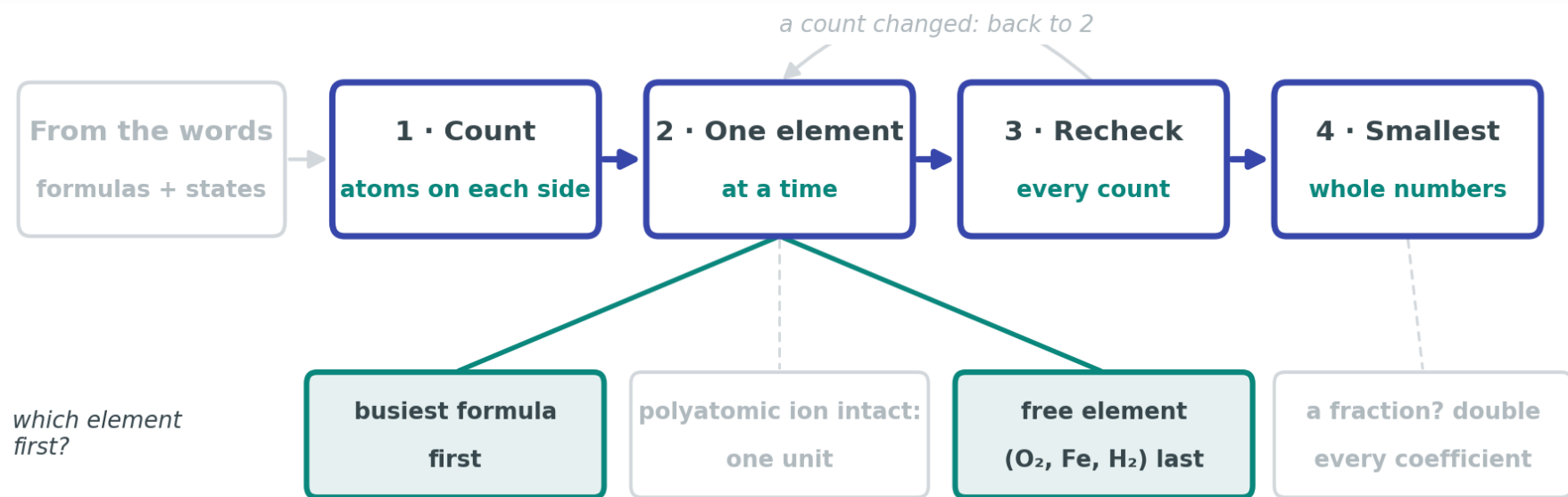
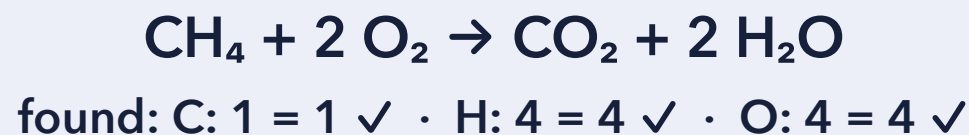


Step 3 • Recheck every count



 **Sense check:** 4 is even, so O₂ lands cleanly: no fractions, smallest whole numbers on the first pass. Saving the lone-element formula for last meant one clean choice at the end.

✓ Worked example 4: the route



 **Sense check:** CH₄ is the busiest formula: C, then H. O₂ is a free element, so its coefficient came last and changed no other count. Nothing sent the solution back.



Worked example 5: a fraction appears

Butane fuels lighters.

Step 1 • Write the atom count for each side



C: 4 ≠ 1 · H: 10 ≠ 2 · O: 2 ≠ 3

Same order: **C first, H second, O last.**

Balance it. A fraction will appear along the way.

✓ Worked example 5: solution



Step 2 • Balance one element at a time

Step 3 • Recheck every count

Step 4 • Finish with the smallest whole numbers

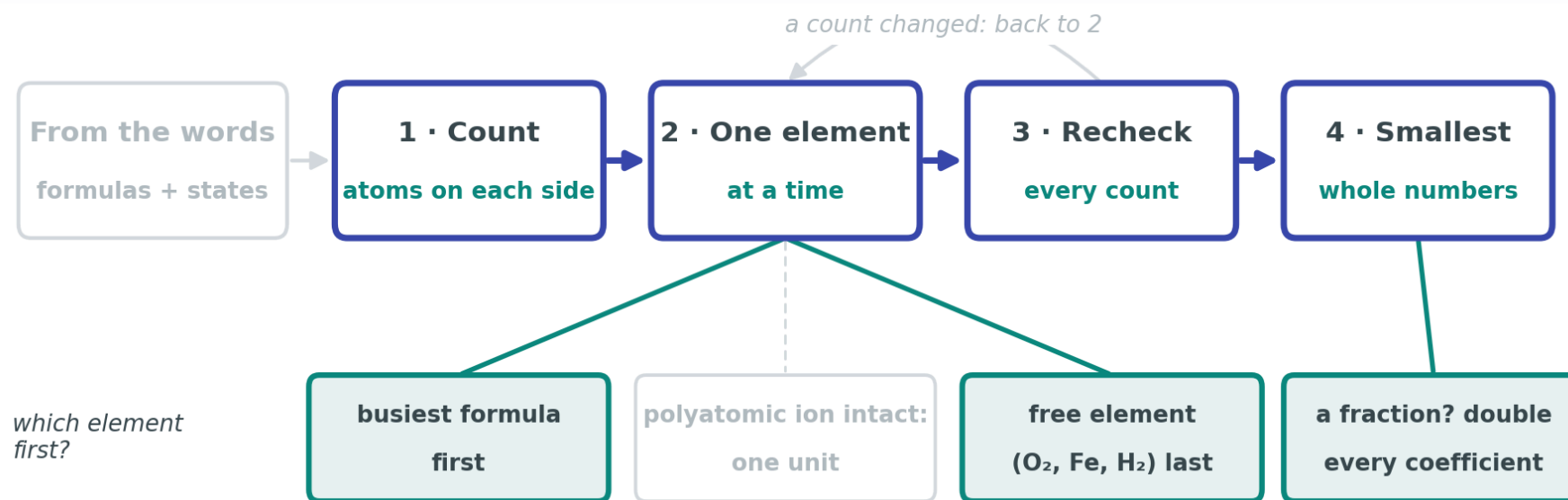
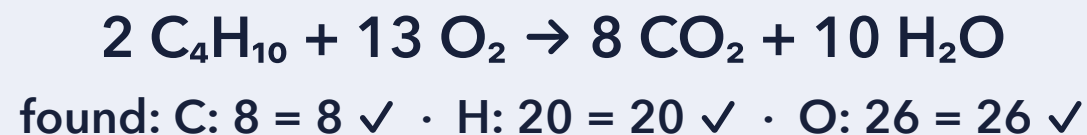
step	equation
C, then H	$\text{C}_4\text{H}_{10} + \text{O}_2 \rightarrow 4 \text{CO}_2 + 5 \text{H}_2\text{O}$
O: right side holds 13	$\text{C}_4\text{H}_{10} + 13/2 \text{O}_2 \rightarrow 4 \text{CO}_2 + 5 \text{H}_2\text{O}$
double it	$2 \text{C}_4\text{H}_{10} + 13 \text{O}_2 \rightarrow 8 \text{CO}_2 + 10 \text{H}_2\text{O}$



C: 8 = 8 ✓ · H: 20 = 20 ✓ · O: 26 = 26 ✓

🧠 **Sense check:** 13 is odd, so no common factor remains. These are already the smallest whole numbers.

✓ Worked example 5: the route



 **Sense check:** C_4H_{10} first, O_2 last. The free element took the odd count as $13/2$, and doubling every coefficient cleared the fraction.



Practice 5: combustion



Xylene, a paint-thinner solvent, burns in air. Balance with smallest whole numbers. What is the sum of **all** the coefficients?

- A. 35
- B. 24.5
- C. 49
- D. 25

✓ Practice 5: answer C



C first: 8 CO₂ · H next: 5 H₂O · O last: 8 × 2 + 5 = 21 on the right, so 21/2 O₂



C: 16 = 16 ✓ · H: 20 = 20 ✓ · O: 42 = 32 + 10 ✓ · sum: 2 + 21 + 16 + 10 = 49 (answer C)

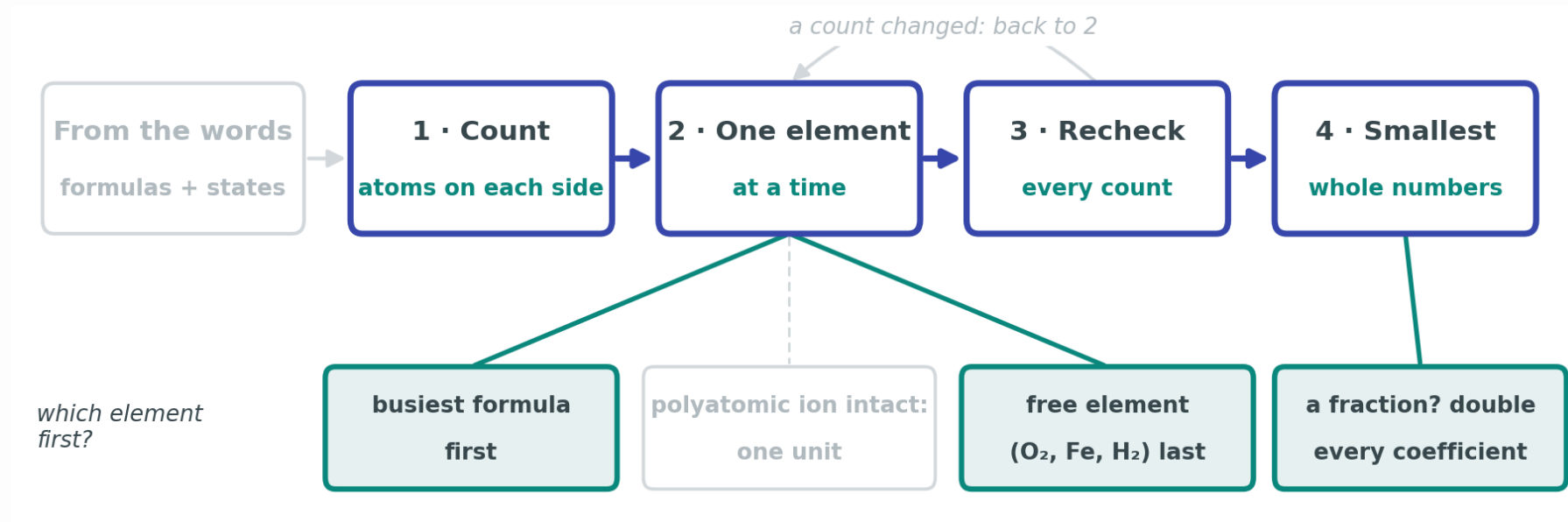
B stopped at the fraction: 1 + 21/2 + 8 + 5 = 24.5, not whole numbers. A doubled only the O₂: 1 + 21 + 8 + 5 = 35, with 42 O on the left against 21 on the right. D rounded 21/2 up to 11: 1 + 11 + 8 + 5 = 25, and 22 O ≠ 21.

 **Sense check:** A fraction clears only when every coefficient doubles. 21 is odd, so 2, 21, 16, 10 share no factor: 49 is the smallest-whole-number sum.

✓ Practice 5: the route



found: C: 16 = 16 ✓ · H: 20 = 20 ✓ · O: 42 = 42 ✓ · sum 49



🧠 **Sense check:** C_8H_{10} first, O_2 last as $21/2$, then every coefficient doubled to clear the fraction.

Practice 6: two polyatomic ions from words

"Aqueous calcium nitrate and aqueous potassium phosphate react to form solid calcium phosphate and aqueous potassium nitrate."

given: nitrate NO_3^- · phosphate PO_4^{3-}

Write the balanced equation with states. What is the sum of all the coefficients, unwritten 1s included?

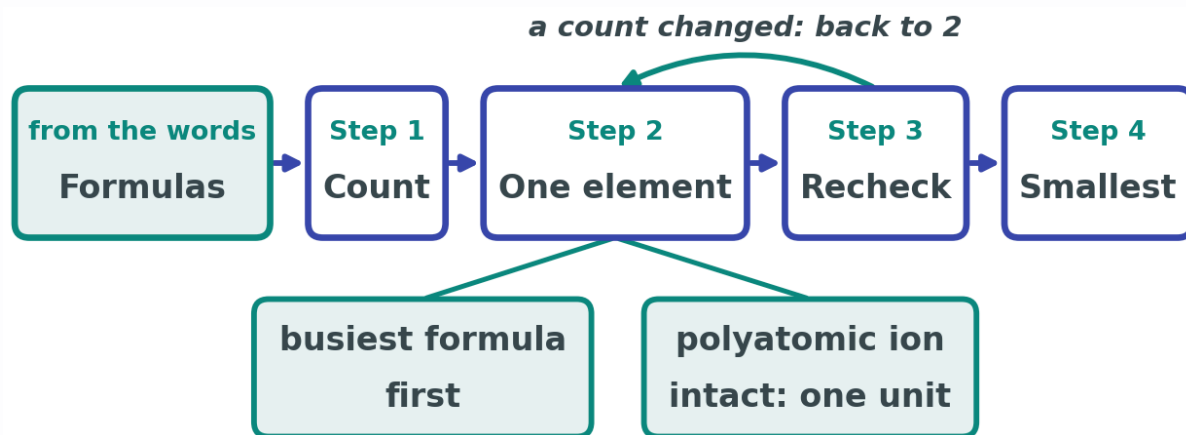
- A. 11
- B. 4
- C. 12
- D. 9

✓ Practice 6: answer C



Ca: $3 = 3$ ✓ · PO₄: $2 = 2$ ✓ · K: $2 \times 3 = 6$ ✓ · NO₃: $3 \times 2 = 6$ ✓ · sum: $3 + 2 + 1 + 6 = 12$

B read the skeleton as balanced: $1 + 1 + 1 + 1 = 4$. D set 3 KNO₃, then doubled K₃PO₄ without a recheck: $3 + 2 + 1 + 3 = 9$, K $6 \neq 3$. A dropped the unwritten 1 on Ca₃(PO₄)₂: $3 + 2 + 6 = 11$.



 **Sense check:** Ca₃(PO₄)₂ set 3 Ca and 2 PO₄, each ion one unit. The recheck found K and NO₃ at 6 each: 6 KNO₃.

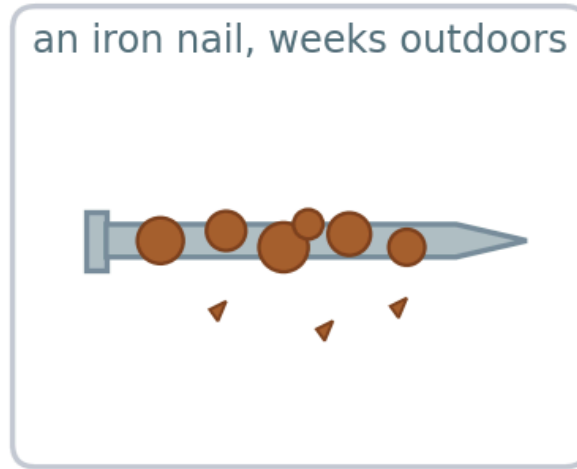
2 · Types of Reactions

Spot the evidence that a reaction occurred, classify any equation as one of the five reaction types, and predict products from the pattern.

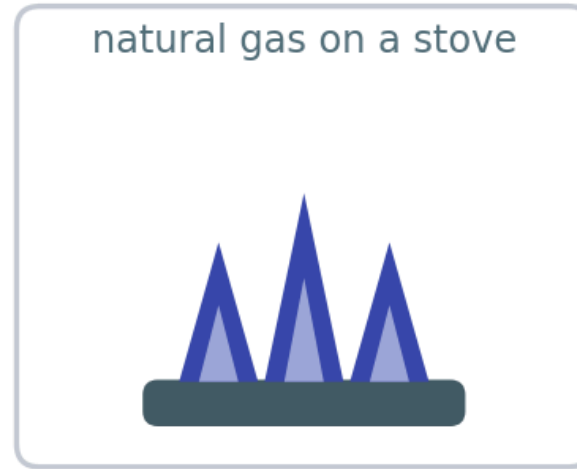
Signs of a new substance



foams up



turns brown and flaky



burns blue

Baking soda and vinegar foam. A nail turns brown and flaky. Stove gas burns blue. Each change makes a new substance, and each leaves a visible sign.

Reactions repeat a few patterns



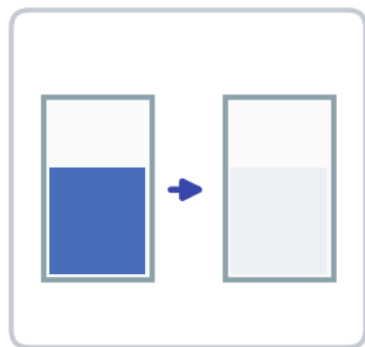
element + element → one compound



element + element → one compound, the same pattern

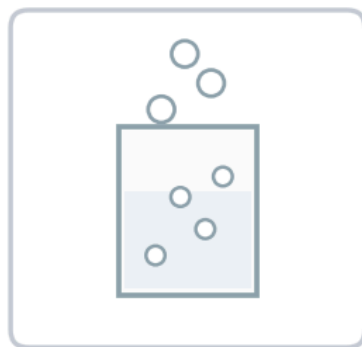
Millions of reactions are known. Nearly all follow a few repeating patterns, visible in the equation's shape. Recognizing the pattern tells what the products must be before any balancing starts.

Evidence a reaction occurred



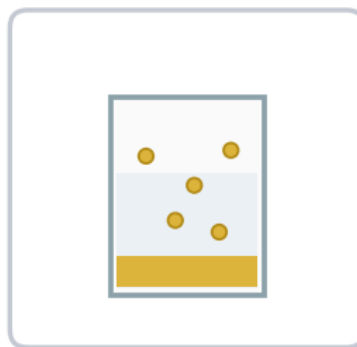
color change

a new color appears



gas forms

bubbles rise out



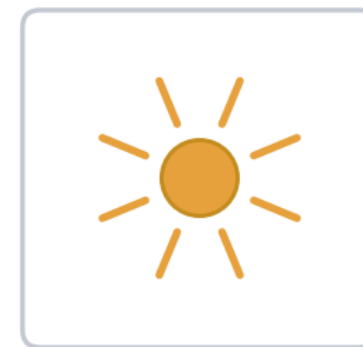
precipitate

a new solid settles out



temperature change

heats up or cools down



light

the mixture glows

New substances have new properties, so the change is visible. Watch for a color change, a gas bubbling out, a solid settling from clear solutions (a **precipitate**), a temperature change, or light.

Element or compound: the first label

Mg · Na · O₂ · Cl₂ · S₈ : elements

one kind of symbol · the subscript counts atoms of that one element

MgO · NaCl · H₂O · CaCO₃ : compounds

two or more kinds of symbol

Every pattern labels each substance element or compound. One kind of symbol in the formula means an element; two or more, a compound. A subscript never makes a compound: O₂ and S₈ are elements.

Reading a pattern



each letter stands for an element or an ion, not one particular substance



$A = \text{Zn}$ · $BC = \text{HCl}$ (B is H, C is Cl) · $AC = \text{ZnCl}_2$ · B leaves as H_2

A pattern is a template: any element or ion can play a letter. Coefficients play no part; the pattern reads only which substances are elements and which are compounds.

The five patterns

combination



decomposition



single displacement



double displacement



combustion



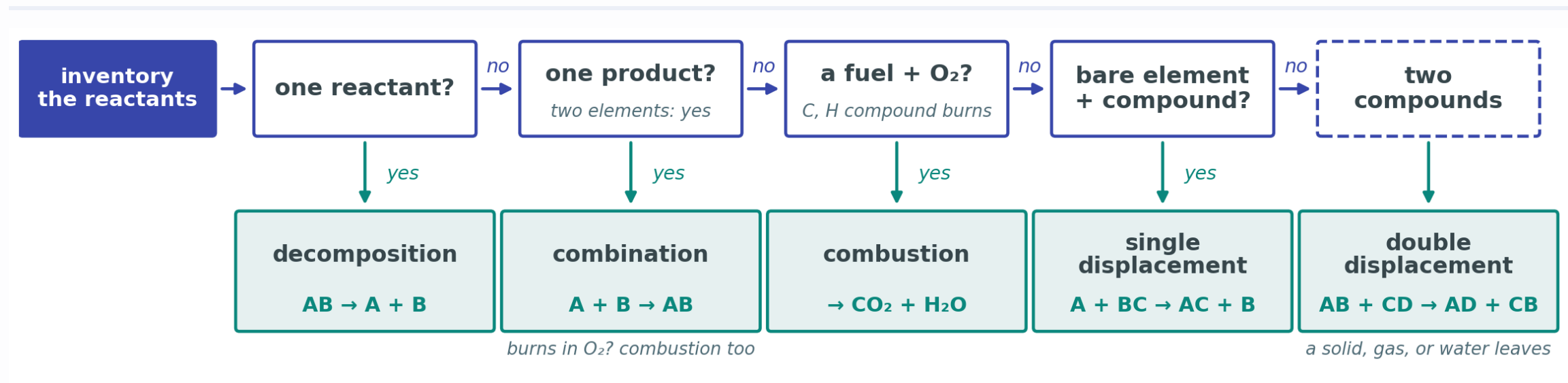
Five shapes suffice: atoms can only join, split apart, or trade partners. The shape carries the classification: how many substances on each side, element or compound. In combustion, fuels burn to CO_2 and H_2O , elements to oxides.



The method

1. **Inventory each side.** Count the substances; mark each as element or compound.
2. **Match the shape.** Pick the pattern the inventory fits.
3. **Name the type and complete the products.** If products are missing, the pattern supplies them.

Four questions sort every reaction



Ask the questions left to right and stop at the first yes. The exit names the type and gives the shape of the products. Every question reads the inventory: how many substances, element or compound.



Guided example: aluminum and bromine

Step 1 • Inventory each side



Al: one kind of symbol, an element • Br₂: one kind of symbol, an element • products not yet written

Aluminum metal reacts with liquid bromine. Classify the reaction, write the product, and balance.

✓ Guided example: solution



element + element · products not yet written

Step 2 · Match the shape

Step 3 · Name the type and complete the products



Al^{3+} with $\text{Br}^- \cdot (3+) + 3 \times (1-) = 0 \checkmark$ · Br_2 's subscript never enters the product

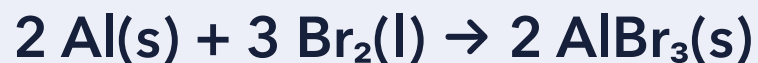
The balance check



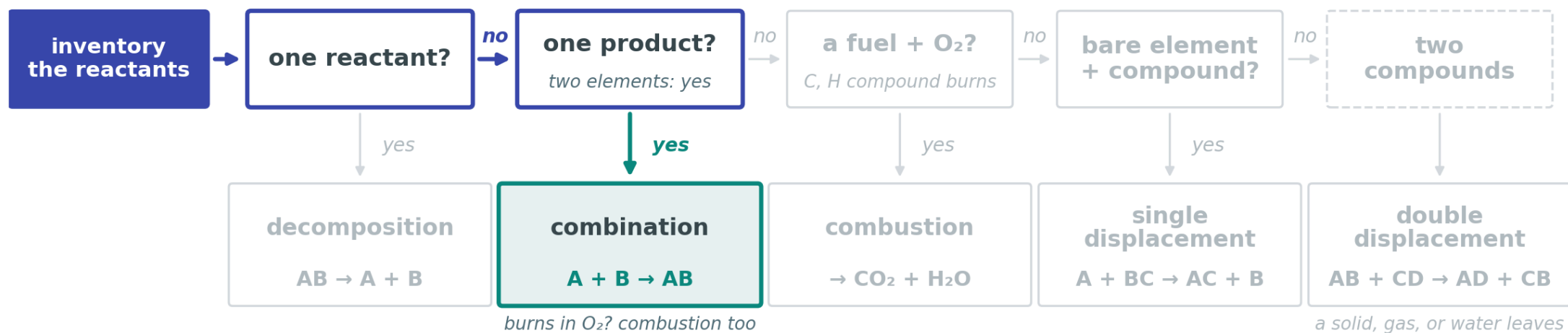
Al: $2 = 2 \checkmark$ · Br: $6 = 6 \checkmark$

 **Sense check:** Two elements in, one compound out. The charges chose AlBr_3 ; balancing chose only the amounts.

✓ Guided example: the route on the map



given: element + element · found: combination, AlBr_3



Sense check: Two questions: two reactants passed the first, and two elements answered yes to the second. Combination fixed one product; the charges fixed its formula. ✓

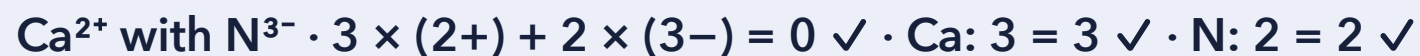
Practice 1: calcium and nitrogen



Calcium metal glows as it is heated in nitrogen gas. What is the formula of the product?

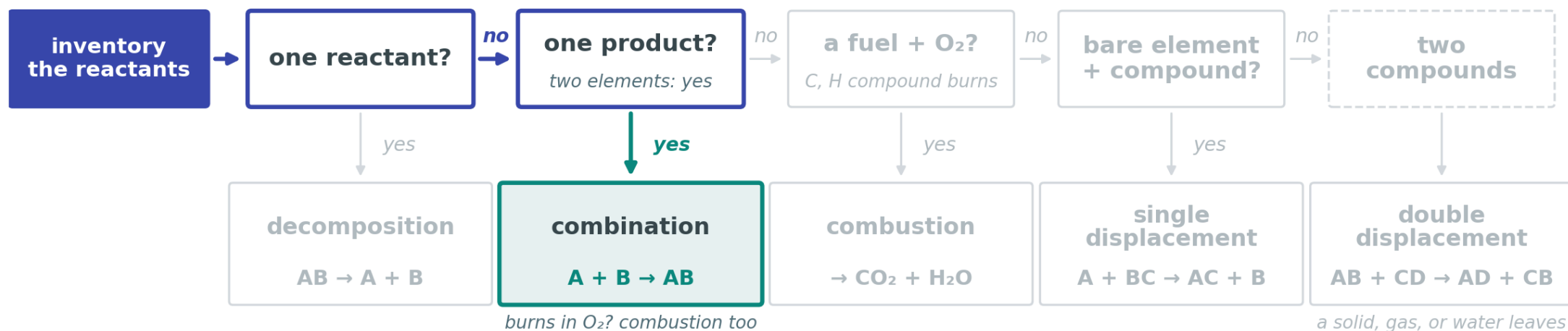
- A. Ca_3N_2
- B. CaN
- C. Ca_2N_3
- D. CaN_2

✓ Practice 1: answer A



 **Sense check:** Two elements formed one compound: combination. The 2 in N_2 counts atoms in the gas; the charges alone set Ca_3N_2 . ✓

The route on the map





Worked example 1: heating limestone

Step 1 • Inventory each side



one reactant, a compound $\rightarrow$ two products, both compounds • O: 3 = 1 + 2 ✓

Limestone breaks down in a hot kiln. Classify the reaction.

A common first attempt: CO_2 forms, so combustion. Test it.

✓ Worked example 1: solution



one reactant, a compound → two products, both compounds

A common first attempt



combustion: fuel or element + $\text{O}_2 \rightarrow$ oxides · no O_2 is consumed here ✕

Step 2 · Match the shape

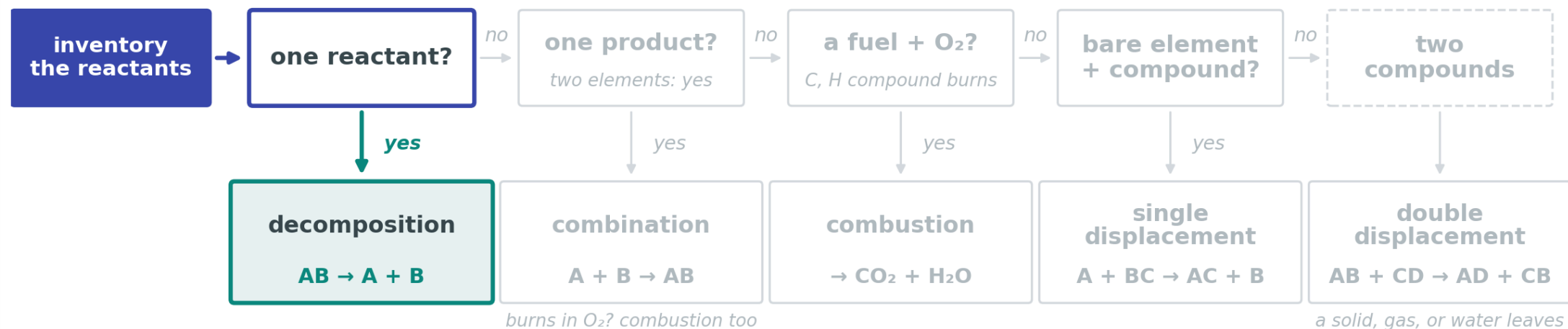
Step 3 · Name the type and complete the products



 **Sense check:** Heat split one compound into two simpler ones. CO_2 appeared without any burning: the products alone cannot name the type.

✓ Worked example 1: the route on the map

$\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$: decomposition
given: one reactant, a compound · found: decomposition



🧠 **Sense check:** The first question settles it: one reactant. The CO_2 never reaches the fuel question. ✓



Worked example 2: propane on a grill

Step 1 • Inventory each side



a carbon-hydrogen fuel + the element O_2 • products not yet written

Propane burns in a grill. Classify the reaction, write the products the pattern requires, and balance.

✓ Worked example 2: solution



a carbon-hydrogen fuel + the element O_2

Step 2 • Match the shape

Step 3 • Name the type and complete the products



every C leaves in CO_2 • every H leaves in H_2O

The balance check



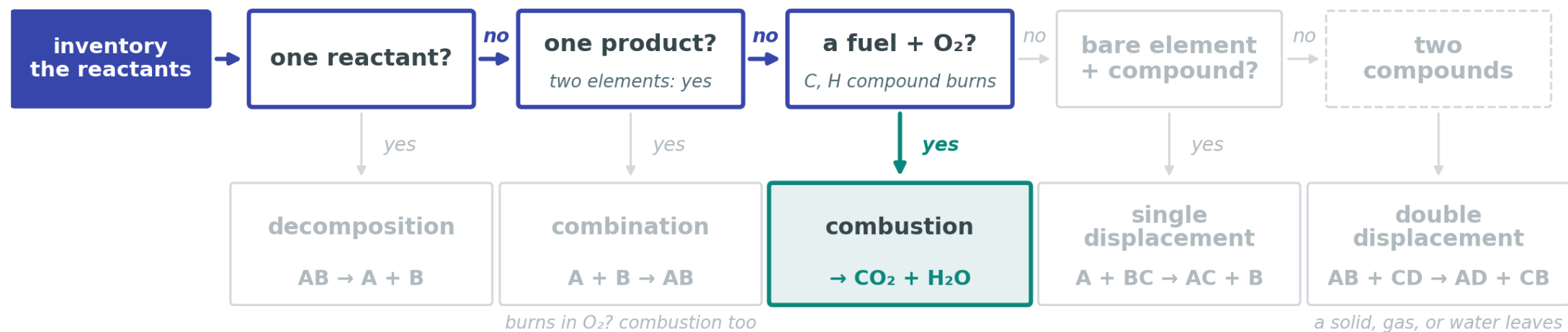
C: $3 = 3$ ✓ • H: $8 = 8$ ✓ • O: $10 = 6 + 4$ ✓

 **Sense check:** Every carbon-hydrogen fuel burns to the same two products. The pattern chose CO_2 and H_2O ; balancing only chose the amounts.

✓ Worked example 2: the route on the map



given: a fuel + O₂ · found: combustion, CO₂ and H₂O



Sense check: Two reactants, and two products, not one: the first two exits pass. A C, H fuel with O₂ exits at combustion, and that exit fixes CO₂ and H₂O. ✓

Your turn: magnesium in acid



bubbles rise as the metal dissolves · H: 2 = 2 ✓ · Cl: 2 = 2 ✓

step	question	answer
1 · Inventory each side	element or compound?	bare element + compound → compound + bare _____
2 · Match the shape	which pattern fits?	A + BC → _____ + B
3 · Name the type		_____ displacement

Complete the three steps.



Mg displaces hydrogen from HCl · the escaping H₂ gas is the visible evidence

Where this goes wrong

Reading any two-and-two equation as a partner swap. $\text{Zn} + \text{CuSO}_4 \rightarrow \text{ZnSO}_4 + \text{Cu}$ shows two reactants and two products, but Zn enters as a bare element. Double displacement needs two compounds; a bare element displacing another is single displacement.

Calling every CO_2 producer combustion. $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$ releases CO_2 with no O_2 consumed. Combustion consumes O_2 as a reactant; one compound splitting apart is decomposition.

Reading the arrow backwards. Combination builds one product from several reactants; decomposition splits one reactant into several products. $2 \text{HgO} \rightarrow 2 \text{Hg} + \text{O}_2$ starts from a single compound: decomposition.

Calling every bright, hot reaction combustion. $2 \text{Na} + \text{Cl}_2 \rightarrow 2 \text{NaCl}$ gives off heat and light, yet no O_2 is consumed. Two elements forming one compound: combination.



Practice 2



A welding torch burns acetylene, C_2H_2 , in pure oxygen. Which type best classifies this reaction?

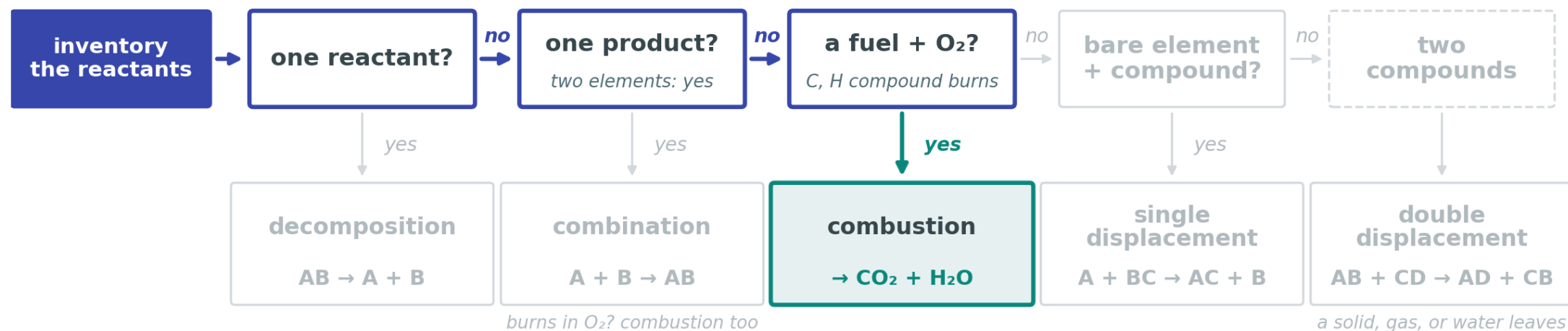
- A. Double displacement: two reactants form two products, so two pairs traded partners
- B. Combination: the fuel and the oxygen combine into new compounds
- C. Combustion: a carbon-hydrogen fuel consumes O_2 and forms CO_2 and H_2O
- D. Decomposition: the heat breaks the C_2H_2 molecule apart

✓ Practice 2: answer C

$2 \text{C}_2\text{H}_2 + 5 \text{O}_2 \rightarrow 4 \text{CO}_2 + 2 \text{H}_2\text{O}$: combustion (answer C)
a carbon-hydrogen fuel consumes O_2 and forms CO_2 and H_2O : the full signature

 **Sense check:** Fuel and O_2 on the left, CO_2 and H_2O on the right. The same signature classifies every burning hydrocarbon.

The route on the map





Practice 3: molten sodium chloride



An electric current splits molten sodium chloride into its elements. Which balanced equation describes the reaction?

- A. $\text{NaCl(l)} \rightarrow \text{Na(l)} + \text{Cl(g)}$
- B. $2 \text{NaCl(l)} \rightarrow 2 \text{Na(l)} + \text{Cl}_2\text{(g)}$
- C. $\text{NaCl(l)} \rightarrow \text{Na(l)} + \text{Cl}_2\text{(g)}$
- D. $2 \text{NaCl(l)} \rightarrow \text{Na}_2\text{(l)} + \text{Cl}_2\text{(g)}$

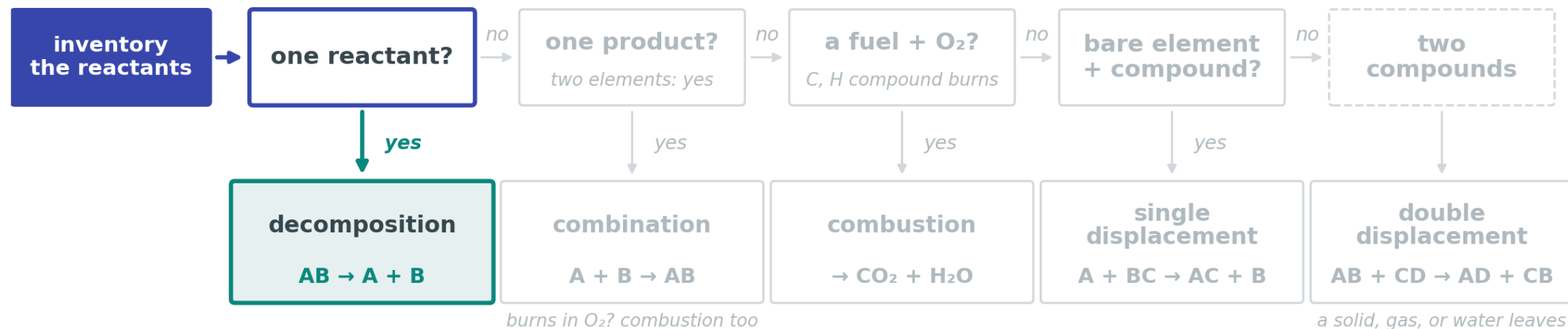
✓ Practice 3: answer B



one compound $\rightarrow$ its elements $\cdot \text{Na}: 2 = 2 \checkmark \cdot \text{Cl}: 2 = 2 \checkmark$

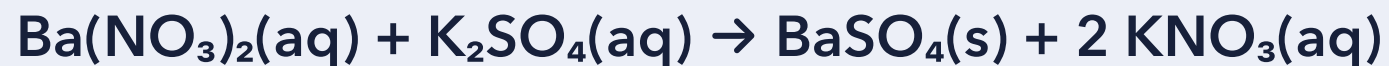
 **Sense check:** One reactant exits at decomposition, and the pattern says its elements come out. Chlorine leaves as Cl_2 , so two NaCl must split. $\checkmark$

The route on the map





Practice 4



two clear solutions mixed; a white solid settles out

Barium nitrate and potassium sulfate solutions are mixed, and a white solid appears.

Which type best classifies this reaction?

- A. Single displacement: barium displaces potassium from its compound
- B. Combination: the two reactants combine into the one solid product
- C. Decomposition: a compound broke down, which is why a solid fell out
- D. Double displacement: two compounds trade partners, and one new pair leaves as a solid

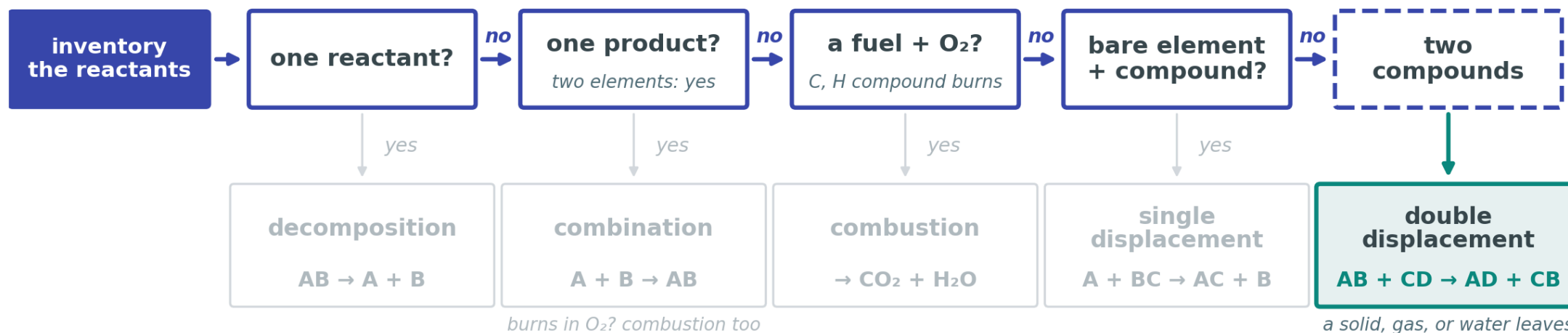
✓ Practice 4: answer D



$\text{AB} + \text{CD} \rightarrow \text{AD} + \text{CB}$ · the new pair BaSO_4 is the precipitate, the visible evidence

 **Sense check:** Two compounds in, two compounds out, one of them insoluble. The white solid is the evidence that the partners traded.

The route on the map





Practice 5: aluminum in copper(II) chloride



Aluminum foil sits in blue copper(II) chloride solution, and a reddish-brown solid forms. Which balanced equation describes the reaction?

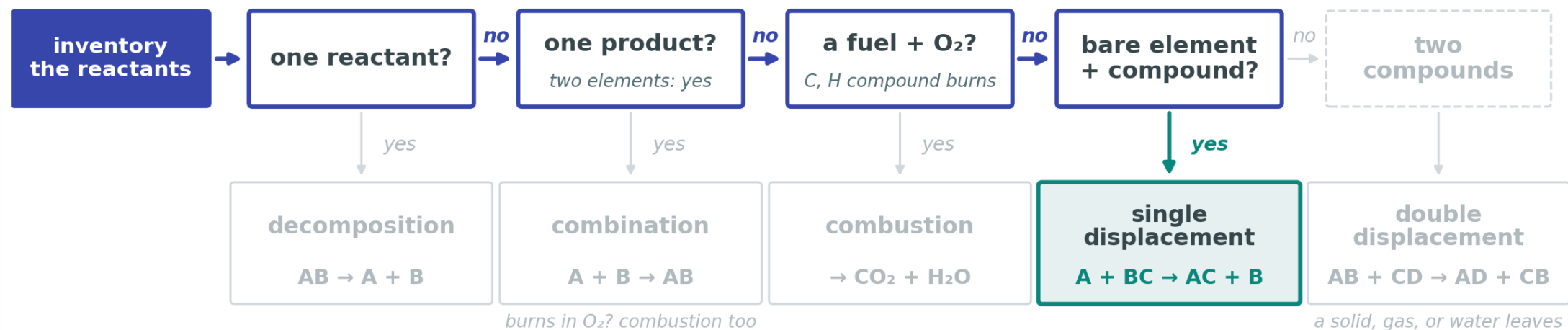
- A. $\text{Al(s)} + \text{CuCl}_2\text{(aq)} \rightarrow \text{AlCl}_2\text{(aq)} + \text{Cu(s)}$
- B. $\text{Al(s)} + \text{CuCl}_2\text{(aq)} \rightarrow \text{AlCuCl}_2\text{(s)}$
- C. $2 \text{Al(s)} + 3 \text{CuCl}_2\text{(aq)} \rightarrow 2 \text{AlCl}_3\text{(aq)} + 3 \text{Cu(s)}$
- D. $\text{Al(s)} + \text{CuCl}_2\text{(aq)} \rightarrow \text{AlCu(s)} + \text{Cl}_2\text{(g)}$

✓ Practice 5: answer C

$2 \text{Al(s)} + 3 \text{CuCl}_2\text{(aq)} \rightarrow 2 \text{AlCl}_3\text{(aq)} + 3 \text{Cu(s)}$: single displacement (answer C)
bare element + compound $\rightarrow$ compound + bare element · Al: $2 = 2$ ✓ · Cu: $3 = 3$ ✓ · Cl: $6 = 6$ ✓

🧠 **Sense check:** The reddish-brown solid is copper metal, pushed out of its compound. The charges fixed AlCl_3 ; the coefficients 2 and 3 balance six chlorides. ✓

The route on the map



A double displacement finishes three ways: a solid, a gas, or water

precipitation: a solid forms · acid-base: water forms · gas formation: a gas bubbles out
partners trade only when one new pair leaves the solution

$\text{H}_2\text{CO}_3 \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ · $\text{H}_2\text{SO}_3 \rightarrow \text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$ · $\text{NH}_4\text{OH} \rightarrow \text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l})$
predicted product → write this instead · all three break apart the moment they form

Three exchange products never survive in water. When the partner swap predicts one, write its gas and water instead. The escaping bubbles are the evidence.



Worked example 4: an antacid in acid

Step 1 • Inventory each side



compound + compound • no bare element • products not yet written

A calcium carbonate antacid tablet meets stomach acid, and the mixture fizzes. Classify the reaction, write the products, and balance.

✓ Worked example 4: the exchange



compound + compound · the mixture fizzes: a gas leaves

Step 2 · Match the shape

Step 3 · Name the type and complete the products



Ca: 1 = 1 · C: 1 = 1 · O: 3 = 3 · H: 2 = 2 · Cl: 2 = 2 ✓

The exchange is ordinary. The product H_2CO_3 , carbonic acid, is not: it cannot survive in water.

 **Sense check:** On paper the swap looks routine. The fizz says otherwise: one of these products refuses to stay in the water.

✓ Worked example 4: the gas appears



the exchange product H_2CO_3 cannot survive in water

The unstable product breaks up



H: $2 = 2$ · C: $1 = 1$ · O: $3 = 1 + 2 = 3$ ✓ · the fizz is CO_2 leaving

Overall



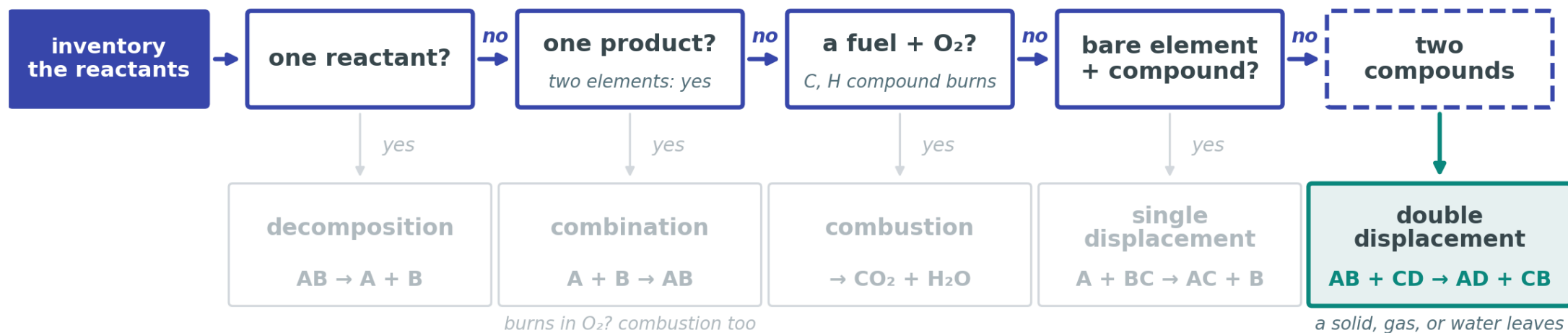
Ca: $1 = 1$ · C: $1 = 1$ · O: $3 = 1 + 2$ ✓ · H: $2 = 2$ · Cl: $2 = 2$ ✓

 **Sense check:** The tablet settles a stomach by turning acid into water and a burp of CO_2 . Any carbonate or bicarbonate meeting an acid ends the same way.

✓ Worked example 4: the route on the map



given: compound + compound · found: double displacement, finished as a gas



Sense check: Two compounds pass every question to double displacement. The note under that exit names the finish: H_2CO_3 leaves as CO_2 and water. ✓



Practice 6



two clear solutions are mixed · the beaker stays clear

Lithium sulfite solution is poured into hydrochloric acid. Which equation describes what happens?

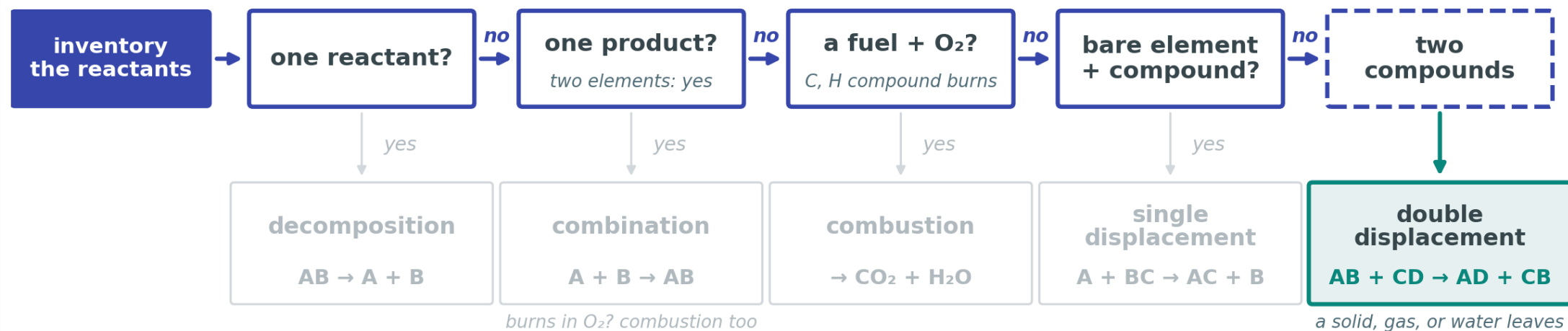
- A. $\text{Li}_2\text{SO}_3(\text{aq}) + 2 \text{HCl}(\text{aq}) \rightarrow 2 \text{LiCl}(\text{aq}) + \text{H}_2\text{SO}_3(\text{aq})$
- B. $\text{Li}_2\text{SO}_3(\text{aq}) + 2 \text{HCl}(\text{aq}) \rightarrow 2 \text{LiCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{SO}_2(\text{g})$
- C. No reaction: the beaker stays clear, so nothing changed
- D. $\text{Li}_2\text{SO}_3(\text{aq}) + 2 \text{HCl}(\text{aq}) \rightarrow 2 \text{LiCl}(\text{s}) + \text{H}_2\text{SO}_3(\text{aq})$

✓ Practice 6: answer B



 **Sense check:** The sharp smell of a struck match rising from the beaker is the SO_2 leaving. A clear beaker can still be a busy one.

The route on the map



Two names for one reaction

by shape: combination · decomposition · single displacement · double displacement
how many substances, element or compound, and how they recombine · the fifth pattern, combustion, is named by its result

by result: precipitation · acid-base · gas formation · combustion
a solid forms · water forms · a gas bubbles out · a substance burns in O₂

AgNO₃ + KCl → AgCl(s) + KNO₃: double displacement, precipitation
HCl + NaOH → NaCl + H₂O(l): double displacement, acid-base · 2 Mg + O₂ → 2 MgO: combination, combustion

Circle every name that fits, usually one from each list. Combustion is any fast burning in O₂. The CO₂ and H₂O signature marks a fuel; a metal burns to its oxide, a combination by shape.

Practice 10: both lenses



baking soda solution meets vinegar · foam pours over the rim

A model volcano erupts on a science-fair table. Complete the reaction, then name it from each list. Which pair of names is correct?

- A. Single displacement, and gas formation
- B. Double displacement, and precipitation
- C. Decomposition, and gas formation
- D. Double displacement, and gas formation

✓ Practice 10: answer D



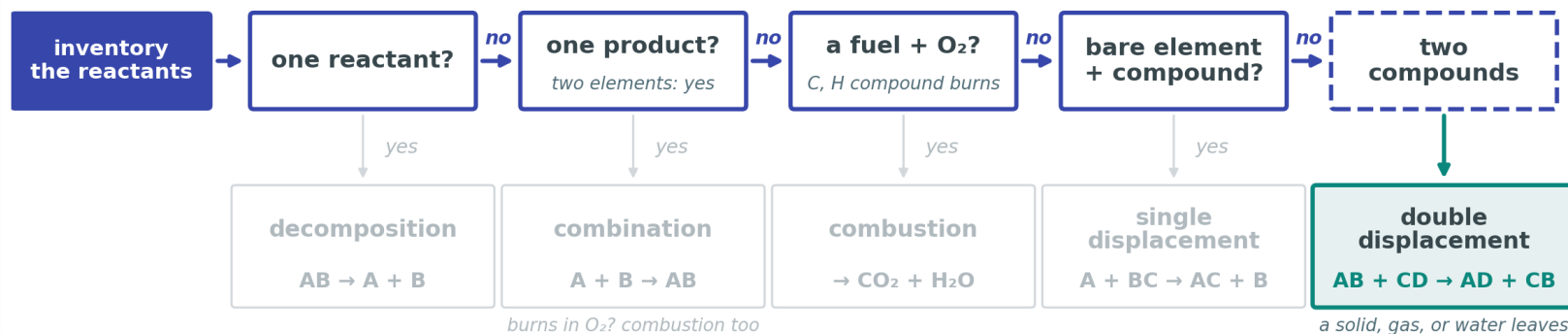
two compounds trade partners · H_2CO_3 never survives in water



Na: $1 = 1$ · C: $1 + 2 = 2 + 1$ ✓ · H: $1 + 4 = 3 + 2$ ✓ · O: $3 + 2 = 2 + 1 + 2$ ✓

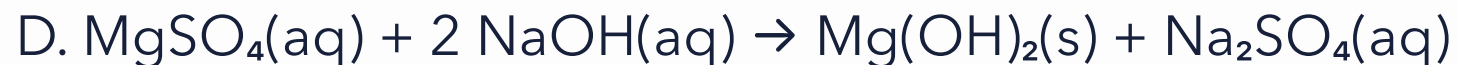
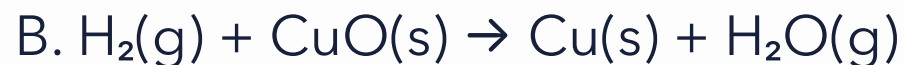
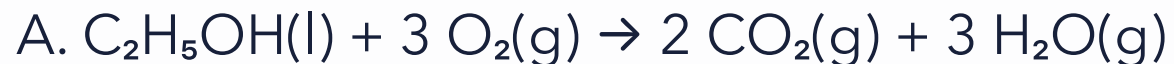
🧠 **Sense check:** The volcano runs on the antacid's chemistry: H_2CO_3 forms, cannot stay, and leaves as foam. Double displacement names the swap; gas formation names the finish.

The route on the map



Practice 11: which one is a combination

Which of these equations represents a combination reaction?



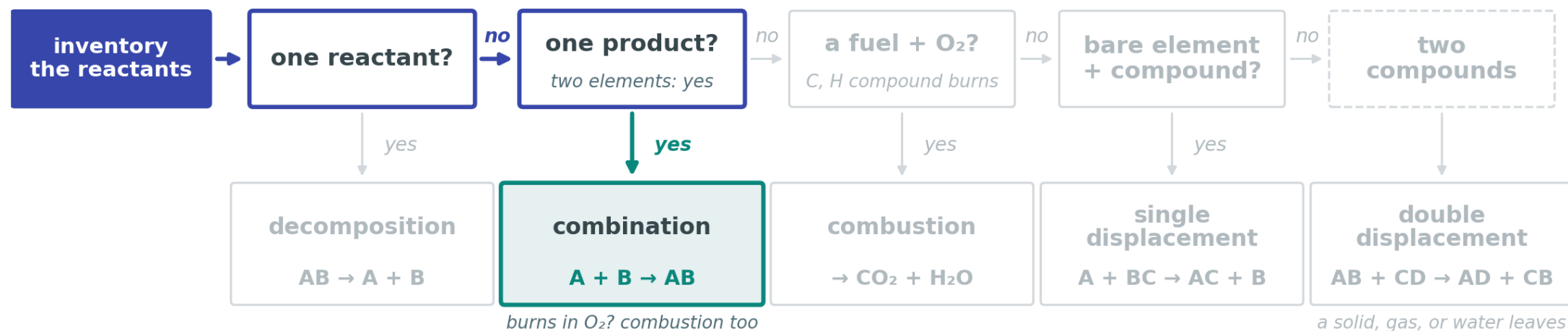
✓ Practice 11: answer E



two compounds $\rightarrow$ one compound $\cdot$ S: $1 = 1$ ✓ $\cdot$ O: $3 + 1 = 4$ ✓ $\cdot$ H: $2 = 2$ ✓

 **Sense check:** Combination means one product, not two elements. Two compounds that join into one, as SO_3 and water do in acid rain, make a combination too. ✓

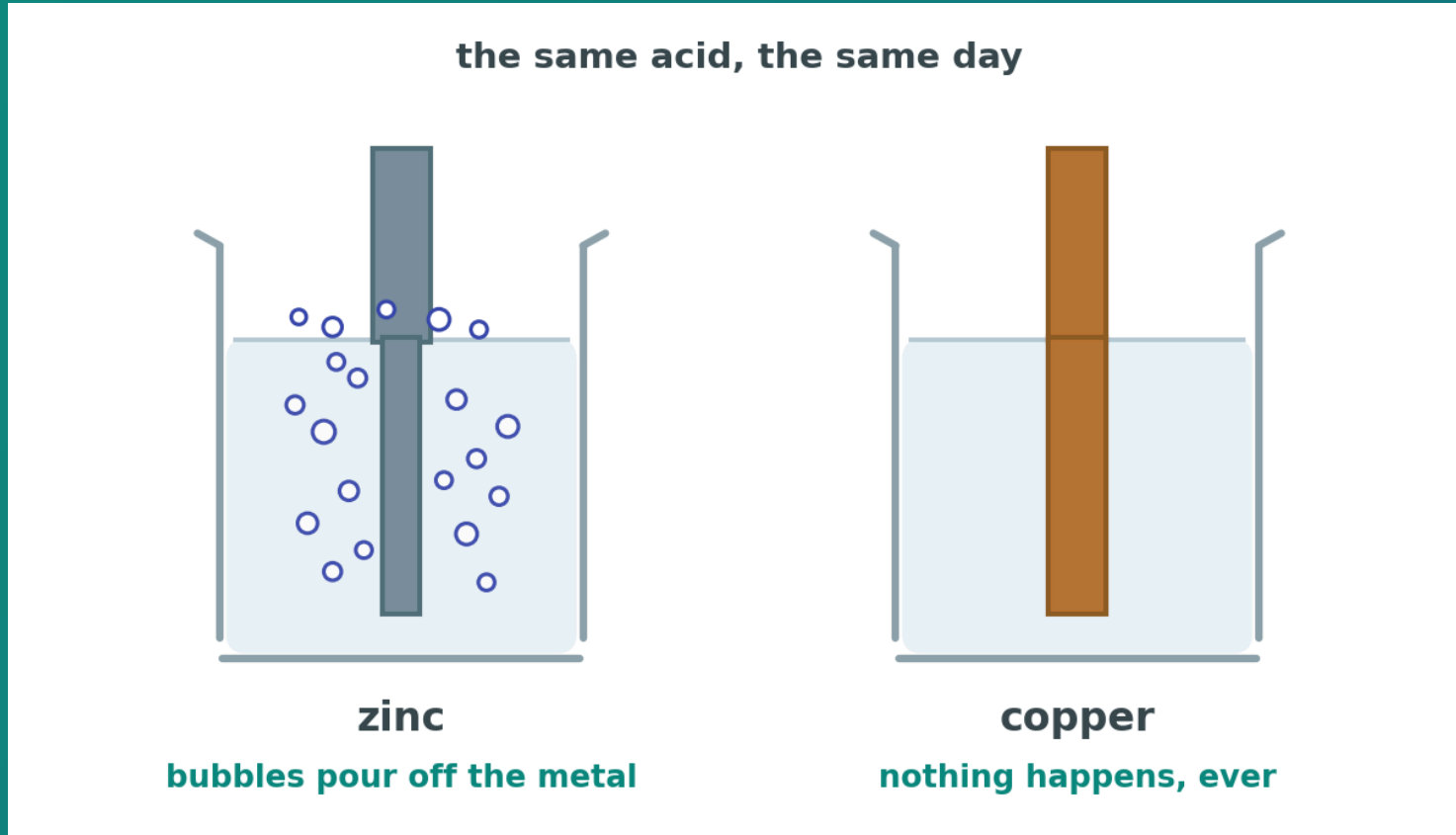
The route on the map



3 • The Activity Series

Use the activity series to predict whether a single-displacement reaction runs, write the products when it does, and write no reaction when it does not.

Two metals, one acid



Zinc fizzes furiously in hydrochloric acid; copper sits in the same acid untouched, forever. Something ranks these metals.

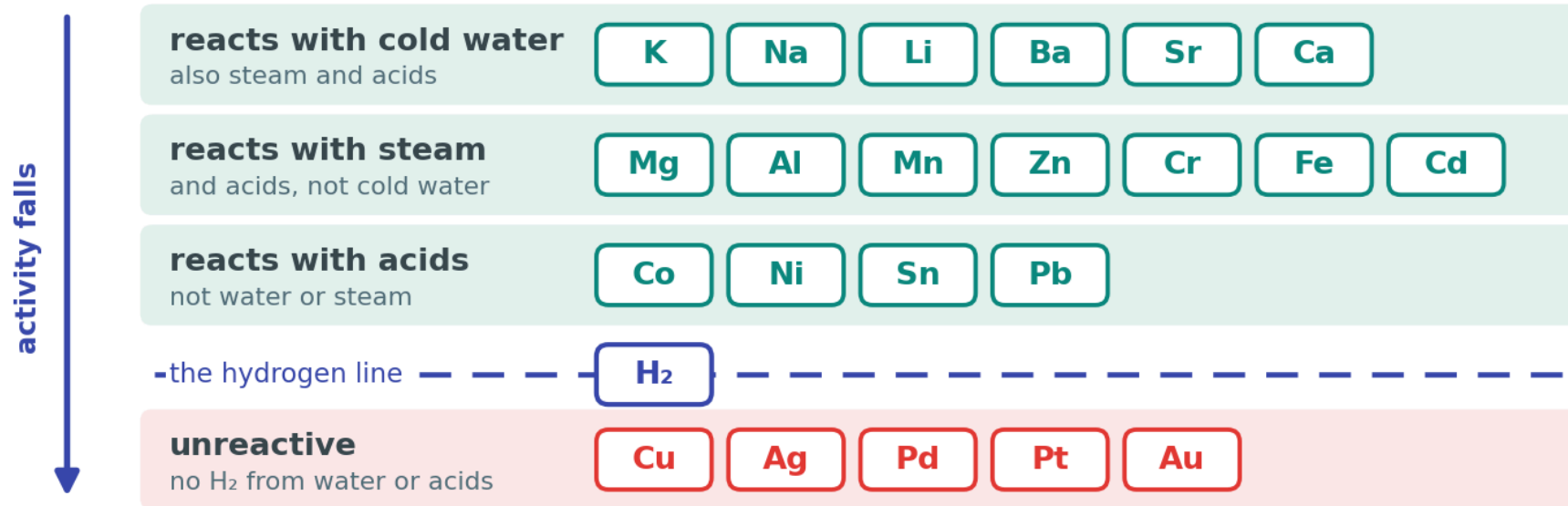
Single displacement: one element takes another's place



element + compound $\rightarrow$ new compound + new element

A free metal takes the place of another element in a compound only when it is the more active of the two. The activity series ranks the metals by activity.

The activity series



a solid metal displaces a partner below it in the series

the reverse never runs · in the steam, acid and unreactive rows, activity falls from left to right

the cold-water tier is one group: all six react with cold water

Four tiers, ranked by reactivity: a more active metal displaces any metal below it from its compounds, never one above.

Two guaranteed product patterns



any metal above hydrogen displaces hydrogen from the acid



the cold-water tier takes its hydrogen from water itself

The series is a measured ranking of reactivity: the more active metal displaces the less active one from its compound.

What the solid metal is compared with

metal + compound of another metal
compare with the metal in the compound

metal + acid
compare with hydrogen: only metals above the H₂ line react

metal + cold water
only the cold-water tier reacts · steam: the top two tiers

In every case the solid metal must be the more active one. If it is not, write no reaction.



The method

1. **Find both metals in the series.** Acid: compare with H_2 . Water: top tier only.
2. **Compare positions.** The solid metal must sit above its partner; otherwise write no reaction.
3. **Write the products from the pattern.**
4. **Balance the equation.**



Guided example: copper wire in silver nitrate

Step 1 · Find both metals in the series



Cu: the unreactive tier, first chip · Ag: the same row, right after Cu · wanted: products, balanced

A copper wire hangs in silver nitrate solution. Silver crystals grow on the wire, and the solution turns blue. Predict the products and balance the equation.

✓ Guided example: solution



Cu: the unreactive tier, first chip · Ag: right after Cu

Step 2 · Compare positions

Step 3 · Write the products from the pattern



charge in the salt: $(2+) + 2(1-) = 0 \checkmark$

Step 4 · Balance the equation



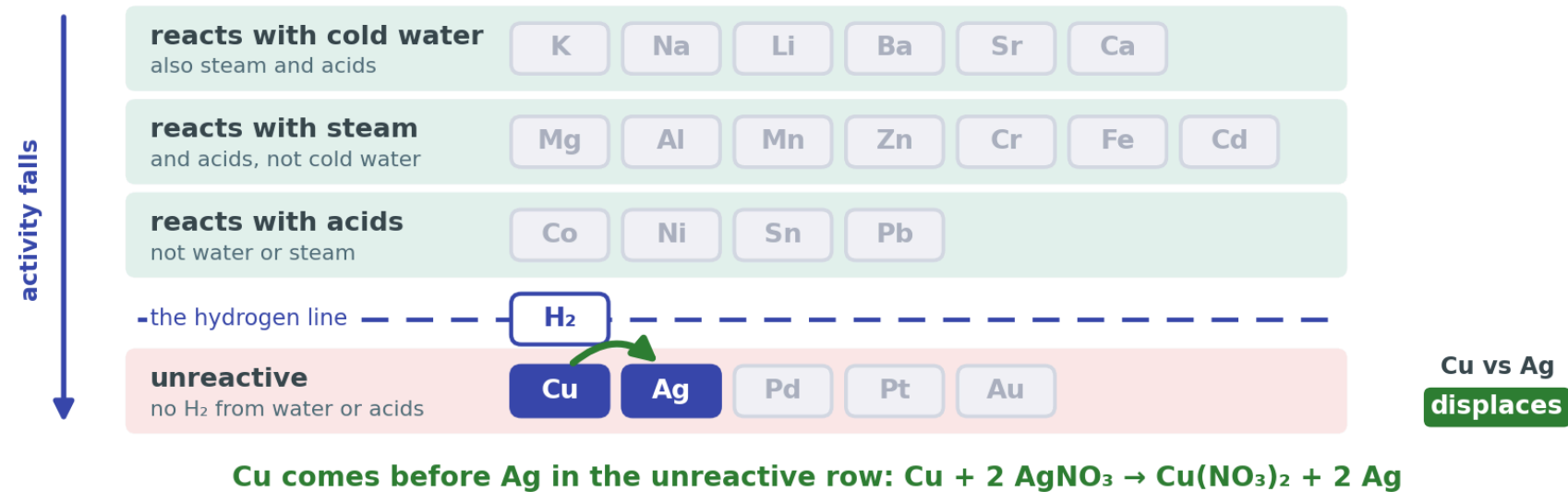
Cu: $1 = 1 \checkmark$ · Ag: $2 = 2 \checkmark$ · N: $2 = 2 \checkmark$ · O: $2(3) = 6 = 6 \checkmark$

 **Sense check:** The silver crystals are the Ag the pattern promised. The blue color is copper entering the solution as Cu^{2+} .

✓ Guided example: the route on the series



solid metal: Cu · partner: Ag, in the compound · found: the reaction runs



🧠 **Sense check:** Both metals sit in the unreactive tier. Cu comes first, so it is the more active one. ✓

Practice 1: displacing iron



wanted: a metal that displaces iron from its compound

Which of these metals can displace iron from iron(II) chloride solution?

- A. Sn
- B. Cu
- C. Mg
- D. Cd

✓ Practice 1: answer C



Mg: first in the steam row · Fe: sixth in the same row · Mg: 1 = 1 ✓ · Fe: 1 = 1 ✓ · Cl: 2 = 2 ✓

🧠 **Sense check:** Only a metal above iron can take its place. Mg heads iron's own row. ✓

activity falls ↓

reacts with cold water also steam and acids	K	Na	Li	Ba	Sr	Ca	
reacts with steam and acids, not cold water	Mg	Al	Mn	Zn	Cr	Fe	Cd
reacts with acids not water or steam	Co	Ni	Sn	Pb			
-the hydrogen line-	H ₂						
unreactive no H ₂ from water or acids	Cu	Ag	Pd	Pt	Au		

Mg vs Fe displaces

Mg comes before Fe in the steam row: $\text{Mg} + \text{FeCl}_2 \rightarrow \text{MgCl}_2 + \text{Fe}$



Worked example 1: magnesium in hydrochloric acid

Step 1 · Find both metals in the series



Mg: the steam tier · H: supplied by the acid · wanted: products, balanced

A magnesium strip dropped into hydrochloric acid dissolves in a rush of bubbles. Predict the products and balance the equation.

✓ Worked example 1: solution



Mg: the steam tier · H: supplied by the acid

Step 2 · Compare positions

Step 3 · Write the products from the pattern



charge in the salt: $(2+) + 2(1-) = 0$ ✓

Step 4 · Balance the equation



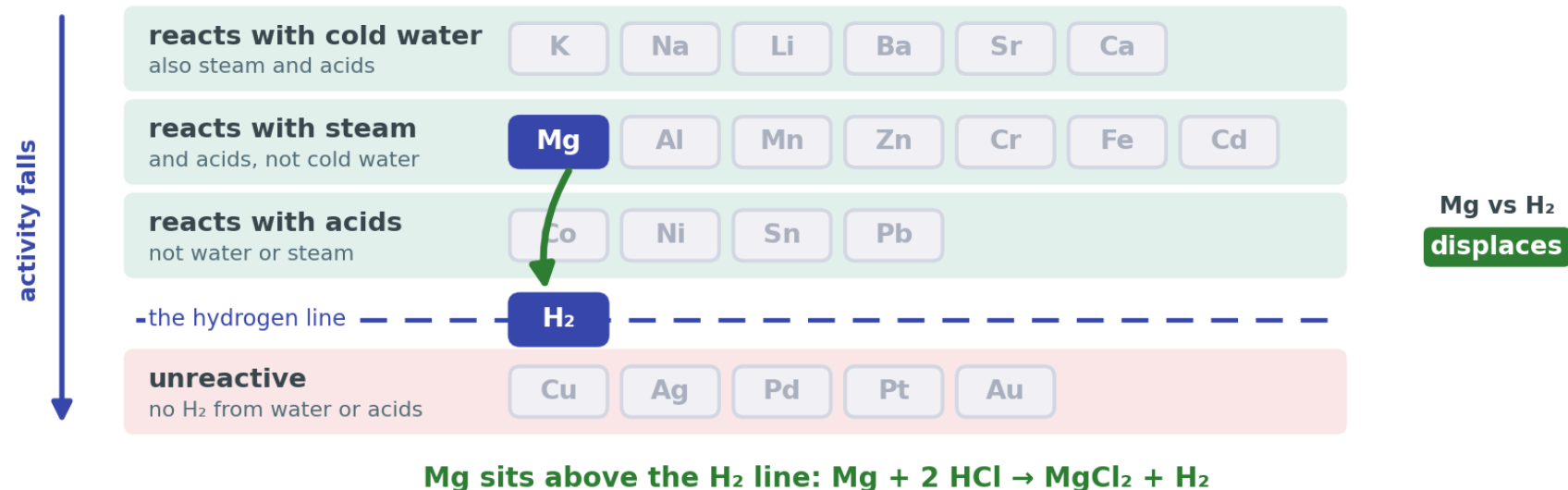
Mg: $1 = 1$ ✓ · H: $2 = 2$ ✓ · Cl: $2 = 2$ ✓

 **Sense check:** The bubbles are the H_2 the pattern promised. Magnesium took hydrogen's place in the compound, and the displaced hydrogen left as the gas.

✓ Worked example 1: the route on the series



solid metal: Mg · partner: hydrogen, from the acid · found: the reaction runs



🧠 **Sense check:** An acid's partner is always hydrogen. Mg sits above the H₂ line, so it displaces hydrogen. ✓



Worked example 2: aluminum in nickel(II) nitrate

Step 1 • Find both metals in the series



Al: the steam tier • Ni: the acid tier, lower • wanted: products, balanced

Aluminum foil sits in green nickel(II) nitrate solution and slowly darkens with nickel. Predict the products and balance the equation.

✓ Worked example 2: solution



Al: the steam tier · Ni: the acid tier, lower

Step 2 · Compare positions

Step 3 · Write the products from the pattern



charge in the salt: $(3+) + 3(1-) = 0$ ✓

Step 4 · Balance the equation



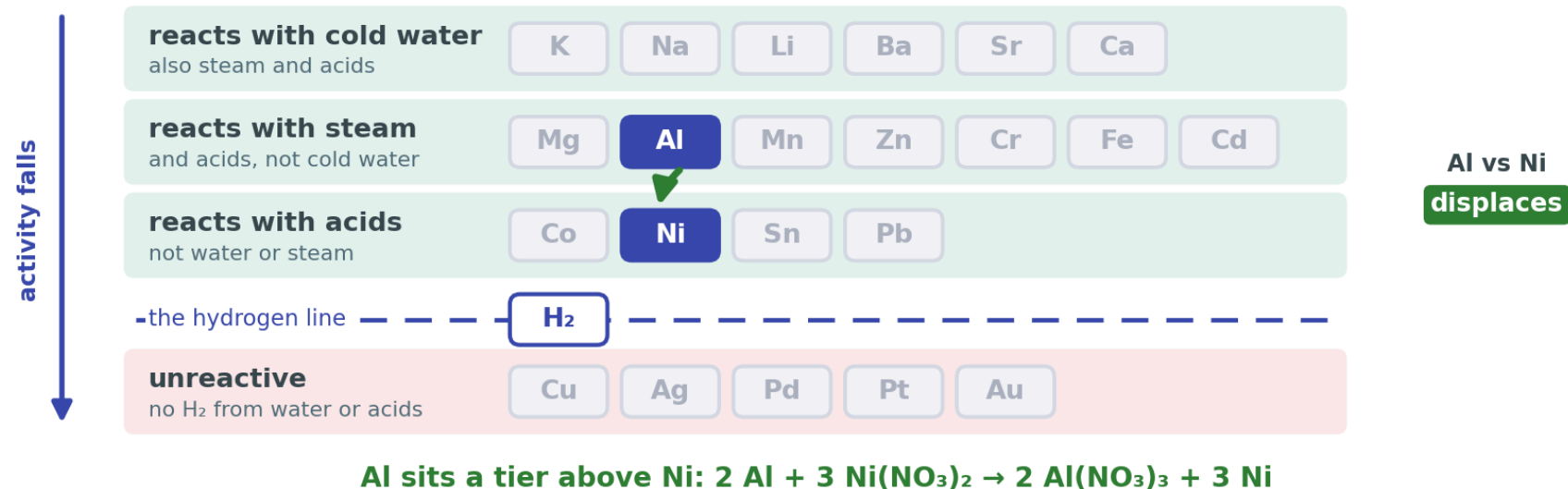
Al: $2 = 2$ ✓ · Ni: $3 = 3$ ✓ · N: $3(2) = 6 = 2(3)$ ✓ · O: $3(6) = 18 = 2(9)$ ✓

 **Sense check:** Aluminum, the more active metal, took nickel's place in the salt; the nitrate ions only change partners.

✓ Worked example 2: the route on the series



solid metal: Al · partner: Ni, in the compound · found: the reaction runs



🧠 **Sense check:** Al sits in the steam tier, a full tier above Ni. The higher metal does the displacing. ✓

Your turn: calcium in cold water



the pattern: active metal + water $\rightarrow$ metal hydroxide + H_2

step	work
1 · find both metals	Ca: the cold-water tier · H: from the water itself
2 · compare positions	Ca sits in the _____ tier, the one tier that reacts with cold water
3 · products from the pattern	Ca(OH)_2 + _____
4 · balance	$\text{Ca} + \text{_____ H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{H}_2$

Complete the table.



Ca: 1 = 1 ✓ · O: 2 = 2 ✓ · H: 2(2) = 4 = 2 + 2 ✓

⚠ Where this goes wrong

Running the series upward. Zinc displaces Cu^{2+} , so it is tempting to write the reverse: $\text{Cu} + \text{ZnSO}_4 \rightarrow \text{CuSO}_4 + \text{Zn}$. Copper sits below zinc, so it cannot displace the more active zinc from its compound. The reverse of a working displacement never runs.

Never writing "no reaction." $\text{Ag} + \text{ZnCl}_2$ swaps neatly on paper into $\text{AgCl} + \text{Zn}$, and it never happens: silver sits in the unreactive tier, below zinc. When the solid metal lies below the dissolved cation, no reaction is the complete answer.



Practice 2



Zn: the steam tier · Pb: the acid tier, lower

A zinc strip hangs in lead(II) nitrate solution, and gray crystals grow on it. Which equation describes the change?

- A. $\text{Zn} + \text{Pb(NO}_3)_2 \rightarrow \text{Zn(NO}_3)_2 + \text{Pb}$: zinc, above lead, displaces lead from its compound
- B. No reaction: lead sits above zinc, so zinc cannot displace it
- C. $\text{Zn} + \text{Pb(NO}_3)_2 \rightarrow \text{ZnNO}_3 + \text{Pb}$: the displacement runs, with zinc as a 1+ ion
- D. Both directions run: $\text{Pb} + \text{Zn(NO}_3)_2 \rightarrow \text{Pb(NO}_3)_2 + \text{Zn}$ works just as well

✓ Practice 2: answer A



Zn: 1 = 1 ✓ · Pb: 1 = 1 ✓ · N: 2 = 2 ✓ · O: 6 = 6 ✓ · Zn above Pb: the reaction runs

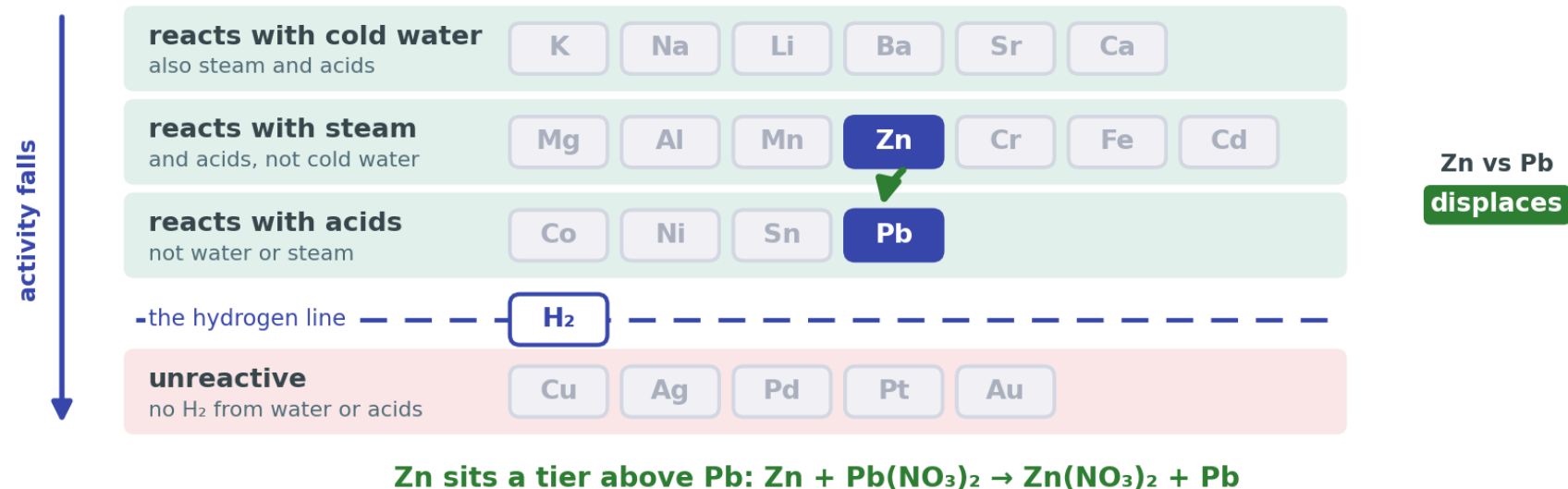
B reverses the ranking: zinc stands in the steam tier and lead in the acid tier below it. C has the displacement right and the salt wrong: zinc forms a 2+ ion and nitrate is 1−, so the salt is $\text{Zn}(\text{NO}_3)_2$, $(2+) + 2(1-) = 0$. D runs the series upward: lead, the lower metal, never displaces Zn^{2+} .

 **Sense check:** Zinc, the more active metal, takes lead's place in the compound. The gray crystals are lead metal leaving the solution.

✓ Practice 2: the route on the series



solid metal: Zn · partner: Pb, in the compound · found: the reaction runs



🧠 **Sense check:** Zn sits in the steam tier, a full tier above Pb, so zinc takes lead's place. ✓



Worked example 3: copper in lithium nitrate

Step 1 · Find both metals in the series



Cu: the unreactive tier · Li: the cold-water tier, at the very top

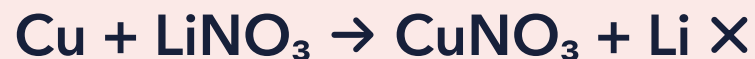
A copper wire stands in lithium nitrate solution. A common first attempt swaps the partners into $\text{CuNO}_3 + \text{Li}$. Test it against the series.

✓ Worked example 3: solution



Cu: the unreactive tier · Li: the cold-water tier, at the very top

A common first attempt



this asks copper to displace lithium, three tiers up

Step 2 · Compare positions



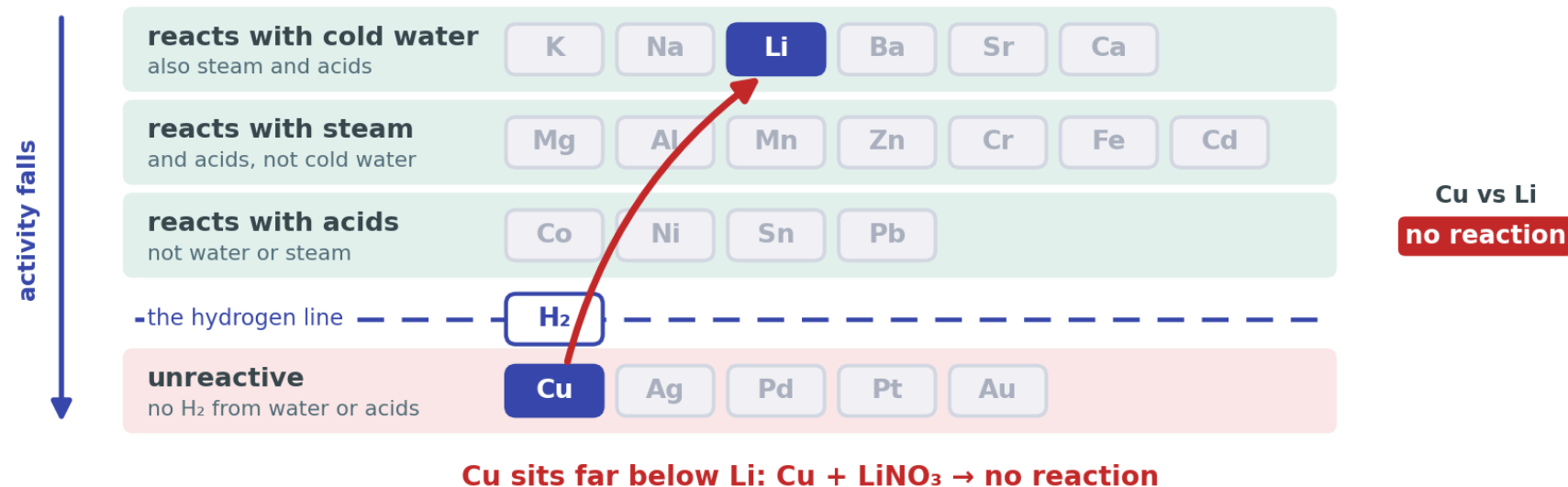
solid metal below the dissolved cation: no displacement

 **Sense check:** The wire can stand there for years. A swap that looks fine on paper still needs the solid metal to be the more active one.

✓ Worked example 3: the route on the series



solid metal: Cu · partner: Li, in the compound · found: no reaction



Sense check: The arrow points up the series. Copper would have to displace a more active metal, so nothing happens. ✓

Practice 3: zinc in cold water



a zinc strip in water at room temperature

A zinc strip is dropped into cold water. Which prediction is correct?

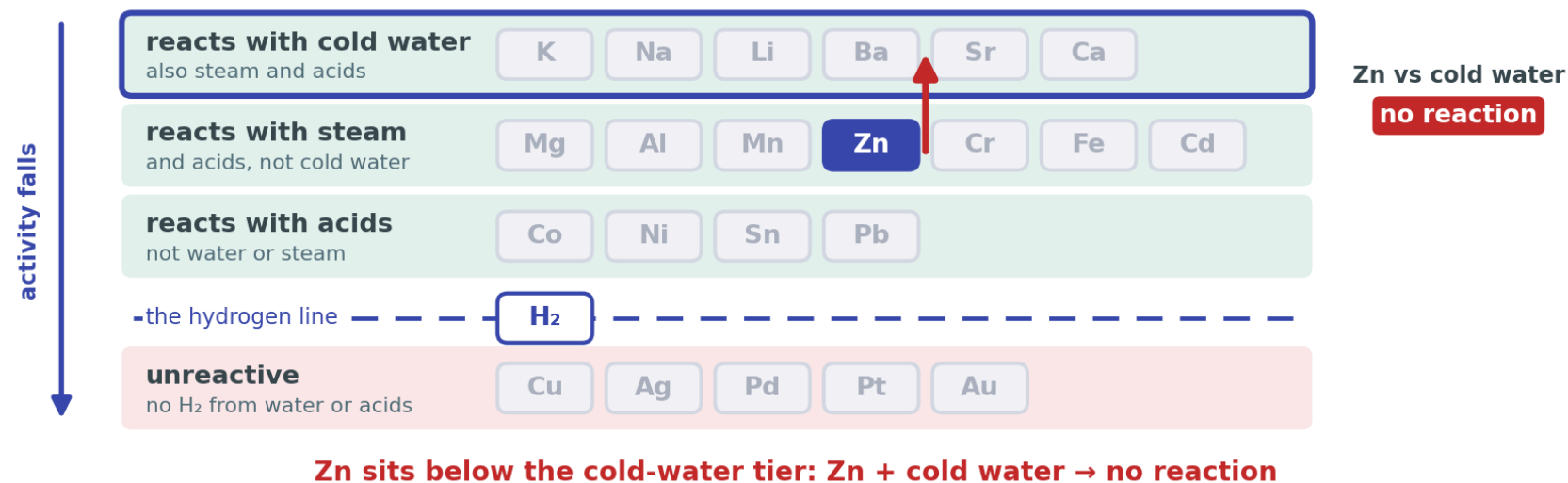
- A. It runs: zinc sits above hydrogen, so it displaces hydrogen from water
- B. No reaction: zinc sits below hydrogen in the series
- C. No reaction: water holds no metal ion for zinc to displace
- D. No reaction: zinc sits in the steam tier, below the cold-water tier

✓ Practice 3: answer D



Zn: the steam tier · partner: cold water, which reacts only with the cold-water tier

🧠 **Sense check:** Zinc reacts with steam and with acids. In cold water it stays bright. ✓





Practice 4



observed: an iron nail in nickel(II) sulfate solution darkens with nickel

A classmate reasons that swapping the roles must work as well, and writes $\text{Ni} + \text{FeSO}_4 \rightarrow \text{NiSO}_4 + \text{Fe}$. Which verdict on that claim is correct?

- A. It stands: every atom count matches, so the reverse runs.
- B. It fails: Ni sits below Fe, so it cannot displace Fe^{2+} . $\text{Ni} + \text{FeSO}_4$ gives no reaction.
- C. It stands: Ni and Fe both sit above hydrogen, so each can displace the other.
- D. It stands, slowly: the reverse runs, just more slowly, since Ni is the less active metal.

✓ Practice 4: answer B



Fe: the steam tier · Ni: the acid tier, lower · the solid metal sits below the dissolved cation

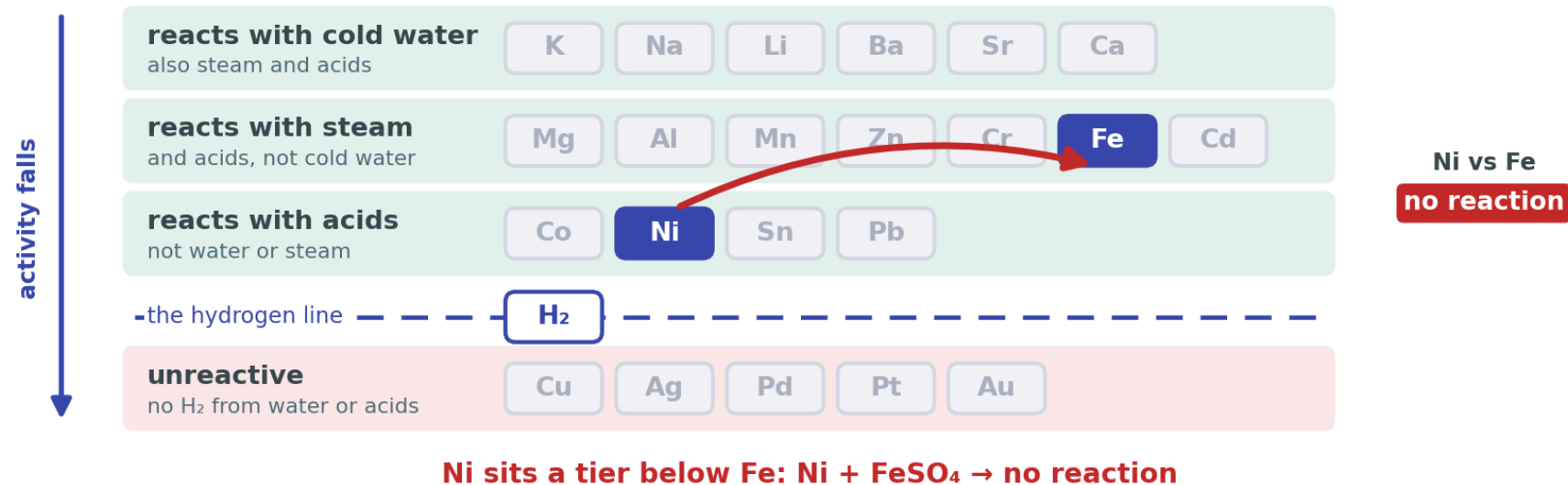
A treats balance as permission: Ni 1 = 1, Fe 1 = 1, S 1 = 1, O 4 = 4, yet a balanced equation can describe a reaction that never happens. C compared each metal with hydrogen; the partner here is Fe^{2+} , which sits above Ni. D: speed never moves a metal up the series; the ranking decides whether displacement happens at all.

 **Sense check:** The forward reaction is the evidence: Fe, the more active metal, displaced nickel from its compound. The same ranking forbids Ni from displacing iron back.

✓ Practice 4: the route on the series



solid metal: Ni · partner: Fe, in the compound · found: no reaction



🧠 **Sense check:** The arrow points up the series: nickel would have to displace the more active iron. ✓



Practice 5: which mixture gives no reaction

four beakers, one metal strip in each
wanted: the mixture that gives no reaction

One metal strip goes into each of four beakers. Which mixture gives no reaction?

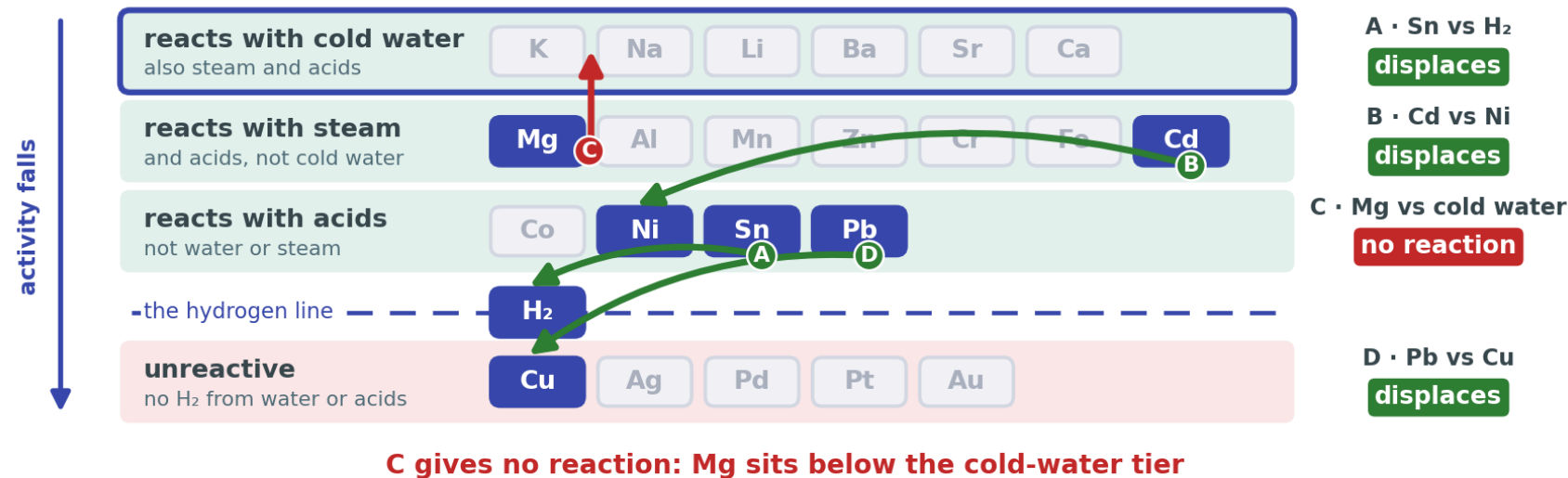
- A. $\text{Sn(s)} + \text{HCl(aq)}$
- B. $\text{Cd(s)} + \text{Ni(NO}_3)_2\text{(aq)}$
- C. $\text{Mg(s)} + \text{H}_2\text{O(l)}$, cold water
- D. $\text{Pb(s)} + \text{Cu(NO}_3)_2\text{(aq)}$
- E. All four react

✓ Practice 5: answer C

$\text{Mg(s)} + \text{H}_2\text{O(l)}, \text{ cold} \rightarrow \text{no reaction (answer C)}$

A: Sn above the H_2 line $\rightarrow$ runs · B: Cd, steam tier, above Ni $\rightarrow$ runs · C: Mg below the cold-water tier $\rightarrow$ none · D: Pb above Cu $\rightarrow$ runs

🧠 **Sense check:** Three partners, three cutoffs: the metal in the compound, the H_2 line, and the cold-water tier. ✓



Summary of reaction types

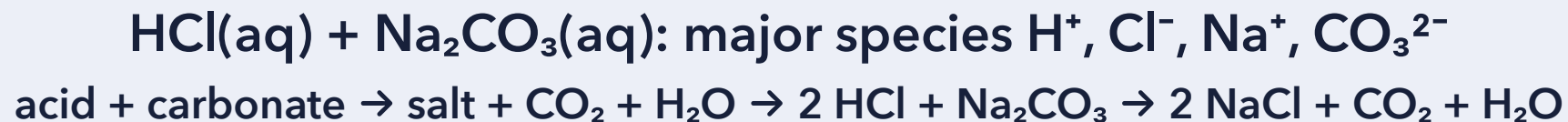
SUMMARY OF REACTION TYPES

you mix	decision tool	products
two dissolved salts	solubility rules	insoluble salt (s) + soluble salt
acid + hydroxide	runs as written	salt + water
acid + carbonate or bicarbonate	runs as written	salt + CO ₂ + H ₂ O
metal + acid or water	activity series	salt or hydroxide + H ₂
metal + metal cation (aq)	activity series	new salt + displaced metal
hydrocarbon + O ₂	runs as written	CO ₂ + H ₂ O

to predict: list the major species present, then find the matching row

Six reactant patterns cover nearly every product prediction. The solubility rules pick the precipitate; the activity series decides whether displacement runs.

Predicting products in aqueous solutions

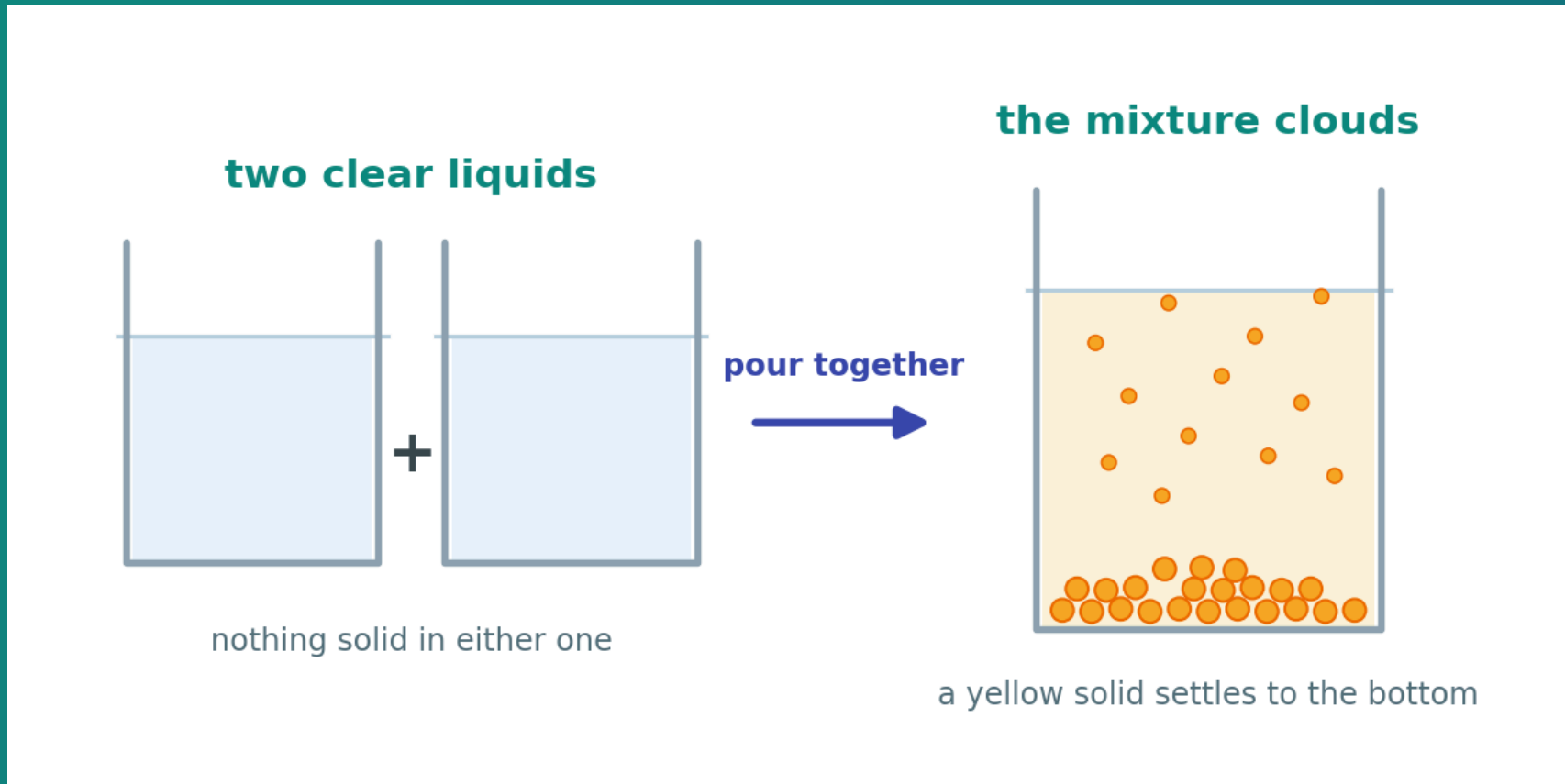


List the major species actually in the beaker. Match them to a reaction-type pattern; the first match names the products. No match on any pattern means no reaction.

4 · Solubility Rules & Precipitation

Predict whether mixing two solutions makes a precipitate: swap the partners, check each new compound against the solubility rules, and write the balanced equation with states.

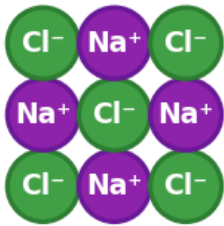
A solid from two clear liquids



Two beakers, two clear liquids. Poured together, they instantly cloud, and a bright yellow solid settles to the bottom. No solid went in.

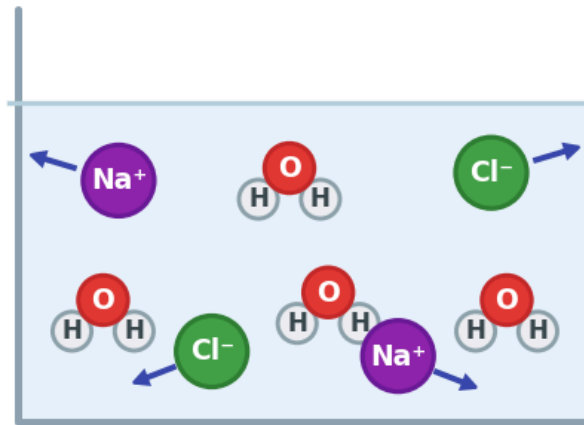
What dissolving looks like

dissolving an ionic solid



NaCl(s)

every ion held by its neighbors



NaCl(aq)

separated ions, each on its own path

the ions separate and travel independently

Dissolving an ionic solid means the ions separate and travel independently. The solid's Na^+ and Cl^- leave the stack one ion at a time and spread through the water.

Soluble or insoluble

NaCl(aq) is soluble: it dissolves, and its ions spread through the water

(aq) = aqueous, dissolved in water

AgCl(s) is insoluble: it stays a solid

(s) = solid; it does not dissolve

An ionic compound in water dissolves or it does not. Dissolving is a tug-of-war: water pulls the ions apart, and for a few pairings the ion-ion attraction wins, so the compound stays solid.

Reading a precipitation equation



soluble · soluble · soluble · insoluble · Ba: 1 = 1 · Cl: 2 = 2 · Na: 2 = 2 · SO₄: 1 = 1

Two dissolved compounds trade partners: a double displacement. Three of the four compounds carry (aq). BaSO₄ carries (s): it did not dissolve, so it forms as a solid. That solid is the **precipitate**.

Check the always-soluble ions first

group 1 cations (Li^+ , Na^+ , K^+ , ...) · NH_4^+ · NO_3^- · $\text{C}_2\text{H}_3\text{O}_2^-$ · HCO_3^- · ClO_3^-
compounds of these never precipitate · any new pairing holding one stays (aq)

These ions never precipitate. Check a new pairing against this short list first; it settles most cases. Only a pairing with none of the listed ions needs the chart's exception lines.

The solubility rules

SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

Li^+ Na^+ K^+ ...: always soluble

NO_3^- · $\text{C}_2\text{H}_3\text{O}_2^-$ · HCO_3^- · ClO_3^-

nitrate, acetate, bicarbonate, chlorate: always soluble

Cl^- · Br^- · I^-

halides: soluble

EXCEPT Ag^+ Pb^{2+} Hg_2^{2+}

SO_4^{2-}

sulfates: soluble

EXCEPT Ag^+ Ba^{2+} Ca^{2+} Hg_2^{2+} Pb^{2+} Sr^{2+}

INSOLUBLE: stays solid → (s)

CO_3^{2-} · CrO_4^{2-} · PO_4^{3-} · S^{2-}

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT group 1 NH_4^+

OH^-

hydroxides: insoluble

EXCEPT group 1 Ba^{2+}

- 1 cation group 1 or NH_4^+ ? yes → (aq), done
- 2 find the anion's line soluble or insoluble
- 3 cation on its EXCEPT list? yes → the verdict flips

NAGSAG: Nitrates · Acetates · Group 1 · Sulfates · Ammonium · Group 17 halides
the mostly-soluble families · EXCEPT lists: sulfates, halides and every insoluble row

One line decides each compound: read its ions, find their line, apply the exception list.

Three looks decide each compound



① Ca^{2+} : not group 1 or NH_4^+ · ② sulfate line: soluble · ③ Ca^{2+} on its EXCEPT list: flips to (s)

SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

Li^+ Na^+ K^+ ...: always soluble

NO_3^- · $\text{C}_2\text{H}_3\text{O}_2^-$ · HCO_3^- · ClO_3^-

nitrate, acetate, bicarbonate, chlorate: always soluble

Cl^- · Br^- · I^-

halides: soluble

EXCEPT Ag^+ Pb^{2+} Hg_2^{2+}

SO_4^{2-}

sulfates: soluble

EXCEPT Ag^+ Ba^{2+} Ca^{2+} Hg_2^{2+} Pb^{2+} Sr^{2+}

$\text{CaSO}_4 \rightarrow (\text{s})$

INSOLUBLE: stays solid → (s)

CO_3^{2-} · CrO_4^{2-} · PO_4^{3-} · S^{2-}

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT group 1 NH_4^+

OH^-

hydroxides: insoluble

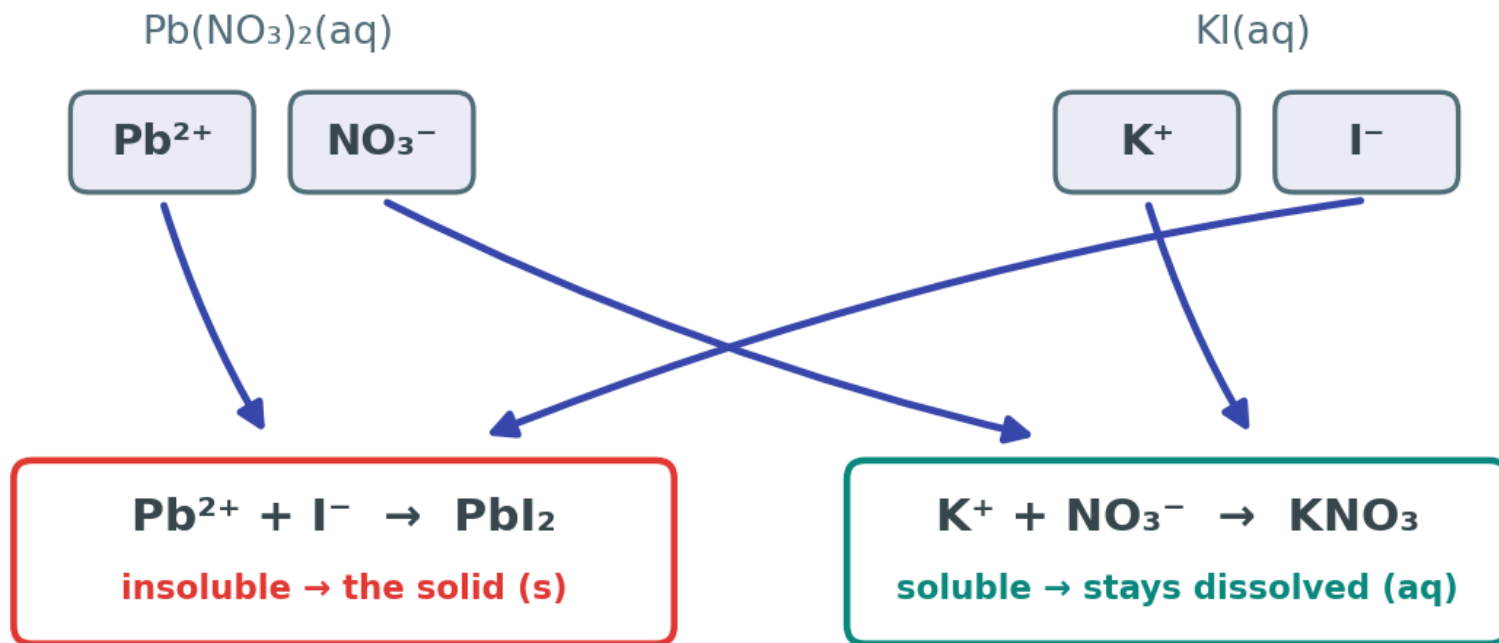
EXCEPT group 1 Ba^{2+}

- 1 cation group 1 or NH_4^+ ? yes → (aq), done
- 2 find the anion's line soluble or insoluble
- 3 cation on its EXCEPT list? yes → the verdict flips

Look at the cation first. Otherwise find the anion's line, then scan that line's EXCEPT list. A listed cation flips the verdict.

Mixing two solutions: the partners swap

double replacement: the partners swap



new pairings: each checked against the solubility rules

Dissolved compounds are separated ions. Mixing two solutions lets each cation meet the other anion. A new pairing the rules call insoluble forms a solid: a **precipitate**.

Warm-up: formulas from charge balance



wanted: the neutral formula each ion pair builds

ions	charge balance	formula
$\text{Ba}^{2+} + \text{OH}^{-}$	$1(2+) + 2(1-) = 0$	$\text{Ba}(\text{OH})\underline{\hspace{1cm}}$
$\text{Al}^{3+} + \text{SO}_4^{2-}$	$2(3+) + 3(2-) = 0$	$\underline{\hspace{1cm}}$

Complete both formulas.



$1(2+) + 2(1-) = 0 \checkmark \cdot 2(3+) + 3(2-) = 0 \checkmark \cdot$ charge balance sets the subscripts, exactly as when naming ionic compounds



The method

1. **Swap the partners.** New cation-anion pairs.
2. **Build each new formula.** Charge balance sets subscripts.
3. **Check each product against the rules.** Soluble $\rightarrow$ (aq); insoluble $\rightarrow$ (s).
4. **Write the balanced equation with states.** Both products (aq): no reaction.



Worked example 1: soluble or insoluble



wanted: the state of each in water, (aq) or (s)

White marble is CaCO_3 . Potash fertilizer, K_2CO_3 , is spread as a clear solution. Assign each compound its state in water.

✓ Worked example 1: solution



wanted: the state of each in water, (aq) or (s)

Read the ions



both compounds are carbonates: the carbonate line decides both

Apply the carbonate line

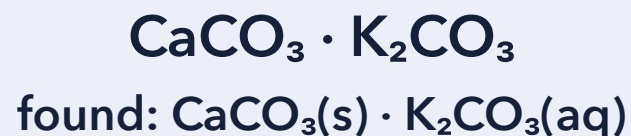
Carbonates are insoluble except with group 1 cations or NH_4^+ .



Ca^{2+} : not on the exception list $\rightarrow$ solid $\cdot$ K^+ : group 1 $\rightarrow$ the exception applies, dissolved

 **Sense check:** Same anion, opposite states. A rule reads the pair of ions; the exception list is part of the rule.

✓ Worked example 1: the route on the table



SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{K}_2\text{CO}_3 \rightarrow (\text{aq})$

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT **Ag^+** **Pb^{2+}** **Hg_2^{2+}**

SO_4^{2-}

sulfates: soluble

EXCEPT **Ag^+** **Ba^{2+}** **Ca^{2+}** **Hg_2^{2+}** **Pb^{2+}** **Sr^{2+}**

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

$\text{CaCO}_3 \rightarrow (\text{s})$

EXCEPT **group 1** **NH_4^+**

OH^-

hydroxides: insoluble

EXCEPT **group 1** **Ba^{2+}**

- 1** cation group 1 or NH_4^+ ? **yes → (aq), done**
- 2** find the anion's line **soluble or insoluble**
- 3** cation on its EXCEPT list? **yes → the verdict flips**

 **Sense check:** K_2CO_3 stops at the first look. CaCO_3 needs all three, and Ca^{2+} is not on the carbonate EXCEPT list.

Practice 1: one compound

four ionic compounds, each stirred into water
three dissolve · one stays a solid

Which compound is insoluble in water?

- A. $(\text{NH}_4)_2\text{S}$
- B. CaCl_2
- C. $\text{Pb}(\text{NO}_3)_2$
- D. CuS

✓ Practice 1: answer D

$\text{CuS} \rightarrow \text{CuS(s)}$ (answer D)

Cu^{2+} : not group 1, not NH_4^+ · sulfide line: insoluble · Cu^{2+} is not on its EXCEPT list

A skipped the EXCEPT list: NH_4^+ is on the sulfide line's list, so $(\text{NH}_4)_2\text{S}$ dissolves. B carried Ca^{2+} over from the sulfate list; the chloride line excepts only Ag^+ , Pb^{2+} and Hg_2^{2+} . C gave Pb^{2+} an exception the nitrates do not have: nitrates always dissolve.

 **Sense check:** Each wrong choice skips or misreads one look. Only CuS pairs an insoluble line with a cation missing from that line's EXCEPT list.

✓ Practice 1: the route on the table



found: CuS(s) , black copper(II) sulfide

SOLUBLE: dissolves $\rightarrow$ (aq)

group 1 cations $\cdot \text{NH}_4^+$

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT Ag^+ Pb^{2+} Hg_2^{2+}

SO_4^{2-}

sulfates: soluble

EXCEPT Ag^+ Ba^{2+} Ca^{2+} Hg_2^{2+} Pb^{2+} Sr^{2+}

INSOLUBLE: stays solid $\rightarrow$ (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT **group 1** **NH_4^+**

$\text{CuS} \rightarrow \text{(s)}$

OH^-

hydroxides: insoluble

EXCEPT **group 1** **Ba^{2+}**

- 1 **cation group 1 or NH_4^+ ?** **yes $\rightarrow$ (aq), done**
- 2 **find the anion's line** **soluble or insoluble**
- 3 **cation on its EXCEPT list?** **yes $\rightarrow$ the verdict flips**

 **Sense check:** Cu^{2+} fails the first look, the sulfide line says insoluble, and no EXCEPT chip matches Cu^{2+} .



Guided example: a red solid



wanted: the solid, and the balanced equation with states

Sodium chromate solution is yellow; silver nitrate solution is colorless. Poured together, they form a brick-red solid. Identify the solid and write the balanced equation with states.

Four moves, one per method step.

✓ Guided example: the swap



the mixed beaker holds four ions: Na^+ , CrO_4^{2-} , Ag^+ , NO_3^-

Step 1 · Swap the partners

Step 2 · Build each new formula

Ag^+ pairs with CrO_4^{2-} ; Na^+ pairs with NO_3^- . Chromate carries a 2– charge, so it takes two Ag^+ .

new pairs: Ag_2CrO_4 and NaNO_3



 **Sense check:** The 2 on silver comes from chromate's charge. Neither reactant formula carries it.

✓ Guided example: states and the equation



new pairs built · wanted: each product's state

Step 3 · Check each product against the rules



chromates: insoluble except group 1 and NH_4^+ ; Ag^+ is neither · Na^+ : group 1, always soluble

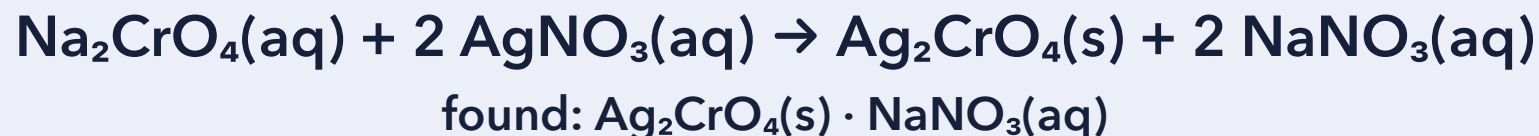
Step 4 · Write the balanced equation with states



Na: 2 = 2 · CrO_4 : 1 = 1 · Ag: 2 = 2 · NO_3 : 2 = 2 · balanced

 **Sense check:** The brick-red solid is Ag_2CrO_4 : the one new pairing on an insoluble line with no exception. Na^+ and NO_3^- stay dissolved.

✓ Guided example: the route on the table



SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{NaNO}_3 \rightarrow (\text{aq})$

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT **Ag^+** **Pb^{2+}** **Hg_2^{2+}**

SO_4^{2-}

sulfates: soluble

EXCEPT **Ag^+** **Ba^{2+}** **Ca^{2+}** **Hg_2^{2+}** **Pb^{2+}** **Sr^{2+}**

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

$\text{Ag}_2\text{CrO}_4 \rightarrow (\text{s})$

EXCEPT **group 1** **NH_4^+**

OH^-

hydroxides: insoluble

EXCEPT **group 1** **Ba^{2+}**

1 cation group 1 or NH_4^+ ? **yes → (aq), done**

2 find the anion's line **soluble or insoluble**

3 cation on its EXCEPT list? **yes → the verdict flips**

 **Sense check:** NaNO_3 stops at the first look. Ag_2CrO_4 takes all three: chromate line, insoluble, Ag^+ not excepted.



Worked example 2: $\text{AgNO}_3 + \text{NaCl}$



wanted: the precipitate

Silver nitrate solution meets salt solution in photographic processing. Both are clear and colorless; mixing them turns the beaker milky white. Predict the solid.

A common first attempt: check AgNO_3 and NaCl against the rules: both soluble, so no solid should form. Test it.

✓ Worked example 2: testing the first attempt



wanted: the precipitate

A common first attempt

AgNO_3 soluble ✓ · NaCl soluble ✓ → no solid?

nitrates: always soluble · group 1: always soluble, yet the mixture turns white ✗

Both reactants pass the rules. That is what (aq) already records: they arrived dissolved. The white solid must be a compound neither beaker held.

 **Sense check:** The mixed beaker holds four ions moving independently: Ag^+ , NO_3^- , Na^+ , Cl^- . Two of them meet here for the first time.

✓ Worked example 2: the swap



wanted: the precipitate

Step 1 · Swap the partners

Step 2 · Build each new formula

Ag^+ pairs with Cl^- ; Na^+ pairs with NO_3^- . Both new pairs balance one-to-one.

new pairs: AgCl and NaNO_3



 **Sense check:** Two dissolved compounds went in; two new pairings remain to be checked against the rules.

✓ Worked example 2: states and the equation



new pairs built · wanted: each product's state

Step 3 · Check each product against the rules



chlorides: soluble except Ag^+ , Pb^{2+} , Hg_2^{2+} ; Ag^+ is on the list · nitrates: always soluble

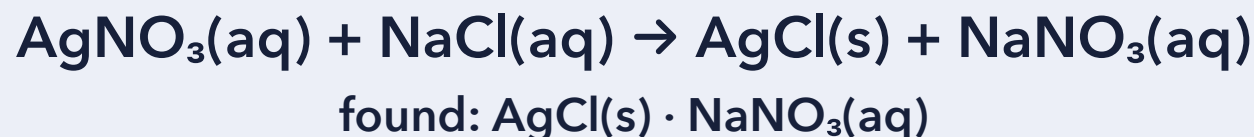
Step 4 · Write the balanced equation with states



Ag: 1 = 1 · NO₃: 1 = 1 · Na: 1 = 1 · Cl: 1 = 1 · balanced as written

 **Sense check:** The milky white is AgCl, the one new pairing the rules call insoluble. Na^+ and NO_3^- never left the water.

✓ Worked example 2: the route on the table



SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{NaNO}_3 \rightarrow (\text{aq})$

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT Ag^+ Pb^{2+} Hg_2^{2+}

$\text{AgCl} \rightarrow (\text{s})$

SO_4^{2-}

sulfates: soluble

EXCEPT Ag^+ Ba^{2+} Ca^{2+} Hg_2^{2+} Pb^{2+} Sr^{2+}

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT group 1 NH_4^+

OH^-

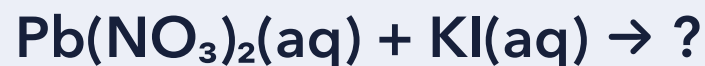
hydroxides: insoluble

EXCEPT group 1 Ba^{2+}

- 1 **cation group 1 or NH_4^+ ?** **yes → (aq), done**
- 2 **find the anion's line** **soluble or insoluble**
- 3 **cation on its EXCEPT list?** **yes → the verdict flips**

 **Sense check:** NaNO_3 stops at the first look. For AgCl , the third look flips the chloride line: Ag^+ is excepted.

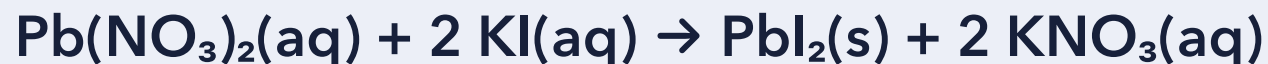
Your turn: $\text{Pb}(\text{NO}_3)_2 + \text{KI}$



two clear solutions · mixing makes a bright yellow solid

step	question	answer
1 · swap the partners	which new pairs form?	Pb^{2+} with I^- · K^+ with NO_3^-
2 · build each new formula	$1(2+) + 2(1-) = 0$	$\text{PbI}_{\underline{\hspace{1cm}}}$ and KNO_3
3 · check each product	which lines of the rules?	$\text{PbI}_2 \rightarrow (\underline{\hspace{1cm}})$ · $\text{KNO}_3 \rightarrow (\underline{\hspace{1cm}})$
4 · write the balanced equation	coefficients	$\underline{\hspace{1cm}}$

Complete the prediction.



PbI_2 : $1(2+) + 2(1-) = 0 \checkmark$ · iodides: soluble except Ag^+ , Pb^{2+} , Hg_2^{2+} · nitrates: always soluble · PbI_2 settles brilliant yellow

⚠ Where this goes wrong

Checking the rules on the starting solutions. AgNO_3 and NaCl both pass: they were already dissolved. The rules judge the products of the swap: Ag^+ with Cl^- gives AgCl , and the chloride line puts Ag^+ on its exception list.

Calling the soluble product the precipitate. $\text{BaCl}_2 + \text{Na}_2\text{SO}_4$ gives two new pairs. NaCl passes the rules, so its ions stay dissolved. The solid is the pairing that does not: BaSO_4 .

Expecting a starting compound to fall out. A compound that arrived dissolved stays dissolved. The precipitate is always a new pairing: ions that arrived in different beakers.

Dragging old subscripts into new formulas. $\text{Pb}(\text{NO}_3)_2 + \text{KI}$: copying KI 's one-to-one ratio gives PbI , and $1(+2) + 1(-1) = +1$, not neutral. Charge balance builds the new formula: PbI_2 , $1(+2) + 2(-1) = 0$.



Practice 2



two clear solutions are mixed

Silver nitrate solution is poured into sodium sulfide solution. Which precipitate forms, if any?

- A. Ag_2S
- B. NaNO_3
- C. AgS
- D. No precipitate: both new pairings stay dissolved

✓ Practice 2: answer A

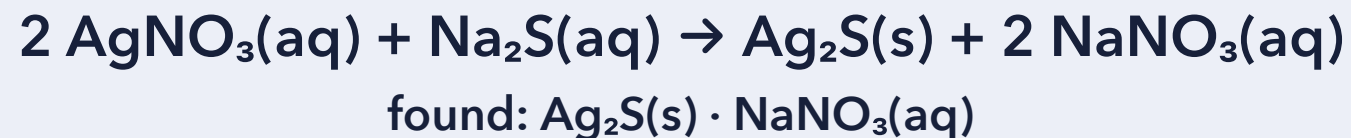


sulfides: insoluble except group 1 and NH_4^+ · Ag_2S : $2(1+) + 1(2-) = 0$ ✓ · Ag: $2 = 2$ · S: $1 = 1$ · Na: $2 = 2$ · NO_3 : $2 = 2$

B is the soluble product: sodium is group 1 and nitrate is always soluble, so NaNO_3 's ions stay dissolved. C has the right pairing and the wrong formula: AgS gives $1(1+) + 1(2-) = -1$, so charge balance needs two Ag^+ per S^{2-} . D skipped the sulfide line: Ag^+ is not group 1 or NH_4^+ , so Ag_2S falls out.

 **Sense check:** Of the four ions mixed, only $\text{Ag}^+ + \text{S}^{2-}$ lands on an insoluble line. One insoluble pairing, one solid: black Ag_2S , the same compound that tarnishes silverware.

✓ Practice 2: the route on the table



SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{NaNO}_3 \rightarrow (\text{aq})$

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT **Ag^+** **Pb^{2+}** **Hg_2^{2+}**

SO_4^{2-}

sulfates: soluble

EXCEPT **Ag^+** **Ba^{2+}** **Ca^{2+}** **Hg_2^{2+}** **Pb^{2+}** **Sr^{2+}**

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT **group 1** **NH_4^+**

$\text{Ag}_2\text{S} \rightarrow (\text{s})$

OH^-

hydroxides: insoluble

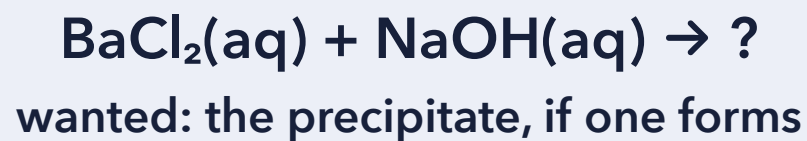
EXCEPT **group 1** **Ba^{2+}**

- 1** cation group 1 or NH_4^+ ? **yes → (aq), done**
- 2** find the anion's line **soluble or insoluble**
- 3** cation on its EXCEPT list? **yes → the verdict flips**

 **Sense check:** Sulfide shares the chromate line, so Ag_2S follows the brick-red solid's path to (s).



Worked example 3: $\text{BaCl}_2 + \text{NaOH}$



Solutions of barium chloride and sodium hydroxide are mixed. Work all four steps.

✓ Worked example 3: the swap

$\text{BaCl}_2(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow ?$
 wanted: the precipitate, if one forms

Step 1 · Swap the partners

Step 2 · Build each new formula

Ba^{2+} pairs with OH^- ; Na^+ pairs with Cl^- . Ba^{2+} needs two OH^- to reach zero charge.

new pairs: $\text{Ba}(\text{OH})_2$ and NaCl

$\text{Ba}(\text{OH})_2$: $1(+2) + 2(-1) = 0 \checkmark$ · NaCl : $1(+1) + 1(-1) = 0 \checkmark$

 **Sense check:** The new formulas come from charge balance, never from the reactants' subscripts.

✓ Worked example 3: solution



new pairs built · wanted: each product's state

Step 3 · Check each product against the rules



hydroxides: insoluble except group 1 and Ba^{2+} · group 1: always soluble

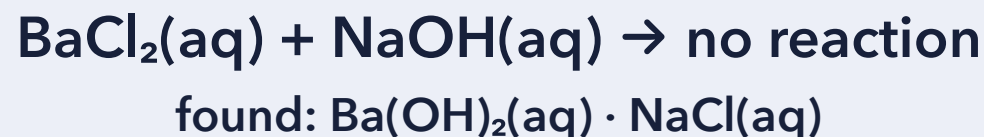
Step 4 · Write the balanced equation with states



both new pairings stay dissolved: nothing leaves the solution

 **Sense check:** The mixed beaker stays clear: it holds four kinds of dissolved ions. A precipitate needs one insoluble pairing, and here there is none.

✓ Worked example 3: the route on the table



SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{NaCl} \rightarrow (\text{aq})$

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT

Ag^+

Pb^{2+}

Hg_2^{2+}

SO_4^{2-}

sulfates: soluble

EXCEPT

Ag^+

Ba^{2+}

Ca^{2+}

Hg_2^{2+}

Pb^{2+}

Sr^{2+}

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT

group 1

NH_4^+

OH^-

hydroxides: insoluble

EXCEPT

group 1

Ba^{2+}

$\text{Ba}(\text{OH})_2 \rightarrow (\text{aq})$

1 cation group 1 or NH_4^+ ? yes → (aq), done

2 find the anion's line soluble or insoluble

3 cation on its EXCEPT list? yes → the verdict flips

 **Sense check:** The third look flips the hydroxide line for $\text{Ba}(\text{OH})_2$. Two teal verdicts: nothing leaves the solution.



Practice 3: the equation with states



two solutions are mixed

Which equation is balanced and carries the correct states?

- A. $\text{Cu}(\text{NO}_3)_2(\text{aq}) + 2 \text{KOH}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{aq}) + 2 \text{KNO}_3(\text{s})$
- B. $\text{Cu}(\text{NO}_3)_2(\text{aq}) + 2 \text{KOH}(\text{aq}) \rightarrow \text{Cu}(\text{OH})_2(\text{s}) + 2 \text{KNO}_3(\text{aq})$
- C. $\text{Cu}(\text{NO}_3)_2(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow \text{CuOH}(\text{s}) + \text{KNO}_3(\text{aq})$
- D. No reaction: both new pairings stay dissolved

✓ Practice 3: answer B

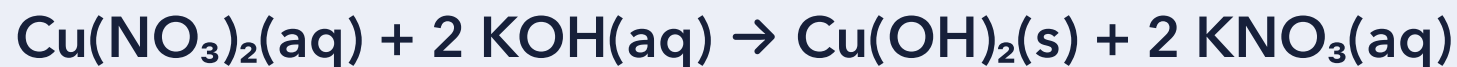


$\text{Cu}(\text{OH})_2$: $1(+2) + 2(-1) = 0$ ✓ · hydroxides: insoluble except group 1 and Ba^{2+} · Cu: $1 = 1$ · NO_3 : $2 = 2$ ·
K: $2 = 2$ · OH: $2 = 2$

A swapped the states: KNO_3 holds K^+ , group 1, so it stays dissolved; $\text{Cu}(\text{OH})_2$ is the solid. C copied the one-to-one ratio: CuOH gives $1(+2) + 1(-1) = +1$, not neutral, and leaves NO_3 at $2 \neq 1$. D gave Cu^{2+} barium's exception: the hydroxide line excepts only group 1 and Ba^{2+} .

 **Sense check:** The pale blue solid is $\text{Cu}(\text{OH})_2$. Two OH^- per Cu^{2+} put the 2 in front of KOH , and KNO_3 follows.

✓ Practice 3: the route on the table



found: $\text{Cu}(\text{OH})_2(\text{s}) \cdot \text{KNO}_3(\text{aq})$

SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

$\text{KNO}_3 \rightarrow (\text{aq})$

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT

Ag^+

Pb^{2+}

Hg_2^{2+}

SO_4^{2-}

sulfates: soluble

EXCEPT

Ag^+

Ba^{2+}

Ca^{2+}

Hg_2^{2+}

Pb^{2+}

Sr^{2+}

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT

group 1

NH_4^+

OH^-

hydroxides: insoluble

EXCEPT

group 1

Ba^{2+}

$\text{Cu}(\text{OH})_2 \rightarrow (\text{s})$

1

cation group 1 or NH_4^+ ? yes → (aq), done

2

find the anion's line soluble or insoluble

3

cation on its EXCEPT list? yes → the verdict flips

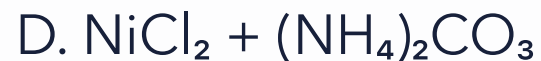
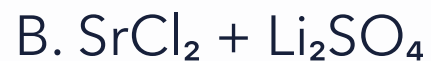
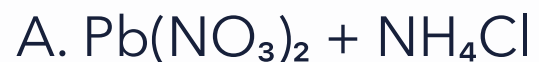
 **Sense check:** The hydroxide line with no exception: Cu^{2+} is neither group 1 nor Ba^{2+} , so $\text{Cu}(\text{OH})_2$ stays solid.



Practice 4

four beakers · one pair of clear solutions mixed in each
three beakers turn cloudy · wanted: the mixture that stays clear

Which mixture stays clear?



✓ Practice 4: answer C

new pairs: $\text{BaI}_2 \rightarrow (\text{aq}) \cdot \text{NaNO}_3 \rightarrow (\text{aq}) \rightarrow \text{no reaction (answer C)}$

BaI_2 : $1(+2) + 2(-1) = 0$ ✓ · iodides: soluble except Ag^+ , Pb^{2+} , Hg_2^{2+} · Ba^{2+} sits on the sulfate list, not the iodide list

A: $\text{PbCl}_2(\text{s})$ · B: $\text{SrSO}_4(\text{s})$ · D: $\text{NiCO}_3(\text{s})$

Pb^{2+} : a chloride exception · Sr^{2+} : a sulfate exception · Ni^{2+} : not group 1, not NH_4^+ · each partner (NH_4NO_3 , LiCl , NH_4Cl) stays (aq)

A trusted the always-soluble ions: NH_4^+ and NO_3^- stay dissolved, but the new pair PbCl_2 is on the chloride exception list. B remembered only barium on the sulfate list; Sr^{2+} is there too. D applied the ammonium exception to the wrong pairing: $(\text{NH}_4)_2\text{CO}_3$ arrived dissolved, but NiCO_3 has no exception.

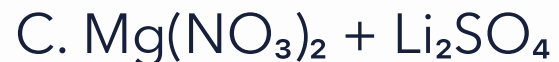
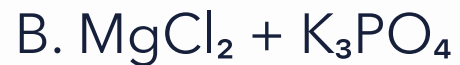
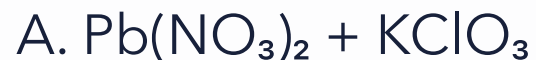
 **Sense check:** Barium fails the sulfate line and passes the halide lines. An exception list belongs to one anion: no cation precipitates with everything.



Practice 5

each beaker: two clear solutions poured together
one beaker clouds · three stay clear

A technician tests four pairs of solutions. Which pair forms a precipitate?



✓ Practice 5: answer B



phosphates: insoluble except group 1 and NH_4^+ · $\text{Mg}_3(\text{PO}_4)_2$: $3(+2) + 2(-3) = 0$ ✓ · Mg: $3 = 3$ · Cl: $6 = 6$ ·
K: $6 = 6$ · PO_4 : $2 = 2$

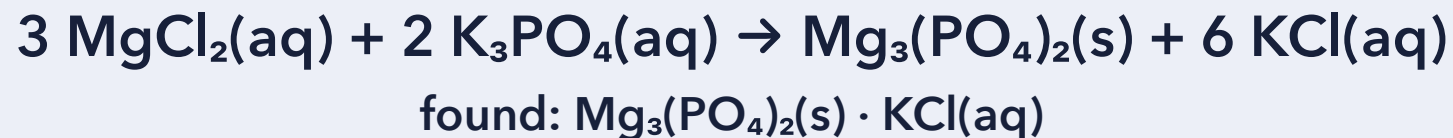


chlorates: always soluble · Mg^{2+} : not on the sulfate list · Ca^{2+} : on the sulfate list, not the halide list · each partner stays (aq)

A read ClO_3^- as Cl^- : Pb^{2+} is a chloride exception, but chlorate always dissolves. C stretched the sulfate list to every group 2 cation; Mg^{2+} is not on it. D carried Ca^{2+} from the sulfate list to the bromide line.

 **Sense check:** An EXCEPT list belongs to one line. Mg^{2+} dissolves with sulfate yet precipitates with phosphate; Ca^{2+} precipitates with sulfate, never with bromide.

✓ Practice 5: the route on the table



SOLUBLE: dissolves → (aq)

group 1 cations · NH_4^+

$\text{Li}^+ \text{Na}^+ \text{K}^+ \dots$: always soluble

KCl → (aq)

$\text{NO}_3^- \cdot \text{C}_2\text{H}_3\text{O}_2^- \cdot \text{HCO}_3^- \cdot \text{ClO}_3^-$

nitrate, acetate, bicarbonate, chlorate: always soluble

$\text{Cl}^- \cdot \text{Br}^- \cdot \text{I}^-$

halides: soluble

EXCEPT

Ag^+

Pb^{2+}

Hg_2^{2+}

SO_4^{2-}

sulfates: soluble

EXCEPT

Ag^+

Ba^{2+}

Ca^{2+}

Hg_2^{2+}

Pb^{2+}

Sr^{2+}

INSOLUBLE: stays solid → (s)

$\text{CO}_3^{2-} \cdot \text{CrO}_4^{2-} \cdot \text{PO}_4^{3-} \cdot \text{S}^{2-}$

carbonate, chromate, phosphate, sulfide: insoluble

EXCEPT

group 1

NH_4^+

$\text{Mg}_3(\text{PO}_4)_2 \rightarrow (\text{s})$

OH^-

hydroxides: insoluble

EXCEPT

group 1

Ba^{2+}

1

cation group 1 or NH_4^+ ? yes → (aq), done

2

find the anion's line soluble or insoluble

3

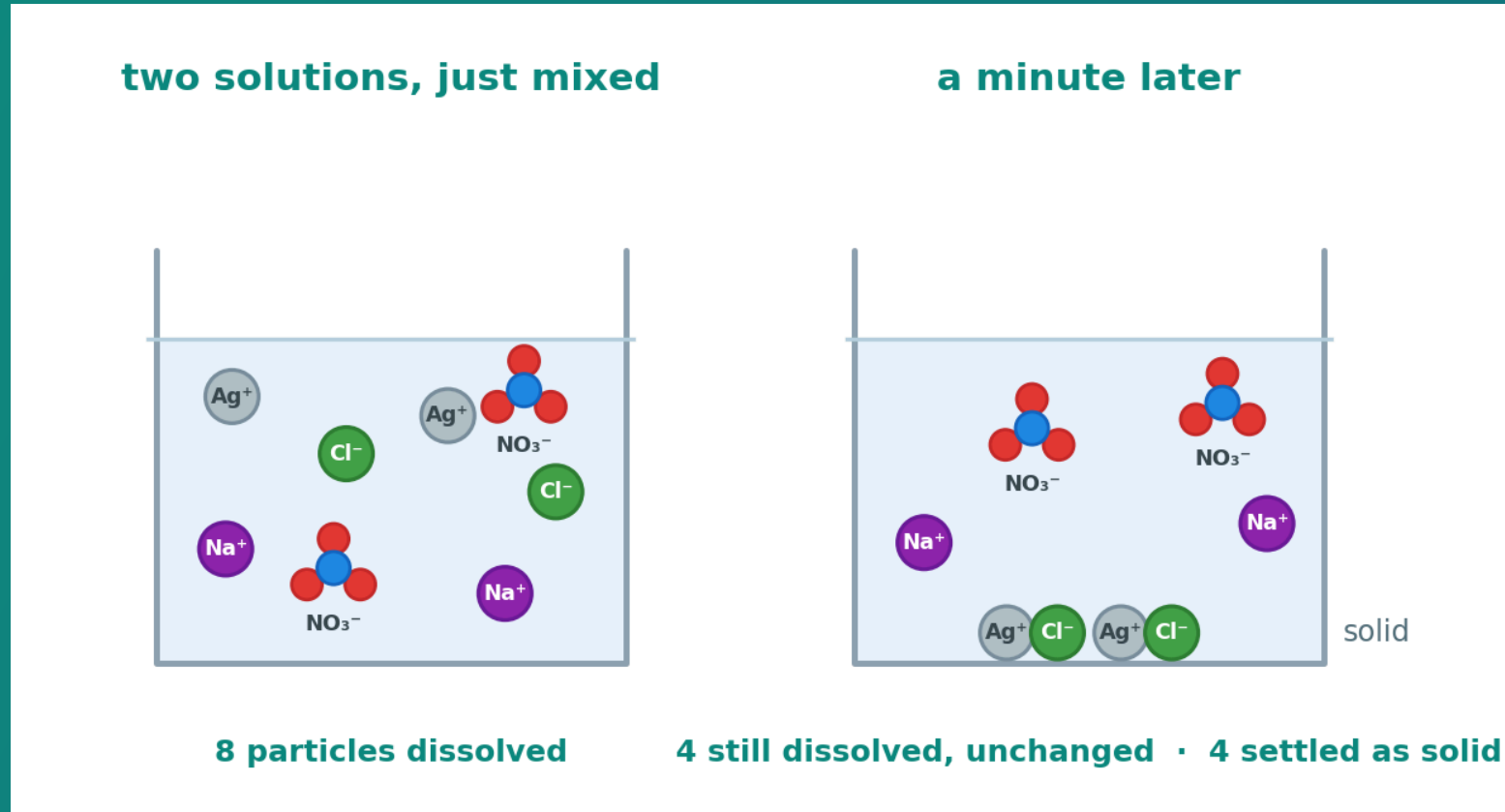
cation on its EXCEPT list? yes → the verdict flips

 **Sense check:** KCl stops at the first look. Mg^{2+} is neither group 1 nor NH_4^+ , so $\text{Mg}_3(\text{PO}_4)_2$ stays solid.

5 • Net Ionic Equations

Write the molecular, complete ionic, and net ionic equations for a reaction in solution, cancel the spectator ions, and check that the result balances in atoms and charge.

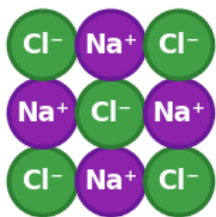
The solid takes only two kinds of particles



Two clear solutions are mixed; a white solid settles. Most dissolved particles are still floating afterward, unchanged. Only two kinds left the water.

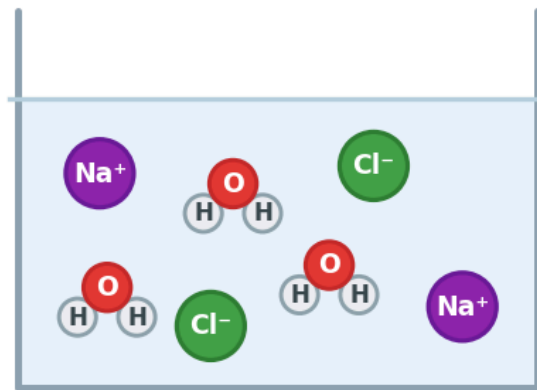
Dissolved means separated into ions

dissolving separates the ions



NaCl(s)

ions locked in a grid



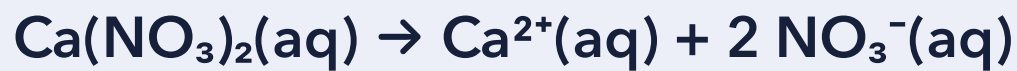
NaCl(aq)

separated ions, each moving on its own

the water holds $\text{Na}^+(\text{aq})$ and $\text{Cl}^-(\text{aq})$: no NaCl particle survives

A soluble ionic compound does not dissolve as molecules. It exists in the water as **separated ions**. Writing the ions shows which of them react and which never change.

Writing one compound as its ions



The subscript outside the parentheses becomes the count of nitrate ions. Nitrate stays whole: NO_3^{-} , never N and O.

Write $\text{Na}_3\text{PO}_4(\text{aq})$ as its ions.



Three views of the same reaction

molecular



write each (aq) compound as its ions; AgCl(s) stays intact

complete ionic



cancel the ions that match on both sides: Na⁺, NO₃⁻

net ionic



one beaker, one reaction: three ways to write it

The molecular equation lists whole compounds. The two ionic views show what the water actually holds.



Sense check: "Molecular equation" means written as whole formulas; most compounds in these equations are ionic.

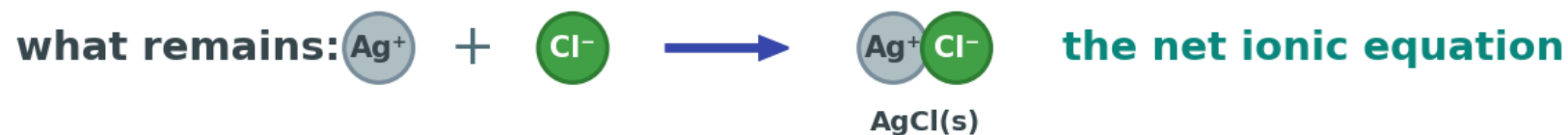
Spectator ions

dissolved before, dissolved after: the spectators cancel



Na⁺ and NO₃⁻: identical on both sides, unchanged

still dissolved, still spectators



charge check: (+1) + (-1) = 0 on the left · the solid is 0 on the right ✓

A **spectator ion** appears identical on both sides. Cancel the spectators; what remains is the **net ionic equation**. Any soluble silver salt plus any soluble chloride gives this same net line.

What separates on the page

written as separated ions: only solutes that separate completely in water
the soluble ionic compounds · the few acids that ionize fully, the strong acids

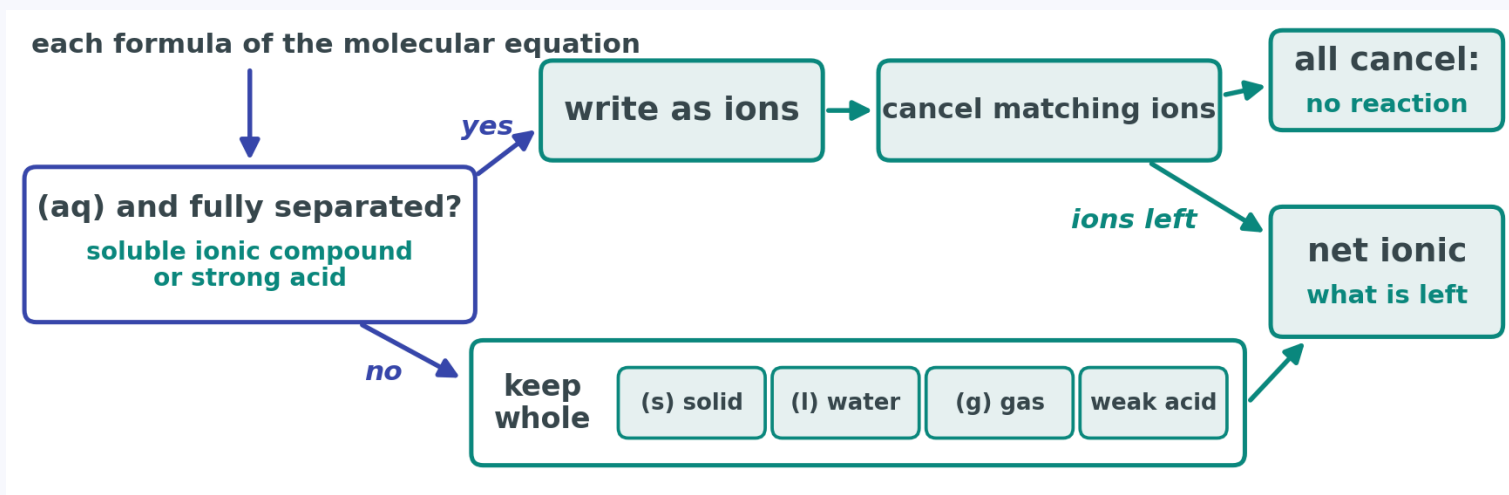
kept whole: everything else
acids that barely ionize: $\text{HC}_2\text{H}_3\text{O}_2(\text{aq})$ stays whole · insoluble solids: $\text{AgCl}(\text{s})$ stays intact · covalent molecules: $\text{H}_2\text{O}(\text{l})$ and sugar

A formula earns ion notation only by existing in the water fully separated. In these reactions that means the soluble salts and the strong acids; everything else keeps its formula whole.



The method

1. **Write the molecular equation with states.**
2. **Write each (aq) compound as its ions.** Keep charges and coefficients; polyatomic ions stay whole; (s) stays intact.
3. **Cancel the spectator ions.**
4. **Check atoms and charge.** Both must balance.





Guided example: copper(II) sulfide

Step 1 • Write the molecular equation with states

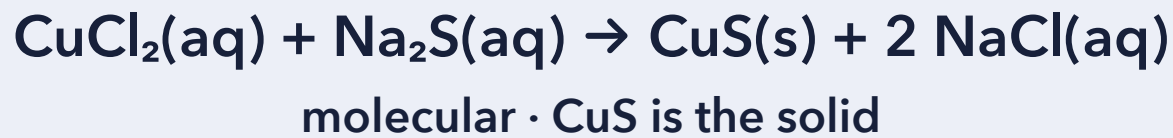


states from the solubility rules: sulfides insoluble except group 1 and NH_4^+ • the two chlorides soluble

Copper(II) chloride and sodium sulfide solutions are mixed, and a black solid settles. Write the complete ionic equation, also called the total ionic equation, then the net ionic equation.

Sort first: for each formula, split it into ions or keep it whole?

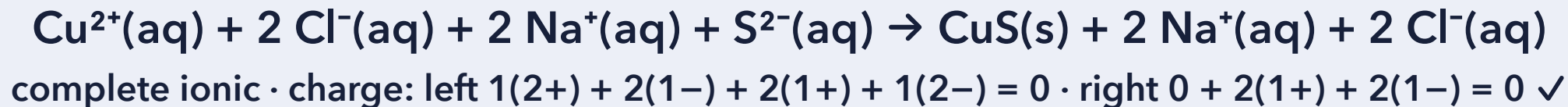
✓ Guided example: sort, then split



Sort each formula

$\text{CuCl}_2(\text{aq})$: split · $\text{Na}_2\text{S}(\text{aq})$: split · $\text{CuS}(\text{s})$: keep whole · $\text{NaCl}(\text{aq})$: split
three soluble ionic compounds separate · the solid stays intact

Step 2 · Write each (aq) compound as its ions



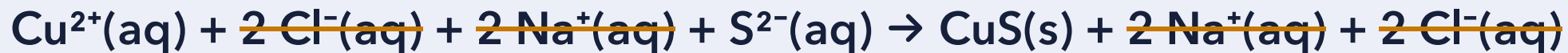
 **Sense check:** Every formula marked (aq) is now written as its ions. Only CuS(s), the solid, kept its formula.

✓ Guided example: cancel and check



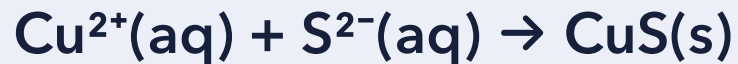
molecular · complete ionic already written

Step 3 · Cancel the spectator ions



spectators: Na^{+} and Cl^{-} · Cu^{2+} and S^{2-} have no match to cancel

Step 4 · Check atoms and charge



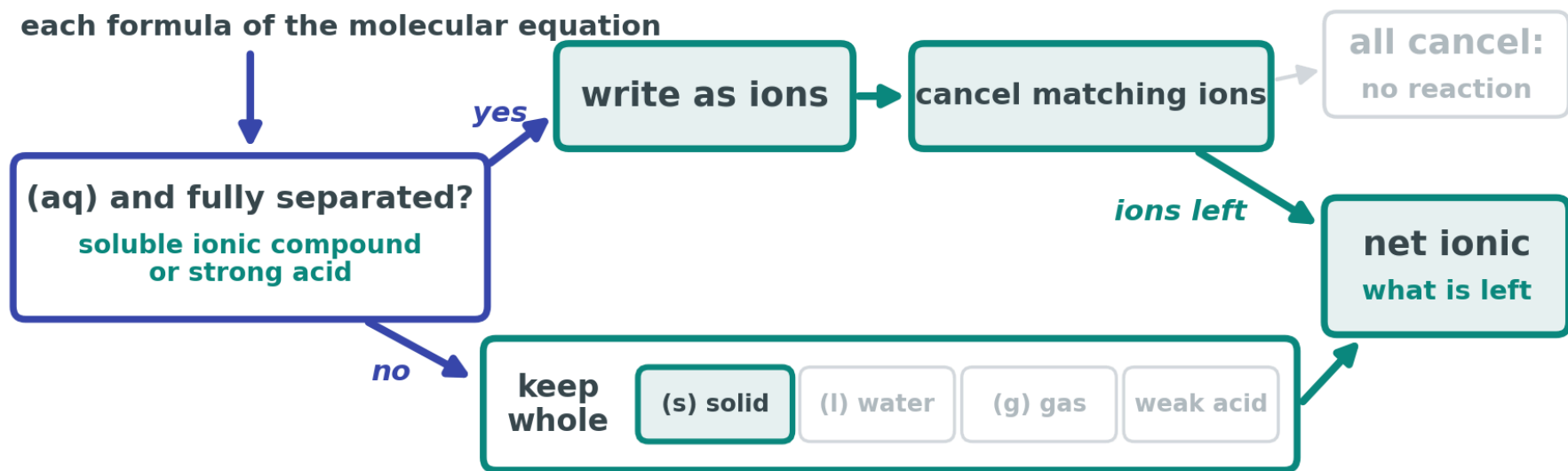
net ionic · atoms: Cu 1 = 1 ✓ · S 1 = 1 ✓ · charge: left 1(2+) + 1(2-) = 0, right 0 ✓

 **Sense check:** One 2+ ion and one 2- ion build one neutral solid, so no coefficient is needed. What is left are the two ions that built the black solid.

✓ Guided example: the route on the strip



split: CuCl_2 , Na_2S , NaCl · kept whole: $\text{CuS}(\text{s})$ · found: $\text{Cu}^{2+}(\text{aq}) + \text{S}^{2-}(\text{aq}) \rightarrow \text{CuS}(\text{s})$

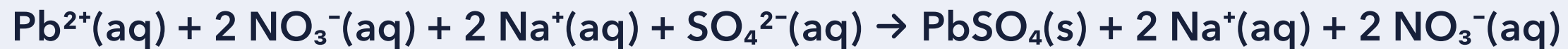


🧠 **Sense check:** Three formulas took the yes branch; the solid took no. The ions that build the solid are all that is left.





Practice 1: spotting the spectators

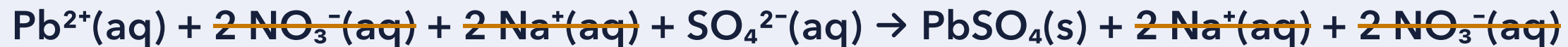


complete ionic equation

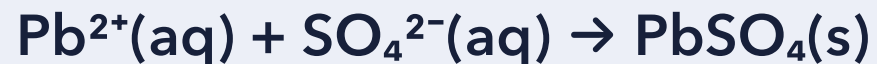
Lead(II) nitrate and sodium sulfate solutions are mixed. Which ions are the spectator ions?

- A. Pb^{2+} and SO_4^{2-}
- B. Na^{+} and NO_3^{-}
- C. Pb^{2+} and NO_3^{-}
- D. Na^{+} and SO_4^{2-}

✓ Practice 1: answer B



spectators: Na^{+} and NO_3^{-} (answer B) · each stands (aq), with the same count, on both sides



net ionic · atoms: Pb 1 = 1 ✓ · S 1 = 1 ✓ · O 4 = 4 ✓ · charge: left 1(2+) + 1(2-) = 0, right 0 ✓

A picked the reacting ions: Pb^{2+} and SO_4^{2-} leave the water inside $\text{PbSO}_4(\text{s})$. C and D paired the ions of one starting compound, $\text{Pb}(\text{NO}_3)_2$ or Na_2SO_4 , instead of comparing the two sides.

 **Sense check:** A spectator is found by comparing the two sides, never by tracing which compound an ion arrived in. ✓



Worked example 1: silver chloride

Step 1 • Write the molecular equation with states



states from the solubility rules: AgCl insoluble, the rest soluble

A drop of silver nitrate turns salty water cloudy white, a standard test for chloride. Write the complete ionic equation, then the net ionic equation.

✓ Worked example 1: the complete ionic equation



molecular · states from the solubility rules

Step 2 · Write each (aq) compound as its ions



complete ionic · charge: left $1(+1) + 1(-1) + 1(+1) + 1(-1) = 0$ · right $0 + 1(+1) + 1(-1) = 0$ ✓

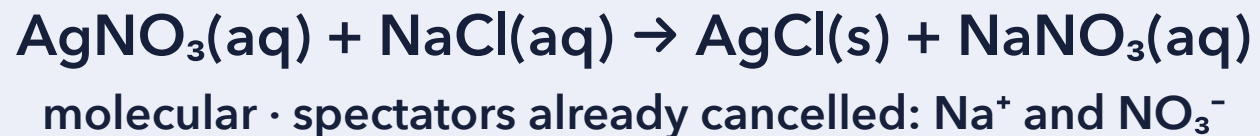
Step 3 · Cancel the spectator ions



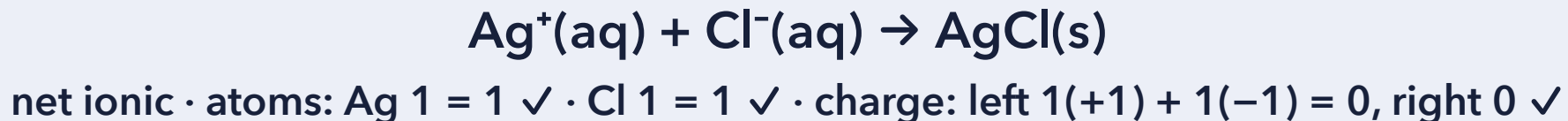
spectators: Na^+ and NO_3^-

 **Sense check:** The compound formulas are gone; the water's actual contents are on the page, and the two ions that never react are struck out.

✓ Worked example 1: the net ionic equation



Step 4 · Check atoms and charge

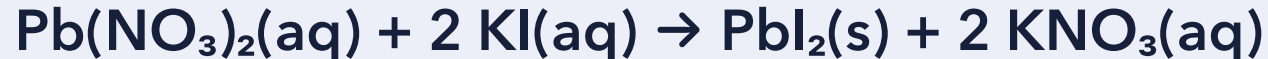


🧠 **Sense check:** The net ionic equation balances twice: every atom matches, and both sides carry zero total charge.



Worked example 2: lead iodide

Step 1 • Write the molecular equation with states

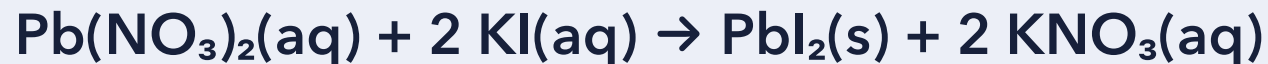


PbI_2 insoluble: the yellow solid of the golden-rain demonstration

Write the complete ionic equation, then the net ionic equation.

A common first attempt for the net: $\text{Pb}^{2+}(\text{aq}) + \text{I}^{-}(\text{aq}) \rightarrow \text{PbI}_2(\text{s})$. Test it.

✓ Worked example 2: the complete ionic equation



molecular · PbI_2 is the solid

Step 2 · Write each (aq) compound as its ions



charge: left $1(+2) + 2(-1) + 2(+1) + 2(-1) = 0$ · right $0 + 2(+1) + 2(-1) = 0$ ✓

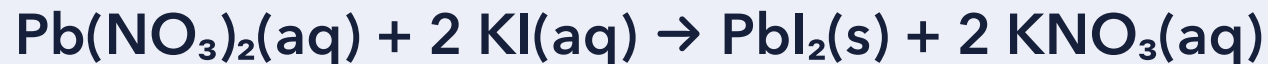
Step 3 · Cancel the spectator ions



spectators: K^{+} and NO_3^{-} · Pb^{2+} and 2I^{-} have no match to cancel

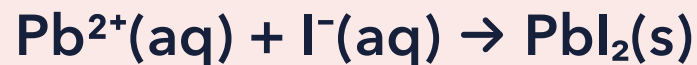
 **Sense check:** Nitrate separates and cancels as one whole unit, never as N and O pieces, and its coefficient 2 stays with it.

✓ Worked example 2: the net ionic equation



molecular · spectators already cancelled: K^+ and NO_3^-

A common first attempt



atoms: I 1 $\neq$ 2 ✗ · charge: left 1(+2) + 1(−1) = +1, right 0 ✗

Step 4 · Check atoms and charge



atoms: Pb 1 = 1 ✓ · I 2 = 2 ✓ · charge: left 1(+2) + 2(−1) = 0, right 0 ✓

 **Sense check:** The solid is neutral, so the ions that build it must sum to zero. Keeping the coefficients is what makes both checks pass.

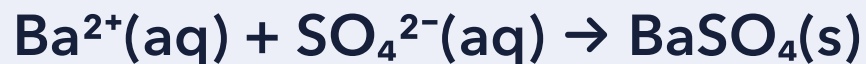
Your turn: barium sulfate



Step 1 done · BaSO_4 insoluble: the X-ray contrast a patient drinks

step	your work
2 · write each (aq) compound as its ions	$\text{Ba}^{2+} + 2 \text{Cl}^- + 2 \text{Na}^+ + \underline{\hspace{1cm}} \rightarrow \text{BaSO}_4(\text{s}) + 2 \text{Na}^+ + 2 \text{Cl}^-$
3 · cancel the spectator ions	$\underline{\hspace{1cm}}$ and $\underline{\hspace{1cm}}$
4 · check atoms and charge	net: $\underline{\hspace{1cm}}$ · left charge $\underline{\hspace{1cm}}$ = right charge 0

Complete steps 2 through 4.



spectators: Na^+ , Cl^- · atoms: Ba 1 = 1 ✓ · S 1 = 1 ✓ · O 4 = 4 ✓ · charge: left $1(+2) + 1(-2) = 0$, right 0 ✓

 **Sense check:** Sulfate stayed whole from the first line to the last. Its charge comes from the given -ate list, and the charge check depends on it.

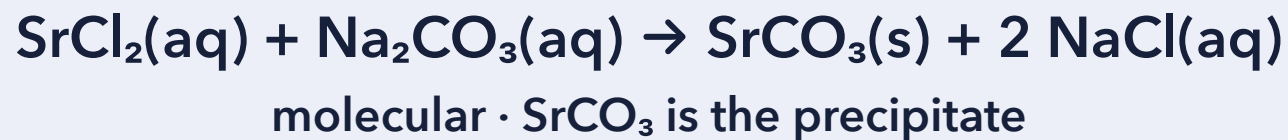
⚠ Where this goes wrong

Splitting the solid into ions. Writing AgCl(s) as $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq})$ lets every ion cancel, and the equation claims nothing happened. A solid formed. Only (aq) compounds separate; (s) stays intact.

Breaking up a polyatomic ion. Dissolved nitrate is $\text{NO}_3^-(\text{aq})$, one whole unit with one charge. Cancel nitrate as nitrate, never as separate N and O.

Dropping the charges. $\text{Ag(aq)} + \text{Cl(aq)} \rightarrow \text{AgCl(s)}$ shows neutral atoms the water does not contain. Without charges, the charge check cannot be run.

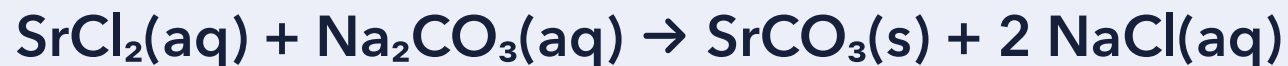
Stopping at the complete ionic equation. If K^+ and NO_3^- still stand on both sides, nothing has been cancelled. The net ionic equation keeps only the ions that build the solid.

 Practice 2

Strontium salts color fireworks red. Aqueous SrCl_2 and Na_2CO_3 are mixed, and SrCO_3 precipitates. Which is the correct net ionic equation?

- A. $\text{SrCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{SrCO}_3(\text{s}) + 2 \text{NaCl}(\text{aq})$
- B. $\text{Sr}^{2+}(\text{aq}) + 2 \text{Cl}^{-}(\text{aq}) + 2 \text{Na}^{+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{SrCO}_3(\text{s}) + 2 \text{Na}^{+}(\text{aq}) + 2 \text{Cl}^{-}(\text{aq})$
- C. $\text{Sr}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{SrCO}_3(\text{s})$
- D. $\text{Sr}^{+}(\text{aq}) + \text{CO}_3^{-}(\text{aq}) \rightarrow \text{SrCO}_3(\text{s})$

✓ Practice 2: answer C



the molecular equation, states from the solubility rules



atoms: Sr 1 = 1 ✓ · C 1 = 1 ✓ · O 3 = 3 ✓ · charge: left 1(+2) + 1(−2) = 0, right 0 ✓

A is the molecular equation; nothing has been written as ions. B is the complete ionic equation: Na^+ and Cl^- still stand on both sides, uncanceled. D halves both charges: strontium is a group 2 metal, Sr^{2+} , and carbonate is CO_3^{2-} , so its $1(+1) + 1(-1) = 0$ only looks balanced.

 **Sense check:** An equation can pass the charge check with two wrong charges. Assign each ion's real charge first, then check.

Worked example 3: sodium chloride and potassium nitrate

Step 1 • Write the molecular equation with states



partners swapped; the solubility rules mark every compound (aq): no solid

The two solutions are mixed and stay clear: no solid, no gas, no color change. Write the complete ionic equation, then the net ionic equation.

✓ Worked example 3: solution



molecular · every compound soluble, every state (aq)

Step 2 · Write each (aq) compound as its ions



complete ionic · no solid to keep intact

Step 3 · Cancel the spectator ions



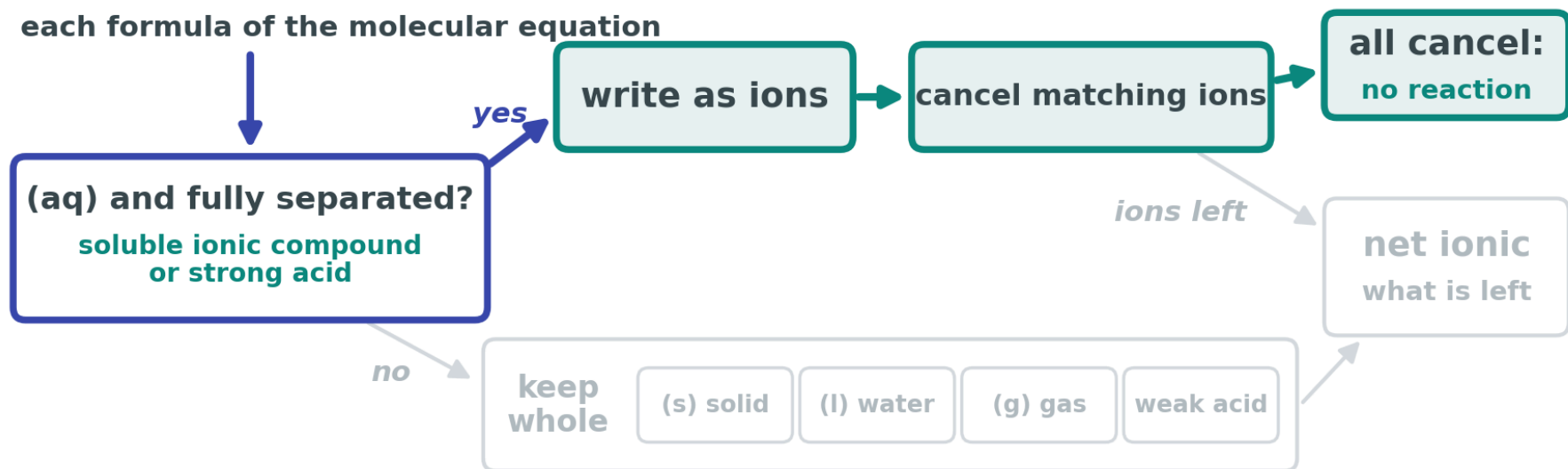
4 – 4 = 0 ions remain: no net ionic equation

 **Sense check:** Mixing produced one solution holding the same four ions. When everything cancels, no reaction occurred, which is exactly what the clear beaker showed.

✓ Worked example 3: the route on the strip



split: all four compounds · kept whole: none · found: every ion cancels



 **Sense check:** Every formula took the yes branch, so nothing was left to build a solid, water or a gas. All ions cancel: no reaction. ✓



Practice 3

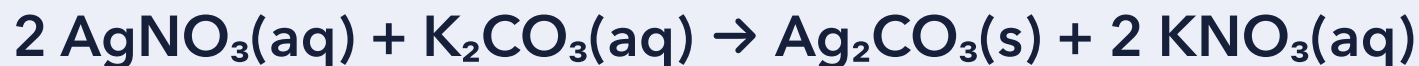


two clear solutions are mixed · a pale yellow solid forms

A few drops of silver nitrate fall into potash solution, K_2CO_3 . Which net ionic equation describes the change?

- A. $2 \text{Ag}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{Ag}_2\text{CO}_3(\text{s})$
- B. $\text{Ag}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{Ag}_2\text{CO}_3(\text{s})$
- C. $\text{K}^+(\text{aq}) + \text{NO}_3^-(\text{aq}) \rightarrow \text{KNO}_3(\text{s})$
- D. $2 \text{Ag}^+(\text{aq}) + 2 \text{NO}_3^-(\text{aq}) + 2 \text{K}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{Ag}_2\text{CO}_3(\text{s}) + 2 \text{K}^+(\text{aq}) + 2 \text{NO}_3^-(\text{aq})$
- E. $\text{Ag}^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{AgCO}_3(\text{s})$

✓ Practice 3: answer A



molecular · carbonates: insoluble except group 1 and NH_4^+ · Ag_2CO_3 : $2(1+) + 1(2-) = 0$ ✓



atoms: Ag 2 = 2 ✓ · C 1 = 1 ✓ · O 3 = 3 ✓ · charge: left $2(1+) + 1(2-) = 0$, right 0 ✓

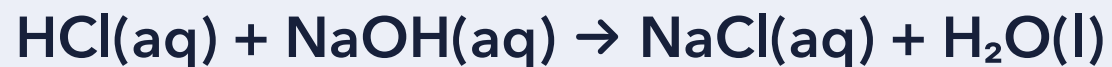
B dropped the coefficient: Ag 1 $\neq$ 2, and charge $1(1+) + 1(2-) = -1$ against 0. C precipitated the soluble pair: K^+ is group 1 and nitrate is always soluble. D is the complete ionic equation, K^+ and NO_3^- uncanceled. E copied a one-to-one ratio into the formula: AgCO_3 sums to $1(1+) + 1(2-) = -1$, not neutral.

 **Sense check:** Two 1+ silvers balance one 2– carbonate. The neutral solid sets the 2 : 1 ratio, and the charge check confirms it.



Worked example 4: acid plus base

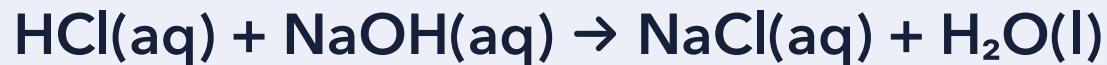
Step 1 • Write the molecular equation with states



HCl: a strong acid, all ions in water • NaOH: a soluble ionic compound • H₂O(l): a covalent liquid

Mixing hydrochloric acid with sodium hydroxide solution gives salt water: nothing visible happens, yet the beaker warms. Write the complete ionic equation, then the net ionic equation.

✓ Worked example 4: the complete ionic equation



molecular · all three (aq) compounds are strong electrolytes

Step 2 · Write each (aq) compound as its ions



charge: left $1(1+) + 1(1-) + 1(1+) + 1(1-) = 0$ · right $1(1+) + 1(1-) + 0 = 0$ ✓

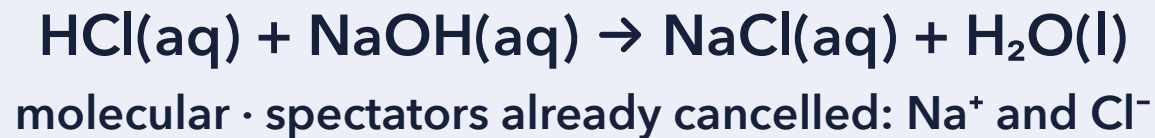
Step 3 · Cancel the spectator ions



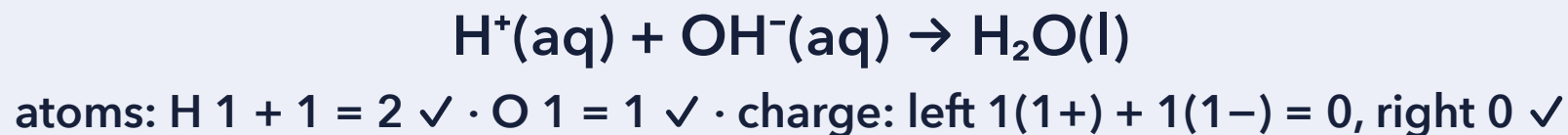
spectators: Na^+ and Cl^- · the salt of the molecular equation never left the water

 **Sense check:** No solid forms this time. The product that drives the reaction is the covalent molecule H_2O , and it keeps its H and O out of the ion pool.

✓ Worked example 4: the net ionic equation



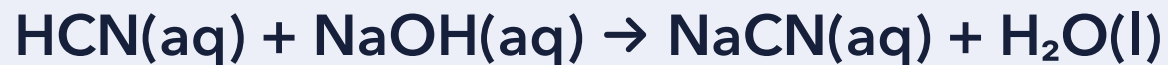
Step 4 · Check atoms and charge



Every strong acid neutralizing every soluble hydroxide gives this same net line, so long as the salt formed stays dissolved.

 **Sense check:** One net ionic equation stands behind thousands of acid-base pairs: H^+ meets OH^- and leaves the ion pool as water.

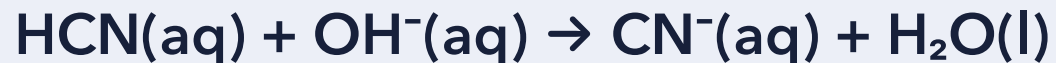
✓ Worked example 4: a weak acid instead



molecular · HCN: a weak acid, almost every molecule stays whole in water

The weak-acid case

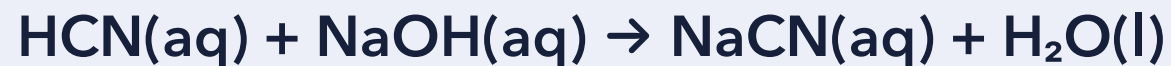
A weak acid is not written as ions: the water really holds HCN molecules.



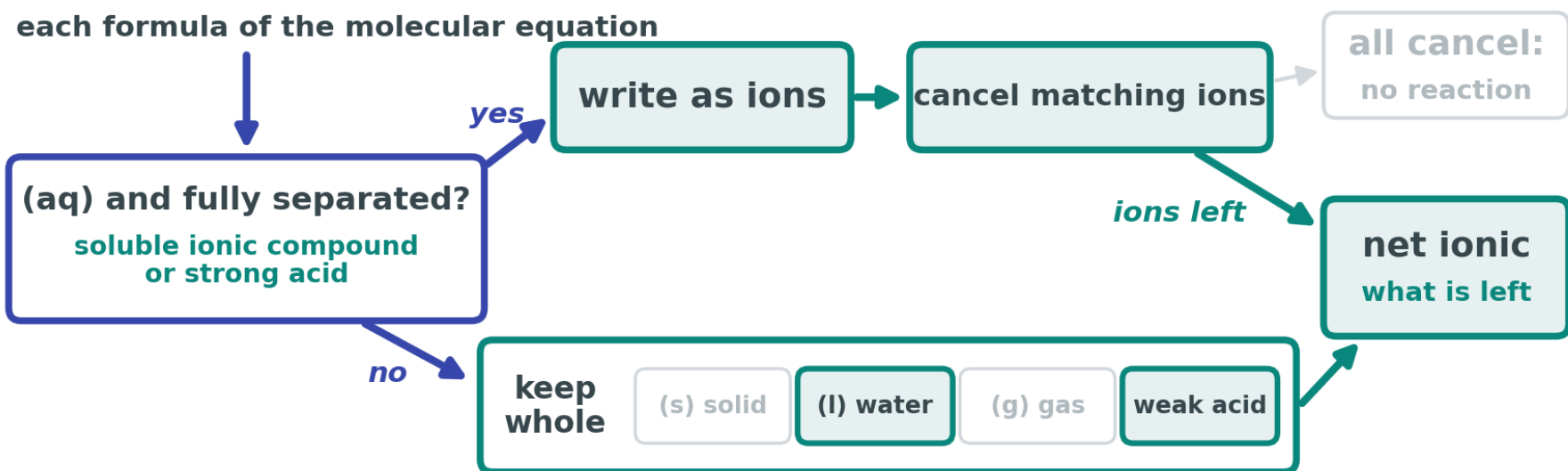
net ionic · Na⁺ is the only spectator · atoms: H 1 + 1 = 2 ✓ · C 1 = 1 ✓ · N 1 = 1 ✓ · O 1 = 1 ✓ · charge:
left 0 + 1(1–) = 1–, right 1(1–) + 0 = 1– ✓

 **Sense check:** The acid appears whole because that is what the solution contains. A net ionic equation may carry a nonzero total charge, as long as both sides match.

✓ Worked example 4: the route on the strip

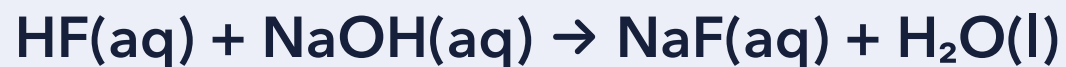


split: NaOH, NaCN · kept whole: HCN (weak acid), H₂O(l) · found: $\text{HCN(aq)} + \text{OH}^{\text{-(aq)}} \rightarrow \text{CN}^{\text{-(aq)}} + \text{H}_2\text{O(l)}$



 **Sense check:** With HCl, only water takes the no branch. With HCN, the weak acid takes it too, so the acid enters the net ionic equation whole. ✓

Practice 4: hydrofluoric acid

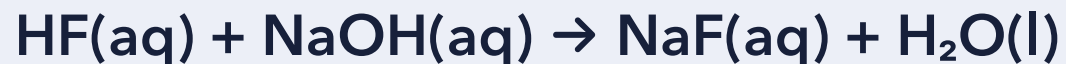


molecular · NaF: a soluble group 1 salt

Hydrofluoric acid is the only weak acid of the halogen group. Which is its net ionic equation with sodium hydroxide?

- A. $\text{H}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{H}_2\text{O(l)}$
- B. $\text{HF(aq)} + \text{NaOH(aq)} \rightarrow \text{NaF(aq)} + \text{H}_2\text{O(l)}$
- C. $\text{HF(aq)} + \text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{Na}^+(\text{aq}) + \text{F}^-(\text{aq}) + \text{H}_2\text{O(l)}$
- D. $\text{HF(aq)} + \text{OH}^-(\text{aq}) \rightarrow \text{F}^-(\text{aq}) + \text{H}_2\text{O(l)}$

✓ Practice 4: answer D



molecular · split: NaOH, NaF · kept whole: HF (weak acid), H₂O(l) · spectator: Na⁺



net ionic · atoms: H 1 + 1 = 2 ✓ · F 1 = 1 ✓ · O 1 = 1 ✓ · charge: left 0 + 1(1–) = 1–, right 1(1–) + 0 = 1–
✓

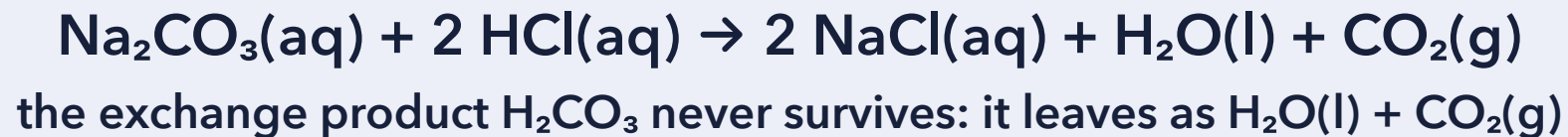
A split the weak acid: the water holds HF molecules, not H⁺ and F[–]. B is the molecular equation; nothing has been written as ions. C is the complete ionic equation: Na⁺ still stands on both sides.

 **Sense check:** A weak acid enters the net ionic equation whole. Both sides carry 1–, and the charge check asks only that they match. ✓



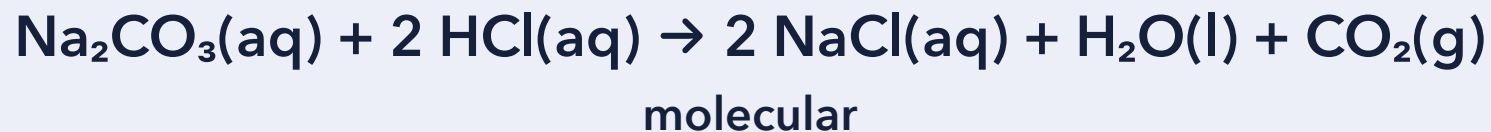
Worked example 5: a carbonate meets acid

Step 1 • Write the molecular equation with states



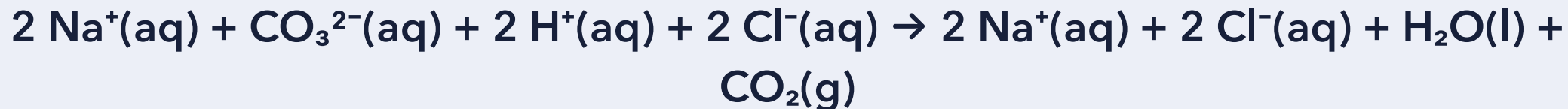
Washing soda solution fizzes when hydrochloric acid is poured in. Write the complete ionic equation, then the net ionic equation.

✓ Worked example 5: the complete ionic equation



Step 2 • Write each (aq) compound as its ions

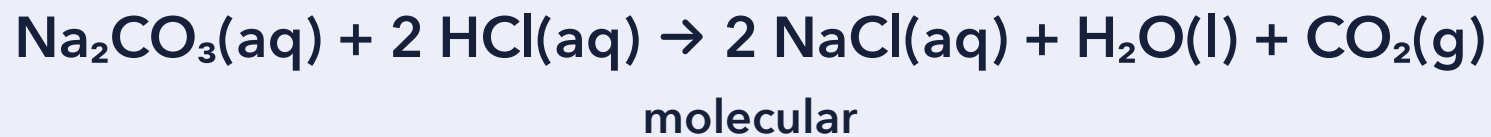
Na_2CO_3 and NaCl are soluble salts, and HCl is a strong acid. Water and CO_2 are molecules: they stay whole.



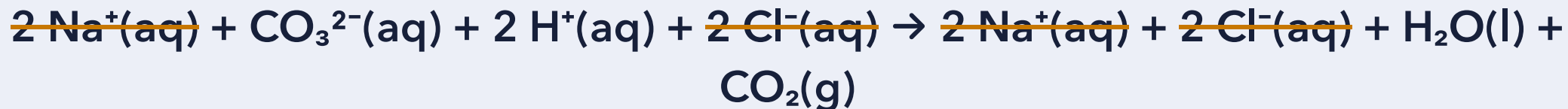
charge: left $2(1+) + 1(2-) + 2(1+) + 2(1-) = 0$ · right $2(1+) + 2(1-) + 0 = 0$ ✓

 **Sense check:** Every (aq) formula is now written as its ions. Only the two molecules, water and CO_2 , stay whole.

✓ Worked example 5: cancel the spectators



Step 3 • Cancel the spectator ions



spectators: Na^+ and Cl^- • carbonate and H^+ have no match to cancel

 **Sense check:** No solid forms here. The reacting ions leave the water as two molecules, and one of them floats away as the fizz.

✓ Worked example 5: the net ionic equation



molecular · spectators already cancelled: Na^+ and Cl^-

Step 4 · Check atoms and charge



net ionic · atoms: C 1 = 1 ✓ · O 3 = 1 + 2 ✓ · H 2 = 2 ✓ · charge: left 1(2−) + 2(1+) = 0, right 0 ✓

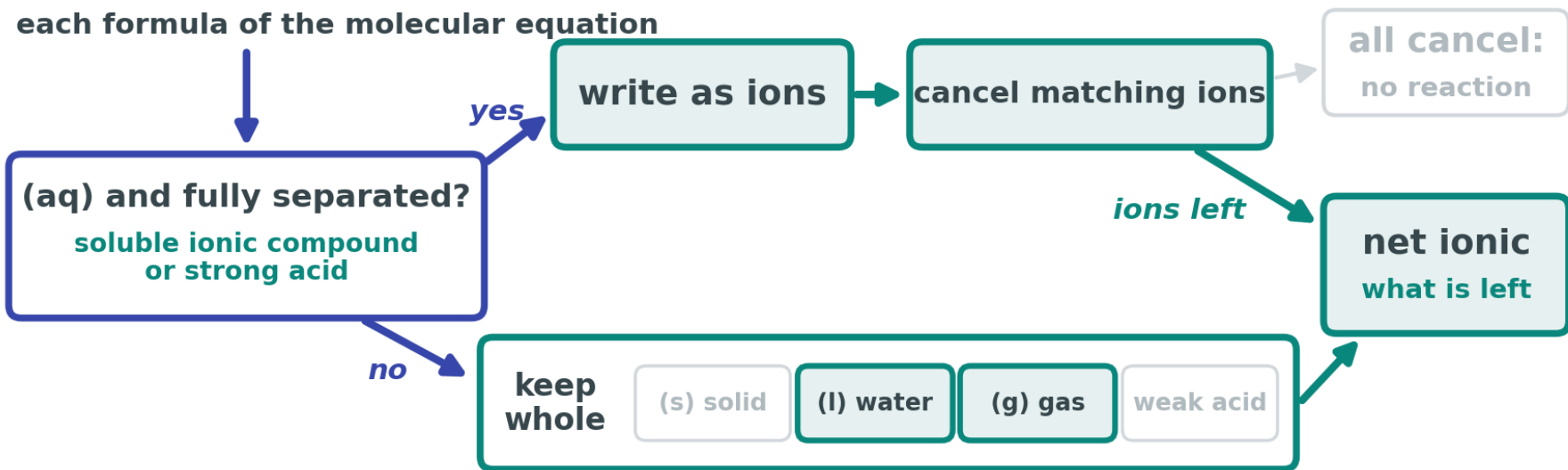
Any dissolved carbonate meeting a strong acid gives this same net line.

 **Sense check:** Two protons turn one carbonate into water and a gas that leaves. The bubbles are written right into the net ionic equation.

✓ Worked example 5: the route on the strip



split: Na_2CO_3 , HCl , NaCl · kept whole: $\text{H}_2\text{O}(\text{l})$, $\text{CO}_2(\text{g})$ · found: $\text{CO}_3^{2-}(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$



Sense check: Two products took the no branch: water and the gas. The ions that built them, CO_3^{2-} and 2H^+ , are all that is left. ✓

✓ Worked example 5: a solid carbonate instead



molecular · CaCO_3 : a solid, the antacid tablet · CaCl_2 : soluble

The solid-carbonate case

A solid is never written as ions, so the carbonate stays inside $\text{CaCO}_3(\text{s})$.



net ionic · Cl^- is the only spectator · atoms: Ca 1 = 1 ✓ · C 1 = 1 ✓ · O 3 = 1 + 2 ✓ · H 2 = 2 ✓ · charge:
left 0 + 2(1+) = 2+, right 1(2+) + 0 = 2+ ✓

 **Sense check:** The tablet enters whole and leaves as dissolved Ca^{2+} plus the fizz. Both sides carry 2+, and the check asks only that they match.

Practice 5: which ions leave



Aqueous NH_4Br and KOH are mixed. Which statement about the ions is correct?

- A. All four ions are spectators; no solid forms, so there is no reaction
- B. NH_4^+ and OH^- are spectators; K^+ and Br^- leave the solution as KBr(s)
- C. K^+ and Br^- are spectators; NH_4^+ and OH^- leave as $\text{NH}_3(\text{g})$ and $\text{H}_2\text{O(l)}$
- D. K^+ and Br^- are spectators; NH_4^+ and OH^- stay dissolved as $\text{NH}_4\text{OH(aq)}$

✓ Practice 5: answer C



molecular · the swap predicts NH_4OH , which never survives: $\text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l})$ · KBr : group 1, soluble



spectators: K^+ and Br^- · atoms: N $1 = 1$ ✓ · H $4 + 1 = 3 + 2$ ✓ · O $1 = 1$ ✓ · charge: left $1(1+) + 1(1-) = 0$, right 0 ✓

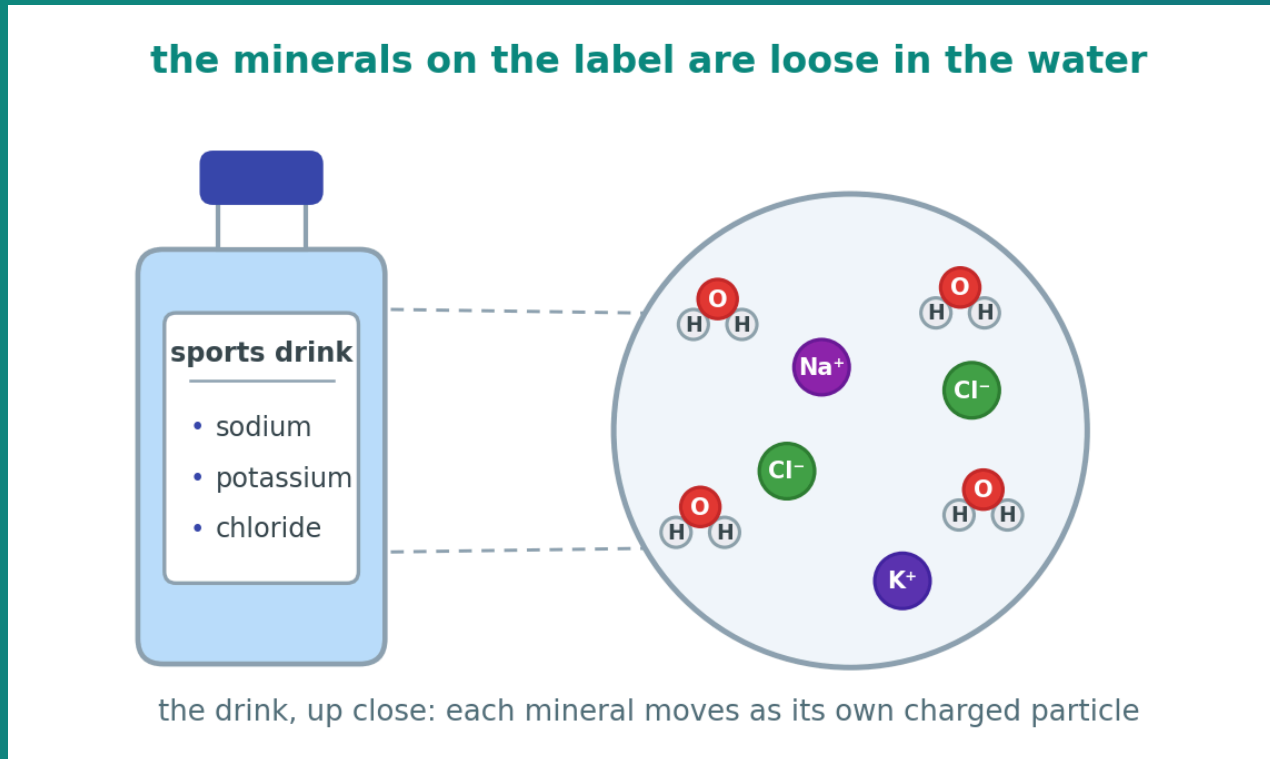
A looked only for a solid: a gas leaving the water is a reaction too. B precipitated a group 1 salt; KBr always stays dissolved. D kept NH_4OH , one of the three exchange products that break apart into a gas and water.

 **Sense check:** No solid formed, yet NH_4^+ and OH^- left the water as ammonia gas and liquid water. The net ionic equation keeps only those two ions. ✓

6 · Electrolytes & Dissociation

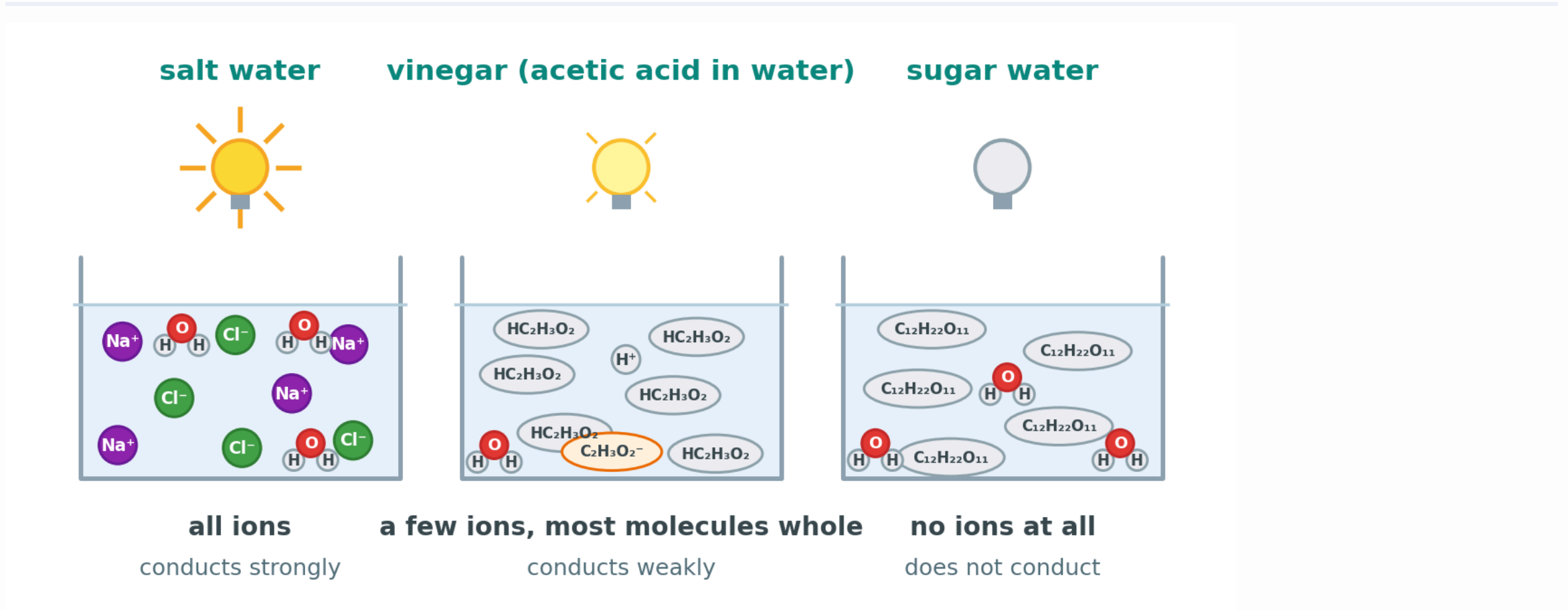
Classify a solute as a strong electrolyte, a weak electrolyte, or a nonelectrolyte from its compound type, and write its dissociation equation with the right ions, coefficients, and charge sum.

Inside a sports drink



The label lists sodium, potassium, chloride. In the bottle, each one travels through the water as a separate charged particle. Nerve and muscle signals run on these moving charges.

Conduction needs moving charges



A solution conducts only if charged particles can move through it. What a solute becomes in water sets how strongly its solution conducts: all ions, a few ions, or no ions at all.

Does it dissolve, and into what?



group 1: soluble · dissolves as separate ions · the bulb lights

AgI(s): stays solid

iodides are soluble except with Ag^+ , Hg_2^{2+} , Pb^{2+} · almost no ions reach the water · the bulb stays dark



table sugar: molecular · dissolves as whole molecules · the bulb stays dark

The solubility rules answer the first question: does it dissolve? The second question is what the dissolved solute becomes. Only ions carry current.

Three classes of solute

strong electrolyte: dissolves entirely as ions

soluble ionic compounds (NaOH, KOH included) · the seven strong acids: HCl · HBr · HI · HNO₃ · H₂SO₄ · HClO₄ · HClO₃

weak electrolyte: a small fraction ionizes

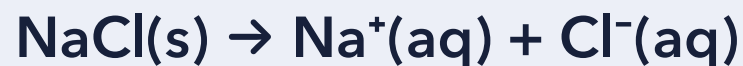
weak acids and weak bases: HC₂H₃O₂ · NH₃; most molecules stay whole

nonelectrolyte: dissolves as whole molecules

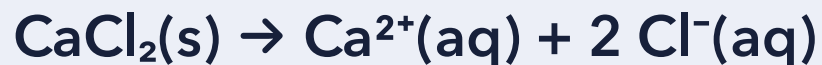
other molecular compounds: sugar · ethanol; no ions, no conduction

An **electrolyte** releases ions in water, and its solution conducts. Compound type assigns the class. Acids and bases get strength lists of their own.

Dissociation equations



1 + 1 = 2 ions per formula unit · charge: (1+) + (1−) = 0



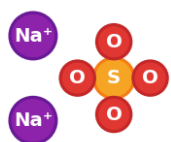
1 + 2 = 3 ions per formula unit · charge: (2+) + 2(1−) = 0

Water pulls an ionic solid apart into its separate ions: **dissociation**. Each ion keeps its identity and its charge. A subscript counts separate ions, so it becomes a coefficient.

Polyatomic ions stay in one piece

dissociation separates the ions and keeps each one whole

one Na_2SO_4 formula unit:
ions held together



water

in water: 3 separate ions,
each one whole



X never into separate atoms

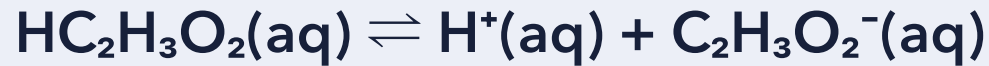


the S-O bonds do not break:
sulfate travels with its own 2- charge



Dissociation separates cations from anions. It never breaks the bonds inside a polyatomic ion: sulfate enters the water whole, carrying its 2- charge.

Weak electrolytes: partial ionization



most molecules stay whole · each ionization: $(1+) + (1-) = 0$



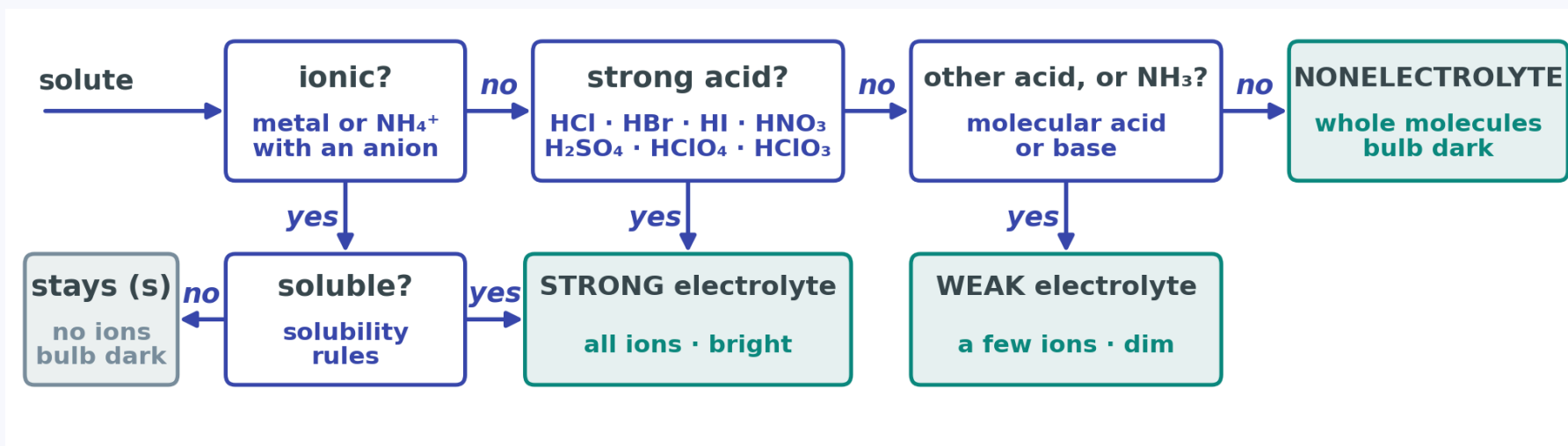
a weak base: only a few molecules react · charge: $(1+) + (1-) = 0$

A molecular acid or base **ionizes**: reaction with water makes new ions. A weak one barely reacts: a few molecules ionize, the rest stay whole. The double arrow marks an incomplete reaction.



The method

1. **Classify the solute.** Soluble ionic and strong acids: strong. Other acids and bases: weak. Other molecular: nonelectrolyte.
2. **Write what water makes.** Separated ions, a few ions, or whole molecules.
3. **Check the charge sum.** The ions must total zero.





Guided example: barium hydroxide

Ba(OH)₂(s) stirred into water

given: barium hydroxide · wanted: class + the dissociation equation

Clear barium hydroxide solution, called baryta water, turns cloudy when breath is bubbled through it. Classify Ba(OH)₂ and write its dissociation equation.

Step 1 takes two questions: ionic or molecular? If ionic, soluble or not?

✓ Guided example: classify the solute

$\text{Ba}(\text{OH})_2(\text{s})$ stirred into water

given: barium hydroxide · wanted: class + the dissociation equation

Step 1 · Classify the solute

ionic or molecular? Ba is a metal; OH^- is a polyatomic ion

move 1 · a metal with an anion · answer: ionic

soluble? hydroxides: insoluble except group 1 and Ba^{2+}

move 2 · the solubility rules · answer: soluble

🧠 **Sense check:** Soluble and ionic: a strong electrolyte. The solubility rules decided it; most hydroxides stay solid, and Ba^{2+} is a named exception. ✓

✓ Guided example: write the ions

$\text{Ba}(\text{OH})_2(\text{s})$ stirred into water
classified: soluble ionic $\rightarrow$ strong electrolyte

Step 2 • Write what water makes

$\text{Ba}(\text{OH})_2(\text{s}) \rightarrow \text{Ba}^{2+}(\text{aq}) + 2 \text{OH}^{-}(\text{aq})$
subscript 2 $\rightarrow$ coefficient $2 \cdot 1 + 2 = 3$ ions per formula unit $\cdot \text{OH}^{-}$ stays whole

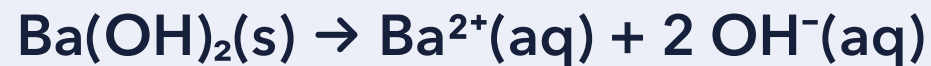
Step 3 • Check the charge sum

$\text{Ba}(\text{OH})_2(\text{s}) \rightarrow \text{Ba}^{2+}(\text{aq}) + 2 \text{OH}^{-}(\text{aq})$
charge: $(2+) + 2(1-) = 0 \checkmark$

 **Sense check:** One 2+ ion against two 1– ions cancels. Hydroxide leaves as one piece: its O and H never separate.

✓

✓ Guided example: the route on the chart



ionic: yes · soluble: yes · found: strong electrolyte, 3 ions per formula unit



🧠 **Sense check:** Two yes answers on the ionic branch reach strong electrolyte. The acid questions never came up. ✓

Practice 1: which one conducts



silver chloride · methanol · sodium nitrate · calcium carbonate

Each substance is stirred into its own beaker of water. Which beaker lights a conductivity bulb brightly?

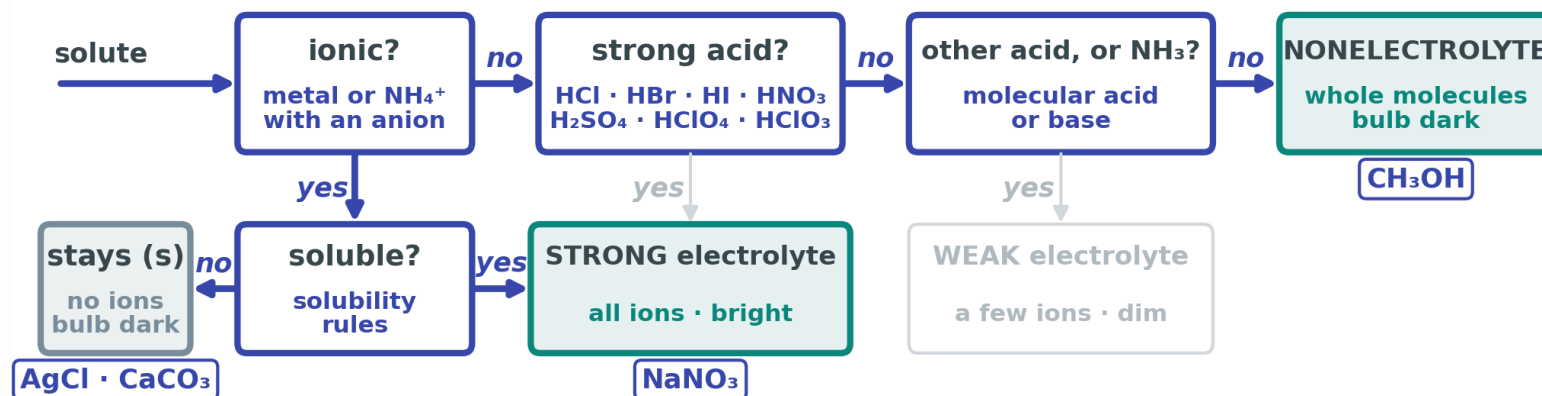
- A. AgCl
- B. CH_3OH
- C. NaNO_3
- D. CaCO_3

✓ Practice 1: answer C



ionic, group 1: soluble · strong electrolyte · $1 + 1 = 2$ ions · charge: $(1+) + (1-) = 0$

A is ionic, but Ag^+ is a chloride exception: AgCl stays solid. B read methanol's OH as hydroxide; it is covalently bonded, and the molecules stay whole. D is ionic, but carbonates are insoluble except with group 1 and NH_4^+ .



🧠 **Sense check:** Ionic is not enough: the compound must also dissolve. Only NaNO_3 passes both questions. ✓



Worked example 1: magnesium chloride

MgCl₂(s) dissolved in water

given: a soluble ionic compound · wanted: class + the dissociation equation

Road crews spread MgCl₂ as a de-icer, and it dissolves freely. Classify it and write the dissociation equation.

✓ Worked example 1: solution

$\text{MgCl}_2(\text{s})$ dissolved in water

given: a soluble ionic compound · wanted: class + the dissociation equation

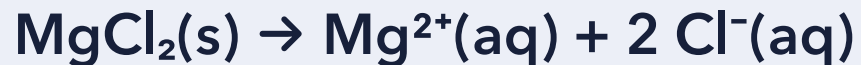
Step 1 · Classify the solute

Step 2 · Write what water makes



subscript 2 → coefficient $2 \cdot 1 + 2 = 3$ ions per formula unit

Step 3 · Check the charge sum



3 ions · charge: $(2+) + 2(1-) = 0$ ✓

 **Sense check:** The solid is neutral, so the ions it releases must cancel: one 2+ against two 1−. A nonzero sum marks a wrong formula or a wrong coefficient. ✓

 Worked example 2: Na_2CO_3 , NH_3 , $\text{C}_2\text{H}_5\text{OH}$ 

washing soda · household ammonia · ethanol · wanted: each class + what each solution contains

All three dissolve freely in water. Classify each and write what its solution contains.

✓ Worked example 2: classifying



washing soda · household ammonia · ethanol

Step 1 · Classify the solute

solute	type	class
Na_2CO_3	soluble ionic compound	strong electrolyte
NH_3	molecular base, not an ionic hydroxide	weak electrolyte
$\text{C}_2\text{H}_5\text{OH}$	molecular, neither acid nor base	nonelectrolyte

 **Sense check:** All three bottles look identical. The compound type, not the appearance, separates them.

✓ Worked example 2: what each solution contains



classified: strong electrolyte · weak electrolyte · nonelectrolyte

Step 2 · Write what water makes

Step 3 · Check the charge sum



2 + 1 = 3 ions · charge: $2(1+) + (2-) = 0$ · carbonate stays one piece



a few ions · charge: $(1+) + (1-) = 0$ · most NH_3 molecules stay whole

$\text{C}_2\text{H}_5\text{OH}(\text{aq})$: dissolves as whole molecules

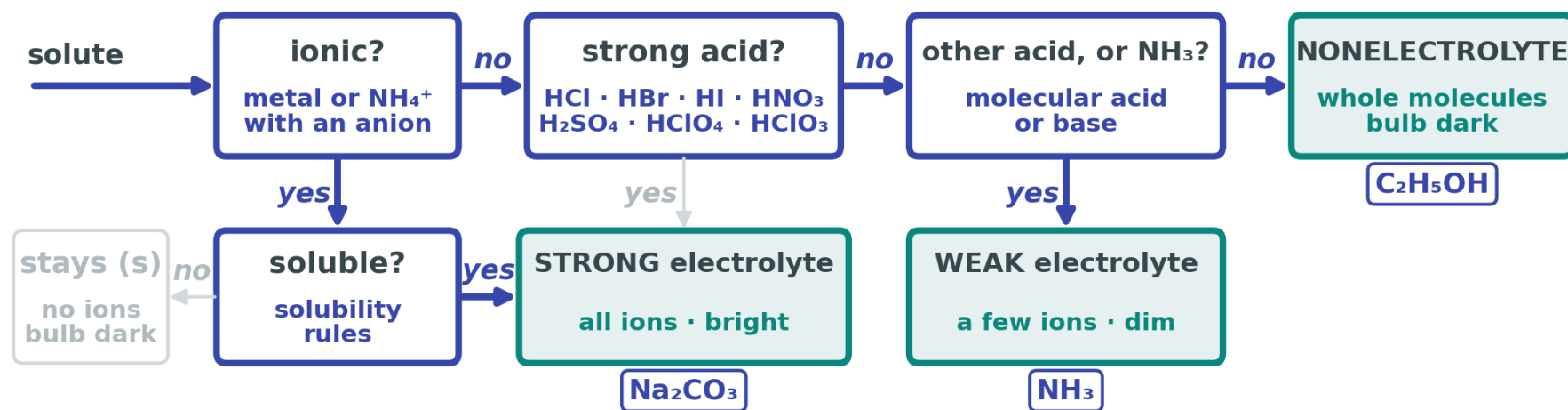
0 ions · the OH is covalently bonded, not OH^-

 **Sense check:** Three clear solutions, three bulb readings: bright, dim, dark. ✓

✓ Worked example 2: the route on the chart



Na_2CO_3 : ionic, soluble · NH_3 : not ionic, not on the acid list, a base · $\text{C}_2\text{H}_5\text{OH}$: every answer no



🧠 **Sense check:** Three solutes leave by three exits. Only the ionic one needed the solubility rules. ✓

Your turn: magnesium nitrate

Mg(NO₃)₂(s) dissolved in water
given: a soluble ionic compound · nitrate: NO₃[−]

step	work	result
1 · classify the solute	soluble ionic compound	_____ electrolyte
2 · write what water makes	Mg(NO ₃) ₂ (s) → Mg ²⁺ (aq) + _____	ions per formula unit: _____
3 · check the charge sum	(2+) + 2(1−)	= _____

Complete the classification and the equation.

Mg(NO₃)₂(s) → Mg²⁺(aq) + 2 NO₃[−](aq)
strong electrolyte · 1 + 2 = 3 ions · charge: (2+) + 2(1−) = 0 · each nitrate leaves whole

⚠ Where this goes wrong

Reading a subscript as a bonded pair. CaCl_2 never releases a Cl_2^{2-} unit. The subscript counts separate ions: $\text{Ca}^{2+} + 2 \text{Cl}^-$ makes $1 + 2 = 3$ ions, not $1 + 1 = 2$.

Breaking a polyatomic ion into atoms. Na_2CO_3 gives $2 \text{Na}^+ + \text{CO}_3^{2-} = 3$ ions, never $2 + 1 + 3 = 6$ pieces. Dissociation separates ions; it does not break the bonds inside one.

Calling sugar a weak electrolyte. Weak means a few ions form. Sugar forms none: its solution conducts no better than pure water. Nonelectrolyte.

Reading a molecular OH as hydroxide. Ethanol's OH is covalently bonded and stays put. Only ionic hydroxides such as NaOH release OH^- .



Practice 2

K_3PO_4 dissolved in water

given: a soluble ionic compound · phosphate: PO_4^{3-}

Fertilizer-grade potassium phosphate dissolves freely in water. Which statement classifies it and describes what its solution contains?

- A. Weak electrolyte: a salt built around a polyatomic ion dissociates only partially
- B. Strong electrolyte: it dissociates completely into 3 K^+ and PO_4^{3-} , four ions per formula unit
- C. Strong electrolyte: it dissociates completely into K_3^+ and PO_4^{3-} , two ions per formula unit
- D. Nonelectrolyte: it dissolves as intact, neutral K_3PO_4 molecules

✓ Practice 2: answer B



$$3 + 1 = 4 \text{ ions} \cdot \text{charge: } 3(1+) + (3-) = 0$$

A: solubility decides, not the anion; a soluble salt dissociates completely, polyatomic ion or not. C: the subscript counts three separate K^+ ions; no K_3^+ unit exists, and $1 + 1 = 2$ undercounts the ions. D: an ionic compound has no molecules; only separated ions enter the water.

 **Sense check:** Four ions from one formula unit, and the charges cancel: $3(1+) + (3-) = 0$. ✓

Practice 3: smelling salts

$(\text{NH}_4)_2\text{CO}_3$ dissolved in water
ammonium carbonate, the compound in smelling salts

Which equation shows ammonium carbonate dissolving in water?

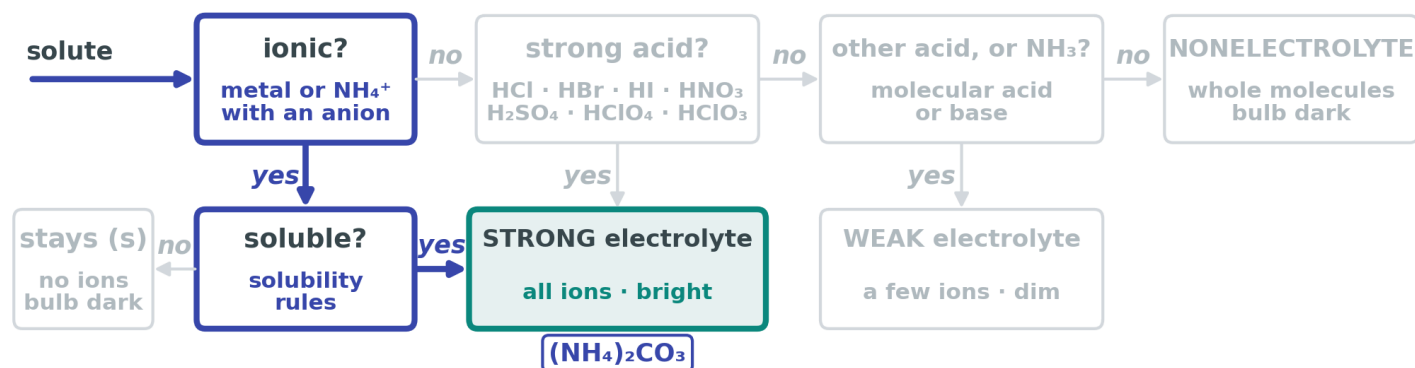
- A. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightleftharpoons 2 \text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- B. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- C. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow (\text{NH}_4)_2^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- D. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow 2 \text{NH}_4^+(\text{aq}) + \text{C}^{4+}(\text{aq}) + 3 \text{O}^{2-}(\text{aq})$
- E. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow 2 \text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$

✓ Practice 3: answer E



NH_4^+ compounds: soluble · strong electrolyte · $2 + 1 = 3$ ions · charge: $2(1+) + (2-) = 0$

A used the weak-base arrow of NH_3 ; an ammonium salt dissociates completely. B dropped the coefficient: $(1+) + (2-) = 1-$. C welded two NH_4^+ into one ion. D broke carbonate into atoms, though $2(1+) + (4+) + 3(2-) = 0$.



🧠 **Sense check:** Both polyatomic ions leave whole; NH_4^+ makes the salt ionic and soluble. ✓



Worked example 3: ion concentrations

0.100 M AlBr_3 dissolved in water

M, molarity = mol of solute per liter of solution · wanted: the molarity of Br^-

Aluminum bromide dissolves freely. Every formula unit that dissolves releases its ions into the same liter. Find the concentration of Br^- in the solution.

✓ Worked example 3: solution

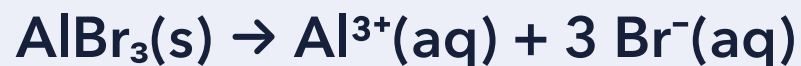


M = mol per liter of solution

Step 1 · Classify the solute

Step 2 · Write what water makes

Step 3 · Check the charge sum



1 + 3 = 4 ions · charge: (3+) + 3(1-) = 0 ✓

Ion molarity · multiply by the coefficient

Each liter holds 0.100 mol of dissolved AlBr_3 , and each mole releases 3 mol of Br^- .

$$0.100 \text{ mol AlBr}_3 \times \frac{3 \text{ mol Br}^-}{1 \text{ mol AlBr}_3} = \mathbf{0.300 \text{ mol Br}^-} \text{ per liter} = 0.300 \text{ M}$$

 **Sense check:** The subscript became a concentration ratio: 0.300 M Br^- against 0.100 M Al^{3+} .

Practice 4: an etching bath

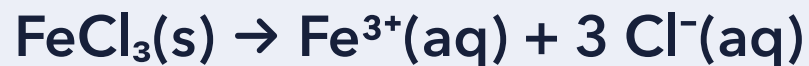
0.15 M FeCl_3 dissolved in water

given: 0.15 M FeCl_3 · wanted: the molarity of Cl^-

Circuit-board etching baths use iron(III) chloride. A bath is mixed to 0.15 M FeCl_3 . What is the molarity of Cl^- in the bath?

- A. 0.60
- B. 0.45
- C. 0.15
- D. 0.050

✓ Practice 4: answer B



soluble ionic: strong electrolyte · 1 + 3 = 4 ions · charge: (3+) + 3(1−) = 0 ✓

$$0.15 \text{ mol FeCl}_3 \times \frac{3 \text{ mol Cl}^{-}}{1 \text{ mol FeCl}_3} = \mathbf{0.45 \text{ mol Cl}^{-}} \text{ per liter} = 0.45 \text{ M (answer B)}$$

A counted every ion: $0.15 \times 4 = 0.60 \text{ M}$ is Fe^{3+} and Cl^{-} together. C skipped the ratio: $0.15 \times 1 = 0.15 \text{ M}$ is the Fe^{3+} molarity. D flipped the ratio: $0.15 \div 3 = 0.050 \text{ M}$.

🧠 **Sense check:** Three chlorides per formula unit: the chloride runs at three times the salt, $3 \times 0.15 = 0.45 \text{ M}$. ✓



Practice 5

$\text{Fe}_2(\text{SO}_4)_3$ dissolved in water

given: 0.60 M SO_4^{2-} required · wanted: the molarity of $\text{Fe}_2(\text{SO}_4)_3$

A water plant's dosing tank must reach 0.60 M sulfate ion, supplied by dissolving iron(III) sulfate. What molarity of $\text{Fe}_2(\text{SO}_4)_3$ does the tank need?

- A. 0.30
- B. 1.8
- C. 0.60
- D. 0.20

✓ Practice 5: answer D



$$2 + 3 = 5 \text{ ions} \cdot \text{charge: } 2(3+) + 3(2-) = 0 \checkmark$$

$$0.60 \text{ mol SO}_4^{2-} \times \frac{1 \text{ mol Fe}_2(\text{SO}_4)_3}{3 \text{ mol SO}_4^{2-}} = \mathbf{0.20 \text{ mol Fe}_2(\text{SO}_4)_3 \text{ per liter} = 0.20 \text{ M (answer D)}}$$

C skipped the ratio: $0.60 \times 1 = 0.60 \text{ M}$ assumes one sulfate per formula unit. B flipped the ratio: $0.60 \times 3 = 1.8 \text{ M}$, a tank at $1.8 \times 3 = 5.4 \text{ M}$ sulfate. A used iron's subscript: $0.60 \div 2 = 0.30 \text{ M}$.

 **Sense check:** Each formula unit releases three sulfates, so the salt runs at one third of the target: $3 \times 0.20 = 0.60 \text{ M}$ sulfate ✓.

Check yourself

1. K_2S dissolves freely in water. Name its class, write the dissociation equation, and check the ion tally and the charge sum.
2. A solution conducts, but only faintly. Which class is the solute, and what does the solution mostly contain?

Every (aq) compound in a reaction equation is shorthand for these separated ions. Which new pairings leave the water, and which ions only watch, is exactly what the solubility rules and the net ionic equation track. The **acids and bases** among these solutes get their own strong and weak lists, and those lists decide which of them count as fully separated.

Can you...?

- ☐ write a balanced equation with physical states from a description, changing coefficients only?
- ☐ classify a reaction as combination, decomposition, single displacement, double displacement, or combustion, and predict its products from the pattern?
- ☐ use the activity series to decide whether a single displacement runs with a metal, an acid, or water, and write no reaction when it does not?
- ☐ apply the solubility rules to predict a precipitate and write the equation with states?
- ☐ recognize a gas-forming reaction, replacing H_2CO_3 , H_2SO_3 , or NH_4OH with the gas and water?
- ☐ write molecular, complete ionic, and net ionic equations, and classify a solute as a strong, weak, or nonelectrolyte?

If any box stays empty, the practice site has a drill for it. 