

Acids & Bases

Preparation for General Chemistry · Dr. Karmach

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

- Recognize acids and bases by their properties and define them by the Arrhenius and Brønsted-Lowry definitions
- Identify the Brønsted-Lowry acid, base, and conjugate pairs in a reaction, and write a species' conjugate acid or base
- Classify acids and bases as strong or weak, write their ionization with the correct arrow, and predict the products of neutralization and gas-forming reactions
- Use K_w , $\text{pH} = -\log[\text{H}_3\text{O}^+]$, pOH , and $\text{pH} + \text{pOH} = 14$ to convert among $[\text{H}_3\text{O}^+]$, $[\text{OH}^-]$, pH , and pOH and label a solution acidic, basic, or neutral
- Find an unknown acid or base concentration from titration data

Today's route

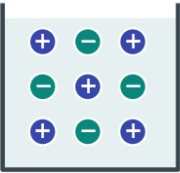
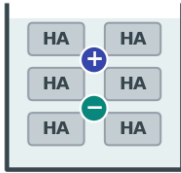
1. **Acids and Bases, Strong vs Weak**
2. **Acids and Bases, Definitions and Neutralization**
3. **The pH Scale**
4. **Electrolytes & Dissociation**
5. **Titration Calculations**

1 • Acids and Bases, Strong vs Weak

Classify any acid or base as strong or weak using the memorize-lists, write its ionization with the correct arrow ($\rightarrow$ for full, $\rightleftharpoons$ for partial), and predict the products of neutralization and gas-evolution reactions.

Strong is not the same as a lot

Strong vs Weak: the degree of ionization, not the amount

STRONG ionizes ~100% → strong electrolyte	WEAK ionizes partially ⇌ weak electrolyte
Strong acids: memorize these 7 HCl · HBr · HI (hydrohalic) HNO ₃ · H ₂ SO ₄ · HClO ₄ · HClO ₃ (oxoacids)	Weak acids: everything else CH ₃ COOH · HF · H ₂ CO ₃ · H ₃ PO ₄ (acetic, hydrofluoric, carbonic...) HCN · HNO ₂ · HClO · H ₂ S (HClO weak ⇌ HClO ₃ , HClO ₄ strong)
Strong bases: 5 + 3 = 8 group 1: LiOH NaOH KOH RbOH CsOH group 2 (heavy): Ca(OH) ₂ Sr(OH) ₂ Ba(OH) ₂	Weak bases NH ₃ (ammonia) CH ₃ NH ₂ and other amines
$\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$  every molecule splits into ions (≈ 100% ionized)	$\text{CH}_3\text{COOH} \rightleftharpoons \text{H}^+ + \text{CH}_3\text{COO}^-$  mostly intact molecules, few ions

Concentrated ≠ strong. Strength = the fraction that ionizes; concentration = how much is dissolved.

Stomach acid is hydrochloric acid, HCl, a *strong* acid, yet dilute. Strong and weak describe how completely an acid ionizes, not how much of it is dissolved.

Three reactions with an acid in them

$\text{Mg(s)} + \text{H}_2\text{SO}_4\text{(aq)}$: bubbles

single displacement · the gas is H_2

$\text{Na}_2\text{CO}_3\text{(aq)} + \text{HCl(aq)}$: bubbles

gas formation · washing soda meets hydrochloric acid

$\text{HNO}_3\text{(aq)} + \text{Ba(OH)}_2\text{(aq)}$: no bubbles, the beaker warms

neutralization · an acid meets a base

In all three, the acid hands over H^+ . Strong and weak describe how completely an acid does that in plain water, before any partner is added.

What makes something an acid or a base

Dissolved in water, an **acid** produces H^+ , carried as the hydronium ion H_3O^+ . A **base** produces OH^- .

acid $\rightarrow \text{H}^+$ (H_3O^+) in water · base $\rightarrow \text{OH}^-$ in water

Arrhenius definitions · Brønsted-Lowry widens them: an acid donates a proton (H^+), a base accepts one

Every acid here has an H to release; every hydroxide carries its OH^- .

Strong vs weak = the degree of ionization

Strong means essentially every molecule ionizes; **weak** means a small fraction. The $\rightleftharpoons$ arrow marks the reverse reaction: ions rejoin as fast as molecules split, so the mixture settles mostly intact.

$\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$ ($\approx 100\%$, one $\rightarrow$ arrow) · $\text{CH}_3\text{COOH} \rightleftharpoons \text{H}^+ + \text{CH}_3\text{COO}^-$ (partial, $\rightleftharpoons$)
strong = fully ionized = a strong electrolyte · weak = barely ionized = a weak electrolyte

What a 1 M acid bottle contains

a bottle labeled 1 M HCl actually has no HCl in it, but 1 M $\text{H}^+(\text{aq})$ and 1 M $\text{Cl}^-(\text{aq})$
strong acid: every molecule ionized · nothing left to match the label

a bottle labeled 1 M HA, where HA is a weak acid, actually has mostly HA in it and
only a small amount of $\text{H}^+(\text{aq})$ and $\text{A}^-(\text{aq})$
weak acid: the molecules survive · few ions

The label names what was dissolved. The strong or weak classification tells what the water holds now.

The seven strong acids: memorize them

Only **seven** common acids are strong; everything not on the list is weak. The list is measured, not deduced: these seven ionize essentially completely in water.



3 hydrohalic (HCl, HBr, HI) + 4 oxoacids (HNO₃, H₂SO₄, HClO₄, HClO₃) = 3 + 4 = 7

not on it: CH₃COOH · HF · H₂CO₃ · H₃PO₄ → all weak, partial ionization ($\rightleftharpoons$)
the structural reason for the split waits for equilibrium

Strong bases, and neutralization

The strong bases are the **metal hydroxides that ionize completely**: every group 1 hydroxide, plus the heavy group 2 hydroxides.

group 1: LiOH NaOH KOH RbOH CsOH · group 2 (heavy): Ca(OH)₂ Sr(OH)₂ Ba(OH)₂
5 + 3 = 8 strong bases · Ca(OH)₂ → Ca²⁺ + 2 OH⁻ releases 2 × 1 = 2 hydroxide ions · Ca(OH)₂ and Sr(OH)₂ barely dissolve (the chart says insoluble), but all that dissolves ionizes fully

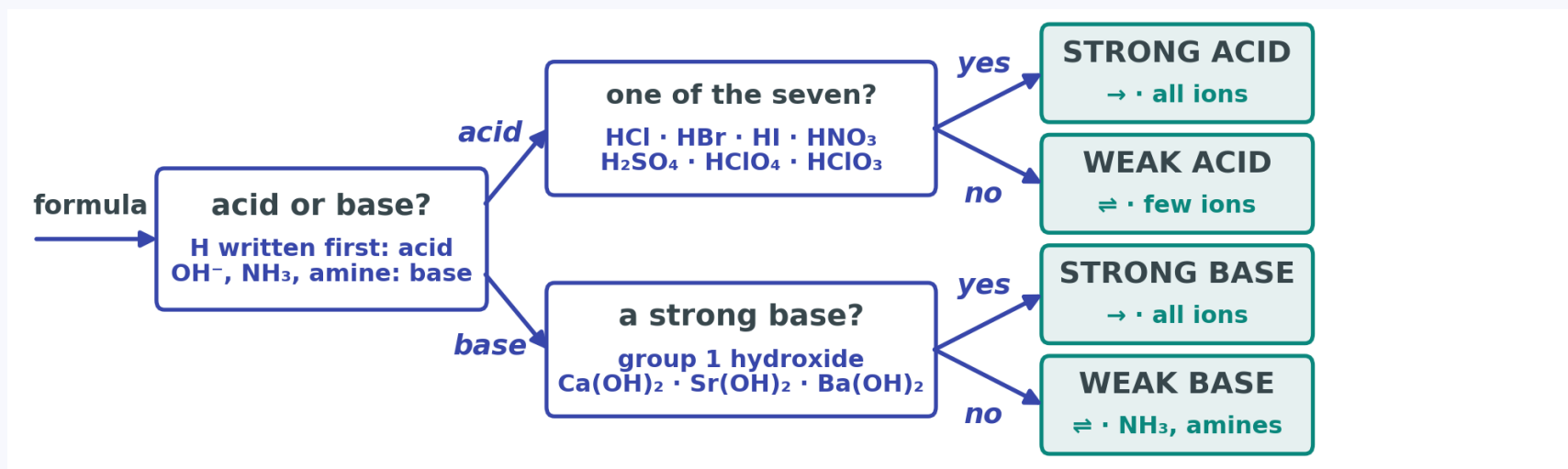


ammonia and amines make OH⁻ only partially: weak bases · an acid and a base neutralize to a salt plus water

Ammonia and the amines are **weak** bases. An acid and a base **neutralize** each other.

The method

1. **Acid or base?** An H to release: acid. Hydroxide or NH_3 /amine: base.
2. **On a memorize list?** Listed: strong. Not listed: weak.
3. **Pick the arrow.** Strong ionizes fully: $\rightarrow$. Weak, partially: $\rightleftharpoons$.
4. **Ignore concentration.** Strength is the fraction ionized.





Guided example: lactic acid

$\text{HC}_3\text{H}_5\text{O}_3$ dissolved in water

given: lactic acid · wanted: strong or weak, and its ionization with the right arrow

Lactic acid sours milk and builds up in hard-working muscle. Classify it and write its ionization.

Each method step is one move. Name the step, then make the move.

✓ Guided example: classify

$\text{HC}_3\text{H}_5\text{O}_3$ dissolved in water

given: lactic acid · wanted: strong or weak, and its ionization

Step 1 · Acid or base?

$\text{HC}_3\text{H}_5\text{O}_3$: an H written first

move 1 · the H in front is the one it releases · answer: an acid

Step 2 · On a memorize list?

$\text{HCl} \cdot \text{HBr} \cdot \text{HI} \cdot \text{HNO}_3 \cdot \text{H}_2\text{SO}_4 \cdot \text{HClO}_4 \cdot \text{HClO}_3$

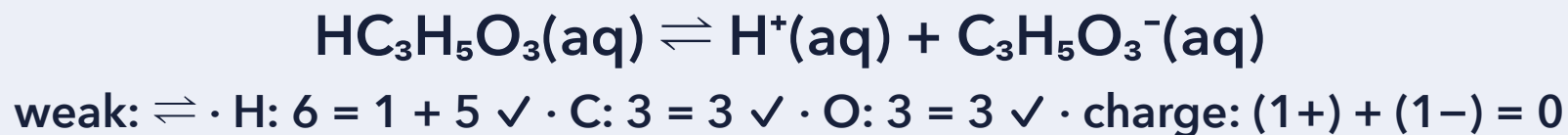
move 2 · $\text{HC}_3\text{H}_5\text{O}_3$ is not among the seven · answer: weak

🧠 **Sense check:** An acid, and off the list: a weak acid. The list decided it, not the look of the formula. ✓

✓ Guided example: write the ionization

$\text{HC}_3\text{H}_5\text{O}_3$ dissolved in water
classified: an acid, not among the seven → weak

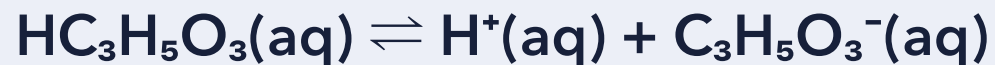
Step 3 • Pick the arrow



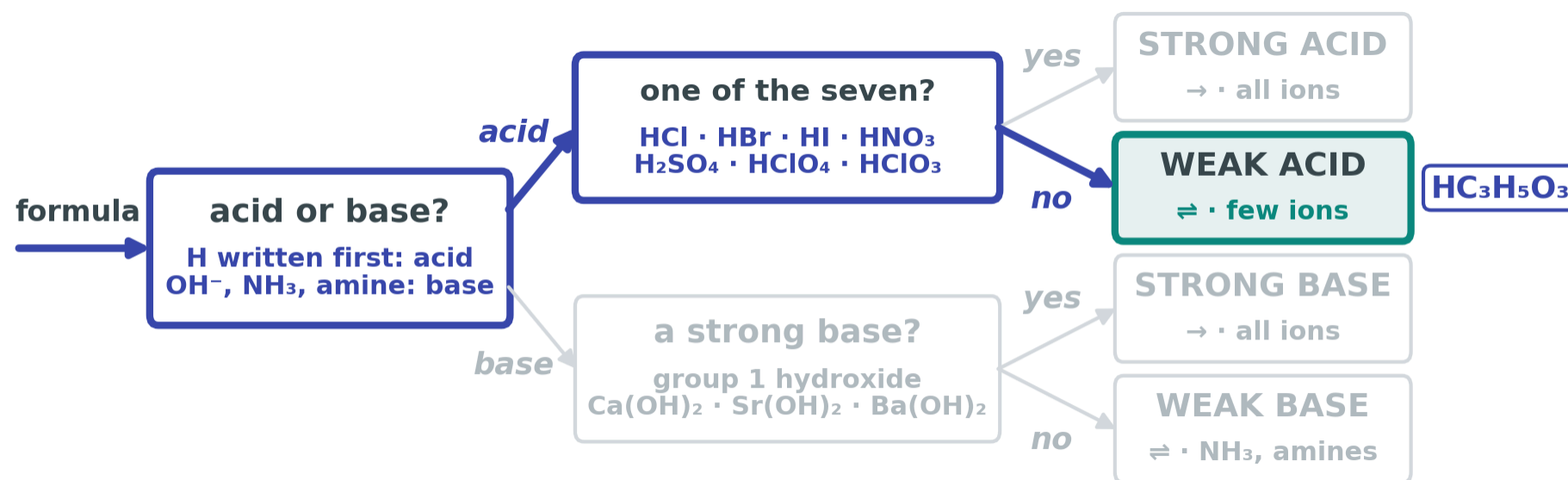
Step 4 • Ignore concentration

 **Sense check:** Four named steps, four moves: acid, off the list, $\rightleftharpoons$, concentration ignored. Only a small fraction of the molecules release H^+ . ✓

✓ Guided example: the route on the chart



acid: yes · one of the seven: no · found: weak acid, $\rightleftharpoons$



🧠 **Sense check:** One branch and one list check. The base questions never came up. ✓



Worked example 1: classify three species



for each: strong or weak? which electrolyte? which arrow: $\rightarrow$ or $\rightleftharpoons$?

Nitric acid, hydrofluoric acid, and calcium hydroxide. Check each against the memorize-lists, then write how it behaves in water.

✓ Worked example 1: solution

HNO₃ · on the strong-acid list



full ionization, single $\rightarrow$ arrow · $1 + 1 = 2$ ions per formula unit

HF · not on the list $\rightarrow$ weak



mostly intact HF molecules · the $\rightleftharpoons$ arrow marks partial ionization

Ca(OH)₂ · a heavy group 2 hydroxide $\rightarrow$ strong base



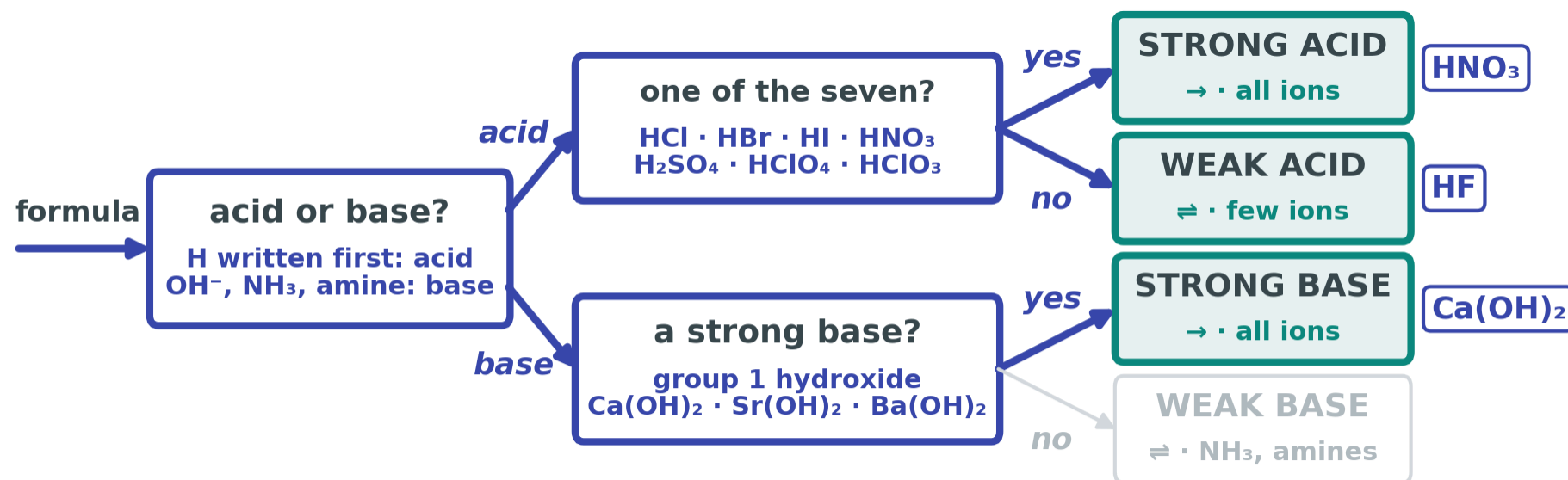
strong base, strong electrolyte · $1 + 2 = 3$ ions, of which $2 \times 1 = 2$ are OH⁻

 **Sense check:** On the lists, HNO₃ and Ca(OH)₂ ionize fully ($\rightarrow$); HF is off the list, mostly intact ($\rightleftharpoons$).

✓ Worked example 1: the route on the chart



HNO_3 : acid, one of the seven · HF : acid, not one of the seven · Ca(OH)_2 : base, a strong base



🧠 **Sense check:** Three formulas leave by three exits. Only the two lists decided strong or weak. ✓

⚠ Where this goes wrong

"HF is strong because F is so electronegative." Electronegativity does not decide it: HF is simply not on the list of seven, so it is weak ($\rightleftharpoons$).

"Concentrated means strong." Concentration is amount dissolved; strength is the fraction ionized. 10 M acetic acid is still weak; 0.01 M HCl is still strong.

Sulfuric $\leftrightarrow$ acetic mix-up. H_2SO_4 is on the list (strong, $\rightarrow$); acetic acid CH_3COOH is not (weak, $\rightleftharpoons$). Being an acid does not make it strong.

" NH_3 can't be a base: it has no OH." It makes OH^- by pulling H^+ off water: $\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-$: a weak base.

Practice 1: spot the exception

Three of these ionize essentially 100% in water. Which one is **not** a strong acid?

- A. HClO_4
- B. HCl
- C. HClO
- D. HNO_3

✓ Practice 1: answer C

$\text{HClO} \rightleftharpoons \text{H}^+ + \text{ClO}^-$: a weak acid (answer C)

HClO (hypochlorous) is not among the seven; HClO_4 , HCl , HNO_3 all are

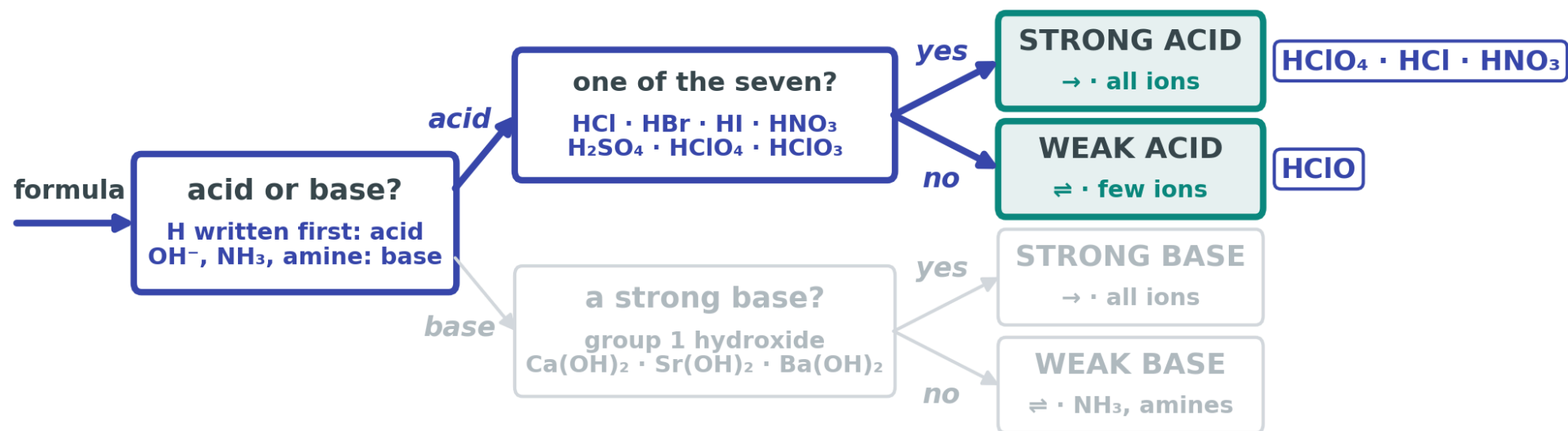
Watch the chlorine oxoacids: HClO_4 (perchloric) and HClO_3 (chloric) are on the strong list, but HClO (hypochlorous) is **weak**: it ionizes only partially ($\rightleftharpoons$). HCl and HNO_3 are strong ($\rightarrow$).

 **Sense check:** Two fewer oxygens separate HClO_3 , strong, from HClO , weak. Classify from the list, not from the look of the formula.

✓ Practice 1: the route on the chart



all four: acids · HClO_4 , HCl , HNO_3 : one of the seven · HClO : not one of the seven



🧠 **Sense check:** All four take the acid branch. The list check splits them: three strong exits, one weak. ✓

Practice 2: label four species

$\text{HClO}_3 \cdot \text{HCOOH} \cdot \text{Ba}(\text{OH})_2 \cdot \text{C}_2\text{H}_5\text{NH}_2$
chloric acid · formic acid · barium hydroxide · ethylamine

Which labels, in order, fit the four species in water?

- A. strong acid · weak acid · weak base · weak base
- B. weak acid · weak acid · strong base · weak base
- C. strong acid · weak base · strong base · weak base
- D. strong acid · weak acid · strong base · weak acid
- E. strong acid · weak acid · strong base · weak base

✓ Practice 2: answer E



HClO_3 : one of the seven, strong acid · HCOOH : the H of $-\text{COOH}$ leaves, off the list, weak acid



$\text{Ba}(\text{OH})_2$: heavy group 2 hydroxide, strong base, $(2+) + 2(1-) = 0$ · ethylamine: an amine, weak base, H:
 $7 + 2 = 9 = 8 + 1$ ✓

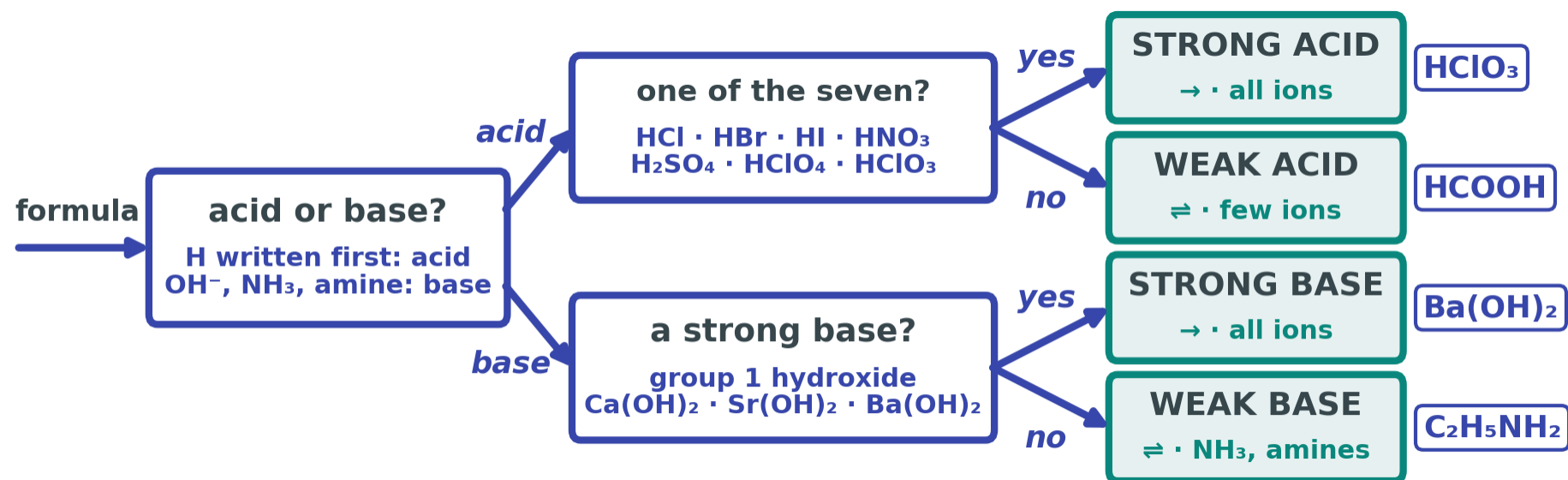
A stopped the strong-base list at group 1; the heavy group 2 hydroxides, $\text{Ba}(\text{OH})_2$ among them, ionize fully too. B mixed up chloric acid HClO_3 with hypochlorous acid HClO . C read the OH inside $-\text{COOH}$ as hydroxide. D counted an amine's H atoms as acidic; its nitrogen takes H^+ from water.

 **Sense check:** Every call came from a list or a formula feature. The strong-base list runs past group 1. ✓

✓ Practice 2: the route on the chart

$\text{HClO}_3 \cdot \text{HCOOH} \cdot \text{Ba}(\text{OH})_2 \cdot \text{C}_2\text{H}_5\text{NH}_2$ (answer E)

two acids: one on the list, one off · two bases: one on the list, one amine



🧠 **Sense check:** Four species leave by all four exits. Each took exactly two questions. ✓



Extra practice 1



nitrous acid: not on the list of seven · sodium nitrite: a soluble salt

Two bottles, same concentration. Which solution has the higher ion concentration?

- A. 1.0 M HNO_2 : it is an acid, and acids ionize completely
- B. 1.0 M NaNO_2 : a soluble salt dissociates completely, so it puts far more ions in the water
- C. They are equal: both dissolve completely, so both separate completely
- D. Neither: both dissolve as whole molecules

✓ Extra practice 1: answer B

$\text{NaNO}_2(\text{s}) \rightarrow \text{Na}^+(\text{aq}) + \text{NO}_2^-(\text{aq}) \cdot \text{HNO}_2(\text{aq}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{NO}_2^-(\text{aq})$ (answer B)
the salt delivers $1.0 + 1.0 = 2.0$ M of ions · the weak acid delivers far less: most HNO_2 stays whole

A assumes every acid ionizes fully; only the seven on the list do, and HNO_2 is not one. C reads dissolves completely as ionizes completely; both dissolve fully, but only the salt separates fully. D misclassifies NaNO_2 : a metal with a polyatomic anion is ionic, and a soluble ionic compound always dissociates.

 **Sense check:** Same NO_2^- anion in both bottles. The partner decides the ion count: Na^+ lets go completely; the acid's H does not.



Extra practice 2

1 M HCl · 1 M HF

same concentration · acidity tracks $[\text{H}_3\text{O}^+]$

Which solution is more acidic?

- A. 1 M HCl: strong, fully ionized, so its $[\text{H}_3\text{O}^+]$ is the full 1 M; HF ionizes only slightly
- B. 1 M HF: fluorine is more electronegative, so HF releases its H^+ more readily
- C. They are equally acidic: both hold 1 M of dissolved acid
- D. 1 M HF: weak means the H^+ is weakly held, so it comes off more easily

✓ Extra practice 2: answer A

$\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$ (all of it) · $\text{HF} \rightleftharpoons \text{H}^+ + \text{F}^-$ (a small fraction) (answer A)

1 M HCl: $1 \times 1 = 1$ M H_3O^+ · 1 M HF: far less

B ranks by electronegativity; the list of seven is measured behavior, and HF is not on it. C confuses concentration with strength: both bottles hold 1 M of acid, but they deliver very different amounts of H_3O^+ . D inverts the vocabulary: weak describes the fraction ionized, not a loose grip on H^+ ; the weak acid is the one that keeps its H.

 **Sense check:** Strong and weak are measured ionization, never electronegativity and never concentration.

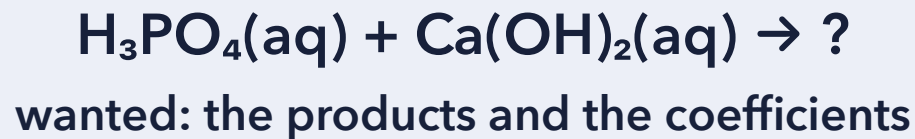
Worked example 2: predict and balance a neutralization



acid + base $\rightarrow$ salt + water · wanted: the products and the coefficients

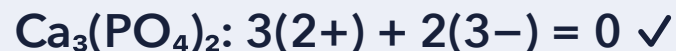
Phosphoric acid meets calcium hydroxide. One HCl releases one H^+ : monoprotic. H_2SO_4 releases two: diprotic. H_3PO_4 releases three: triprotic. Predict both products, then balance.

✓ Worked example 2: the products



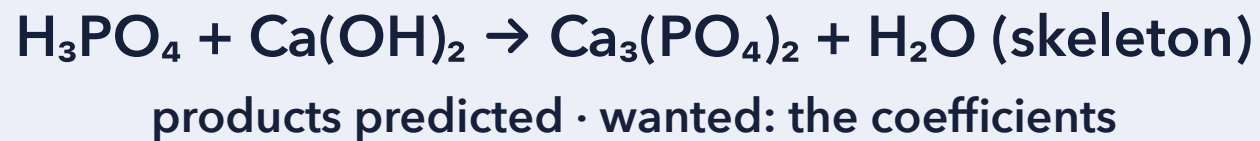
Predict the products

The salt pairs Ca^{2+} with PO_4^{3-} ; charge balance builds $\text{Ca}_3(\text{PO}_4)_2$. The other product of every neutralization is water.

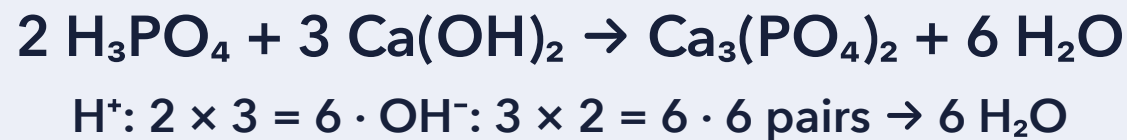


 **Sense check:** The salt's formula comes from the ion charges, never from the coefficients: the products must be neutral before any balancing starts.

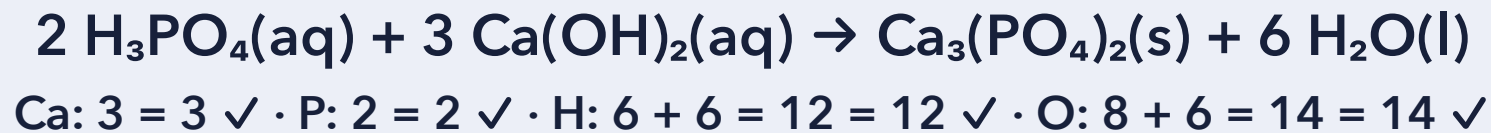
✓ Worked example 2: the coefficients



Match H^+ to OH^-



Recheck every count

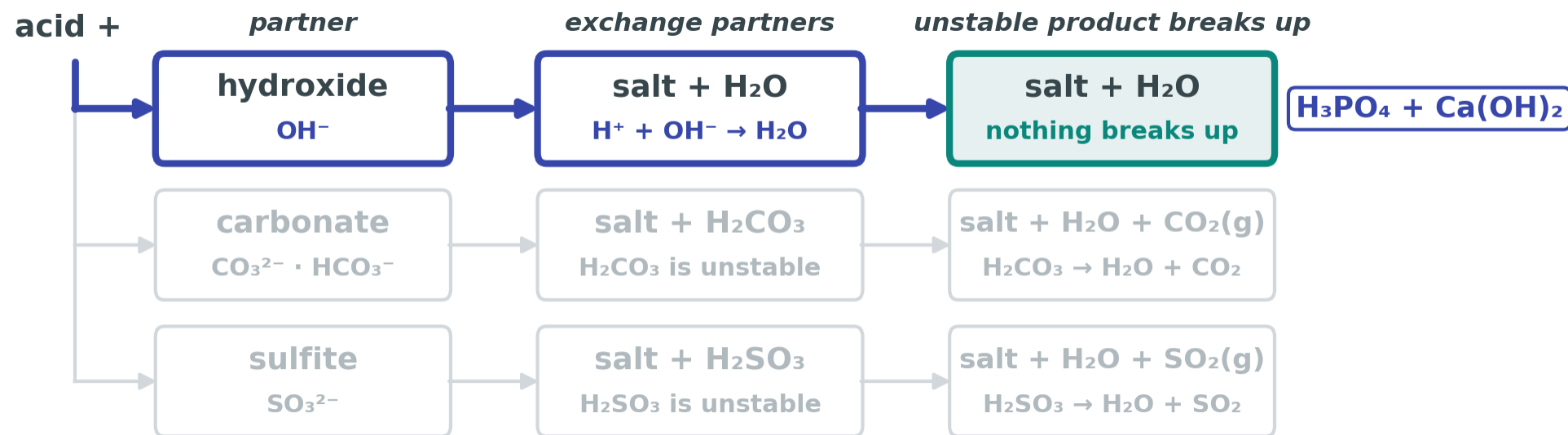


 **Sense check:** The coefficients 2 and 3 came from matching six H^+ to six OH^- , and one water forms per pair: $6 \text{H}_2\text{O}$.

✓ Worked example 2: the route on the chart



partner: a hydroxide · exchange: salt + water · nothing breaks up



🧠 **Sense check:** A hydroxide partner stops after the exchange: a salt and water, no gas. ✓



Practice 3: an acid and a hydroxide

hydroiodic acid + barium hydroxide $\rightarrow$?

both solutions clear · wanted: the balanced equation, with states

Hydroiodic acid is mixed with a solution of barium hydroxide. Which equation shows the reaction?

- A. $\text{HI}(\text{aq}) + \text{Ba}(\text{OH})_2(\text{aq}) \rightarrow \text{BaI}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- B. $\text{HI}(\text{aq}) + \text{BaOH}(\text{aq}) \rightarrow \text{BaI}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
- C. $2 \text{HI}(\text{aq}) + \text{Ba}(\text{OH})_2(\text{aq}) \rightarrow \text{BaI}_2(\text{s}) + 2 \text{H}_2\text{O}(\text{l})$
- D. $2 \text{HI}(\text{aq}) + \text{Ba}(\text{OH})_2(\text{aq}) \rightarrow \text{BaI}_2(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})$

✓ Practice 3: answer D



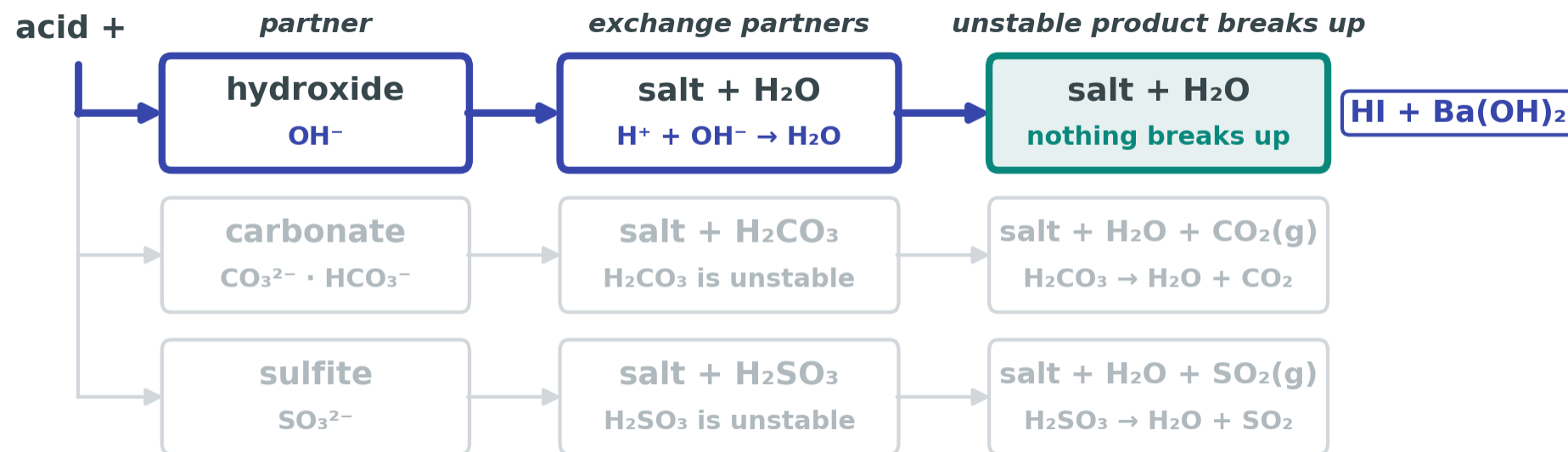
A skipped matching H^+ to OH^- : $\text{I}: 1 \neq 2$, and $\text{H}: 1 + 2 = 3 \neq 2$. B wrote barium hydroxide as BaOH : $(2+) + (1-) = 1+$, and Ba^{2+} needs two OH^- . C called BaI_2 insoluble; iodides dissolve except with Ag^+ , Pb^{2+} , Hg_2^{2+} .

🧠 **Sense check:** Two H^+ meet two OH^- : two waters, and the salt stays dissolved. ✓

✓ Practice 3: the route on the chart



partner: a hydroxide · exchange: salt + water · nothing breaks up



🧠 **Sense check:** The same lane as the phosphoric acid example: a hydroxide partner ends at salt plus water. ✓



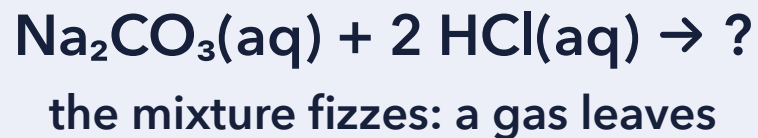
Worked example 3: acid plus a carbonate



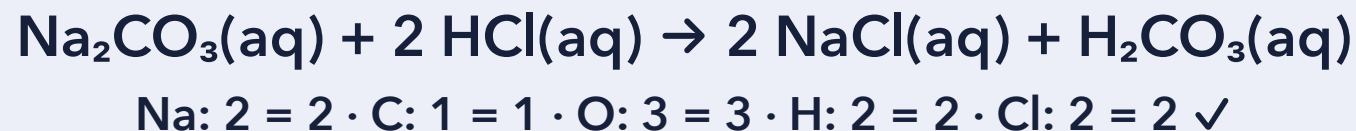
wanted: the products, found in two steps

Washing soda meets hydrochloric acid, and the mixture fizzes. The gas is the product to explain. Work the exchange first, then watch what the exchange product does.

✓ Worked example 3: the exchange



First reaction • exchange partners



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 3: the gas appears



the exchange product H_2CO_3 cannot survive in water

Second reaction • the unstable product breaks up



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

Overall



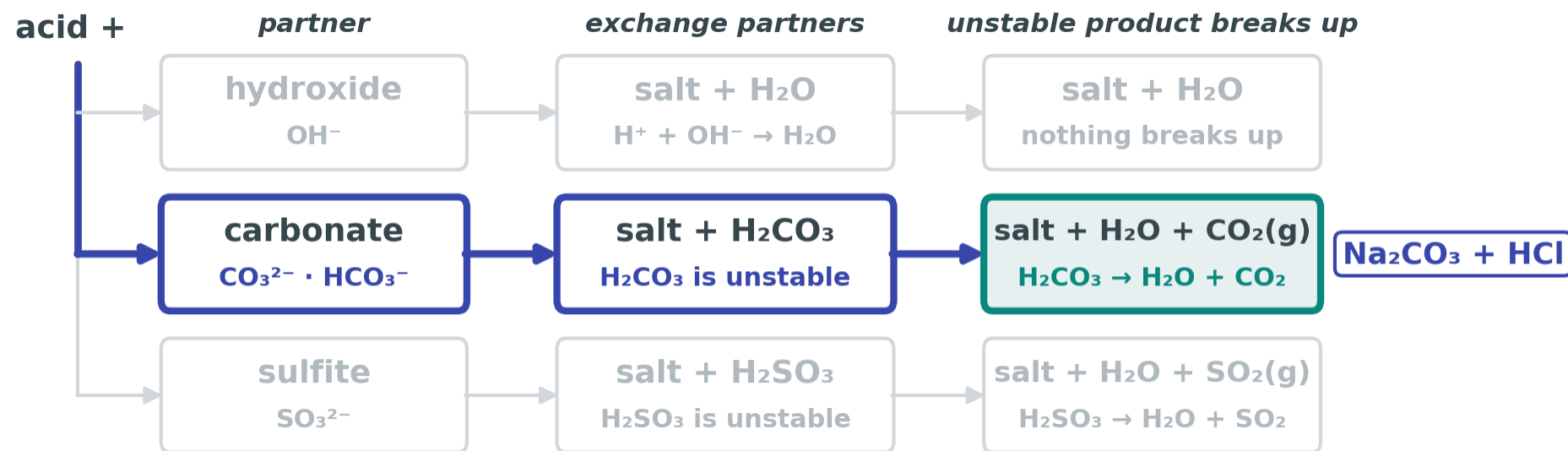
Na: 2 = 2 • C: 1 = 1 • O: 3 = 3 • H: 2 = 2 • Cl: 2 = 2 ✓

 **Sense check:** Acid plus a carbonate or bicarbonate always ends here: CO_2 , water, and a salt. The two-step explains the fizz that one overall line hides.

✓ Worked example 3: the route on the chart



partner: a carbonate · exchange: $\text{NaCl} + \text{H}_2\text{CO}_3$ · H_2CO_3 breaks up



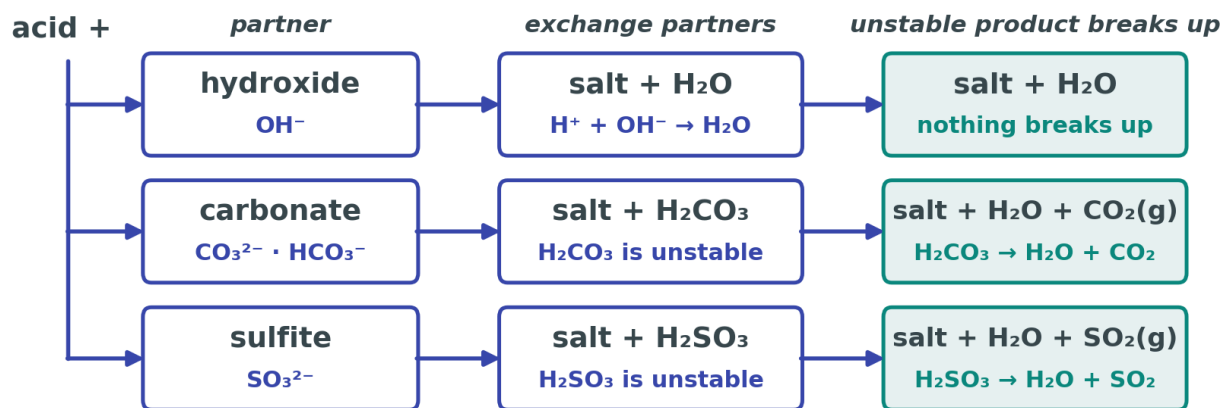
🧠 **Sense check:** A carbonate partner runs the full lane: the exchange, then the breakup into water and CO_2 . ✓

Three products that never survive



memorize all three · each breaks into water plus a gas the moment it forms

Three exchange products are unstable. When one appears among the products, replace it with its water and gas. Acid plus a carbonate or bicarbonate always gives CO_2 , water, and a salt.



Your turn: acid plus a sulfite



exchange first · then check the unstable-products list

step	your work
exchange partners	2 KCl + _____
unstable product breaks up	$\text{H}_2\text{SO}_3 \rightarrow \text{H}_2\text{O}(\text{l}) + \text{_____}$
overall equation	$\text{K}_2\text{SO}_3(\text{aq}) + 2 \text{HCl}(\text{aq}) \rightarrow 2 \text{KCl}(\text{aq}) + \text{_____} + \text{_____}$

Complete all three lines.



 **Sense check:** An acid meeting a sulfite releases SO_2 , the sharp smell of a struck match.



Practice 4



baking soda + vinegar's acetic acid

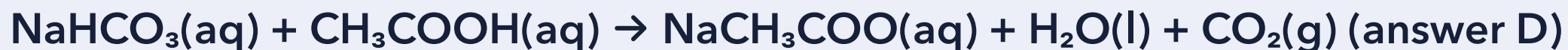
Baking soda is stirred into vinegar. Which products form?

- A. $\text{NaCH}_3\text{COO}(\text{aq}) + \text{H}_2\text{CO}_3(\text{aq})$
- B. $\text{NaCH}_3\text{COO}(\text{aq}) + \text{H}_2(\text{g})$
- C. No reaction: acetic acid is weak, so its molecules stay whole
- D. $\text{NaCH}_3\text{COO}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$

✓ Practice 4: answer D



first reaction: exchange partners · H_2CO_3 is on the never-survive list



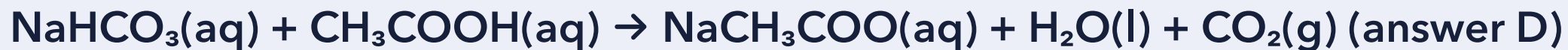
Na: 1 = 1 · C: 1 + 2 = 3 = 2 + 1 · H: 1 + 4 = 5 = 3 + 2 · O: 3 + 2 = 5 = 2 + 1 + 2 ✓

A stopped at the exchange: H_2CO_3 breaks into H_2O and CO_2 the moment it forms. B expects H_2 , the gas an acid releases from an active metal; a bicarbonate trades partners instead. C reads weak as unreactive: weak describes the fraction ionized, and acid plus a carbonate or bicarbonate always gives CO_2 , water, and a salt.

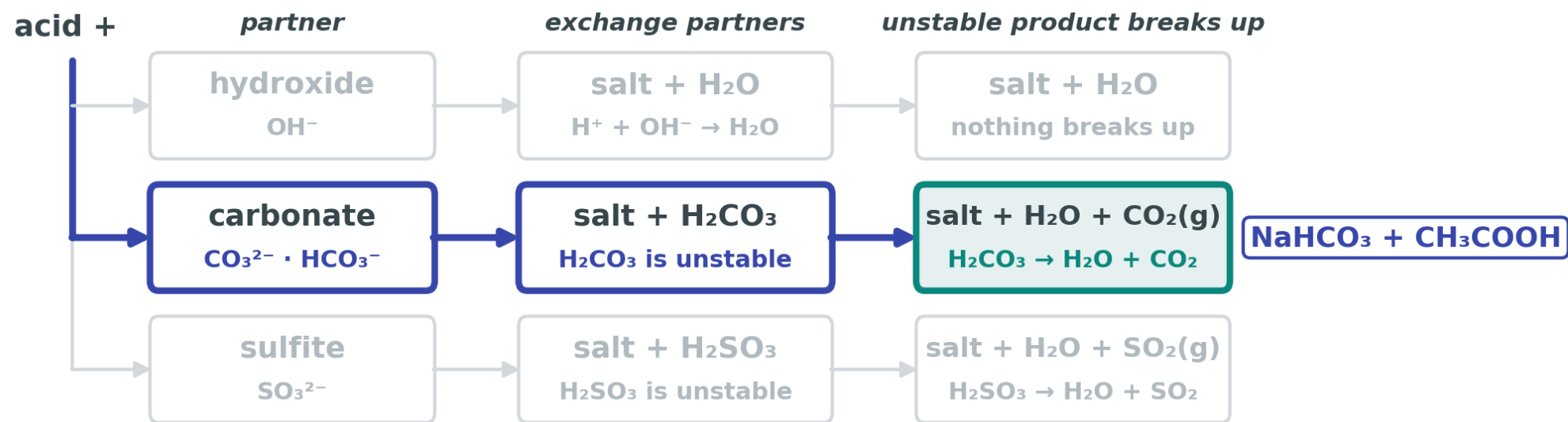


Sense check: The fizz in the cup is the CO_2 from the H_2CO_3 breakup, even with a weak acid.

✓ Practice 4: the route on the chart



partner: a bicarbonate · exchange: $\text{NaCH}_3\text{COO} + \text{H}_2\text{CO}_3$ · H_2CO_3 breaks up



🧠 **Sense check:** A weak acid takes the same lane as HCl. The partner picks the lane; the acid's strength does not. ✓



Practice 5: bicarbonate and sulfuric acid

potassium bicarbonate + sulfuric acid $\rightarrow$?

both solutions clear · wanted: the balanced overall equation, with states

Potassium bicarbonate solution is poured into sulfuric acid. Which equation shows the overall reaction?

- A. $2 \text{KHCO}_3(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + 2 \text{H}_2\text{CO}_3(\text{aq})$
- B. $2 \text{KHCO}_3(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + 2 \text{H}_2\text{O}(\text{l}) + 2 \text{CO}_2(\text{g})$
- C. $\text{KHCO}_3(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{KSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
- D. $2 \text{KHCO}_3(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
- E. No reaction: K_2SO_4 is soluble, so nothing leaves the solution

✓ Practice 5: answer B



first reaction: exchange partners · the two H^+ of H_2SO_4 go to two HCO_3^- · H_2CO_3 never survives



K: $2 = 2$ · H: $2 + 2 = 4 = 4$ · C: $2 = 2$ · S: $1 = 1$ · O: $2 \times 3 + 4 = 10 = 4 + 2 + 4$ ✓

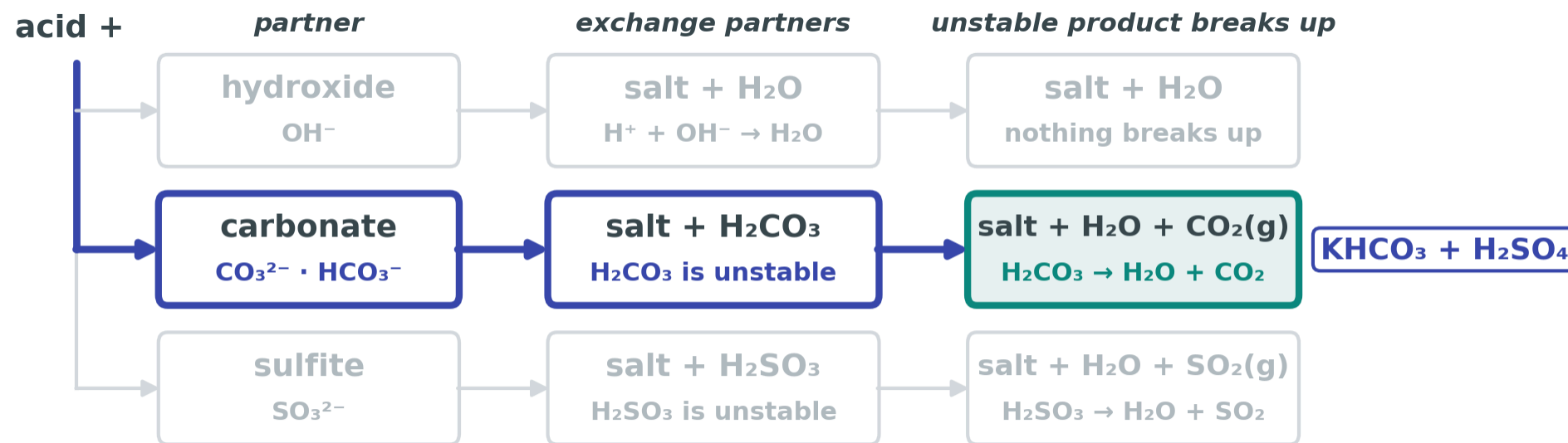
A stopped at the exchange. C swapped partners one for one: KSO_4 strands a charge, $(1+) + (2-) = 1-$. D dropped the 2 in the breakup: C: $2 \neq 1$, O: $10 \neq 4 + 1 + 2 = 7$. E looked only for a precipitate; a gas leaving also drives the reaction.

 **Sense check:** Each bicarbonate makes one H_2CO_3 , and each H_2CO_3 makes one CO_2 : the 2 carries through to the gas. ✓

✓ Practice 5: the route on the chart



partner: a bicarbonate · exchange: $\text{K}_2\text{SO}_4 + 2 \text{H}_2\text{CO}_3$ · each H_2CO_3 breaks up



🧠 **Sense check:** A diprotic acid runs the same lane twice per formula unit: two H_2CO_3 , two CO_2 . ✓

Check yourself

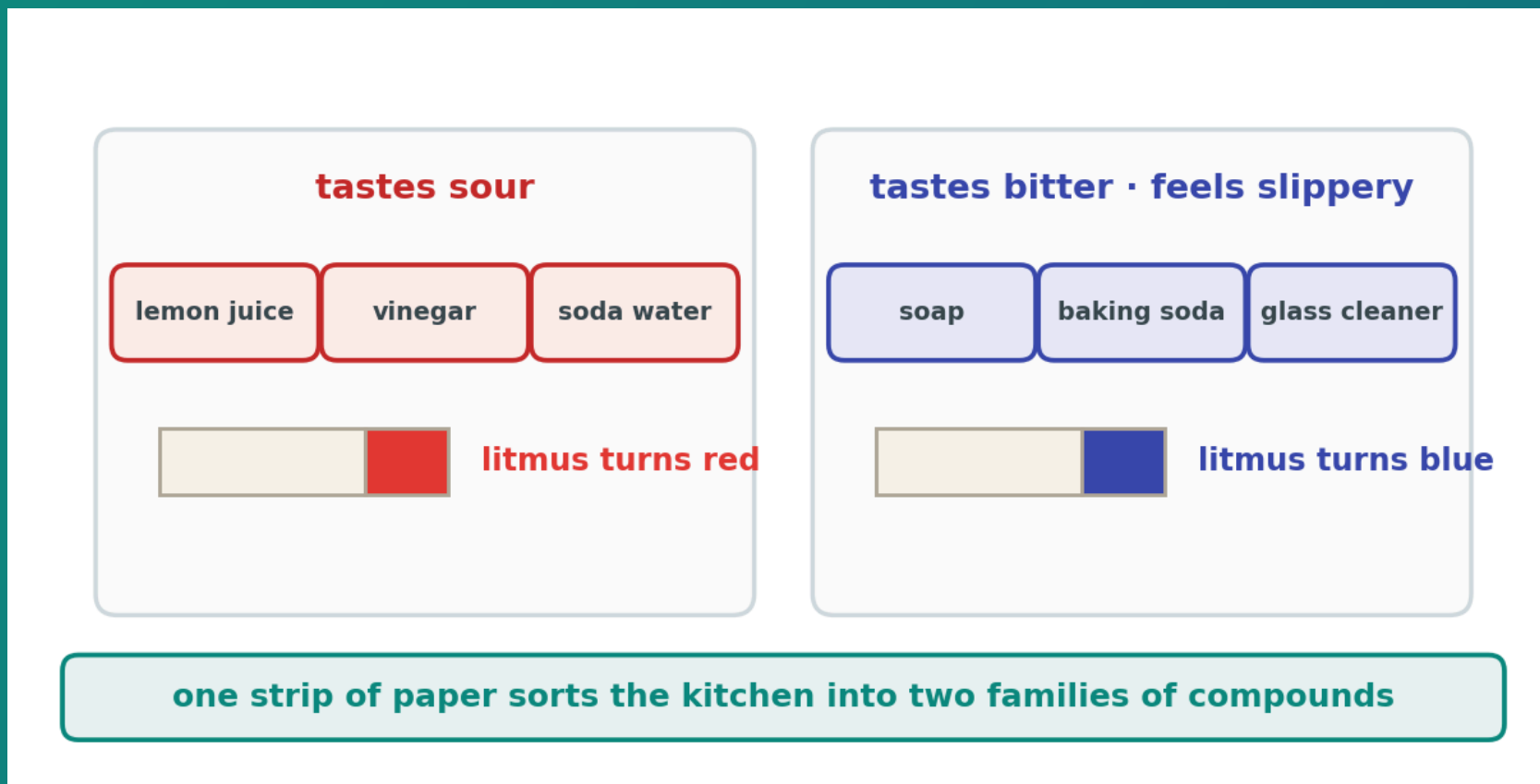
1. Classify each and give its arrow: KOH, H₂CO₃, HI, NH₃.
2. Why is a 12 M solution of acetic acid still called a *weak* acid, while very dilute HBr is *strong*?

Every dissolved ion here carries a definite charge, and the strong lists say which solutes actually deliver those ions. Next comes the question under all of it: what makes a substance an acid or a base, and which partner hands the H⁺ to which.

2 · Acids and Bases, Definitions and Neutralization

Recognize an acid or a base from its properties, state the Arrhenius and Brønsted-Lowry definitions, identify the proton donor and acceptor in an equation, and predict the salt and water a neutralization forms.

Sour, bitter, slippery



Lemon juice and vinegar taste sour. Soap and baking soda taste bitter and feel slippery. A strip of litmus paper sorts household chemicals into the same two families.

What acid reactions share



review · acid + hydroxide: salt + water · acid + carbonate: salt + water + CO_2 , from $\text{H}_2\text{CO}_3 \rightarrow \text{H}_2\text{O} + \text{CO}_2$ ·
H: $1 + 1 = 2$ ✓ · H: $2 = 2$ ✓

In each, the acid's H leaves as H^+ and lands on a partner. OH^- becomes H_2O . CO_3^{2-} becomes H_2CO_3 .

Which reactant lost its H in the first reaction?

 **Sense check:** HBr. Its H now sits in H_2O . ✓

Two families of compounds

Acids share one property set; bases share another. One cause: every member of a family makes the same ion in water.

acids: taste sour · turn litmus red · react with active metals, releasing H₂ gas

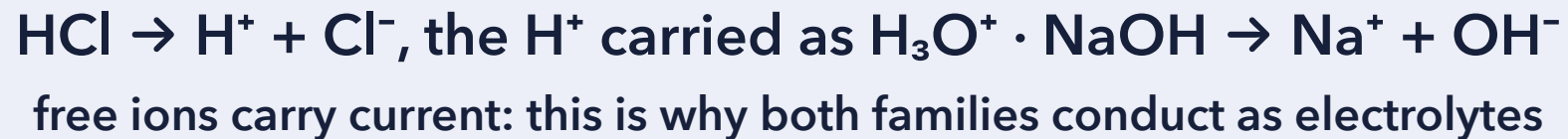
bases: taste bitter · feel slippery · turn litmus blue

both families: dissolved, they conduct electricity

Taste and touch are never tests in a laboratory. Litmus does that work safely.

Arrhenius: the ion each family makes

Dissolved in water, an Arrhenius **acid produces H^+** , which rides on a water molecule as the hydronium ion H_3O^+ . An Arrhenius **base produces OH^-** , the hydroxide ion.



Why H^+ is called a proton

H atom: 1 proton + 1 electron · H^+ ion: 1 proton, 0 electrons

an H^+ ion is a bare proton · donating a proton = giving away H^+

Moving one H^+ changes two things together: one H in the formula and one unit of charge.
Apply it to water.



H: $2 - 1 = 1$, charge $0 - 1 = 1-$ · H: $2 + 1 = 3$, charge $0 + 1 = 1+$

Brønsted-Lowry: donor and acceptor

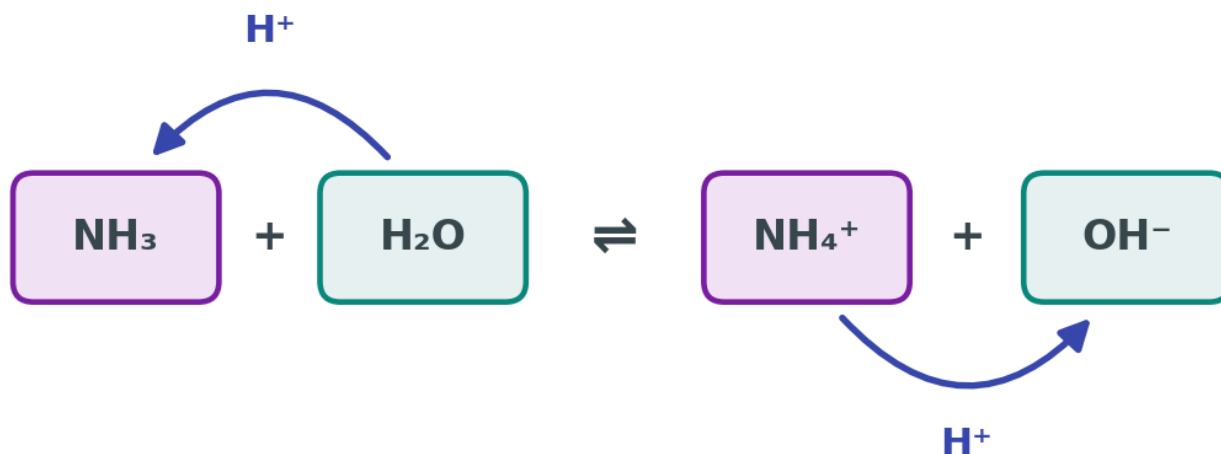
A wider definition tracks the H^+ itself. A Brønsted-Lowry **acid donates a proton**; a **base accepts one**. Every Arrhenius acid or base still qualifies, and the label now depends on the reaction.



HCl loses the H^+ : donor, the acid · H_2O gains it: acceptor, the base

Conjugate pairs

forward: H_2O donates the H^+ (the acid) · NH_3 accepts it (the base)



reverse: NH_4^+ donates the H^+ (the acid) · OH^- accepts it (the base)

conjugate pairs, each differing by one H^+ : $\text{NH}_3 / \text{NH}_4^+$ and $\text{H}_2\text{O} / \text{OH}^-$

NH_3 holds no OH^- , yet it accepts H^+ from water: a base. The $\rightleftharpoons$ transfer also runs backward. Species differing by one H^+ form a **conjugate acid-base pair**.

Your turn: write the conjugate

conjugate base = the acid minus one H^+ : charge drops by 1

conjugate acid = the base plus one H^+ : charge rises by 1

given	wanted	answer
HSO_4^-	conjugate base	_____
H_2PO_4^-	conjugate base	_____
HCO_3^-	conjugate acid	_____
OH^-	conjugate acid	_____

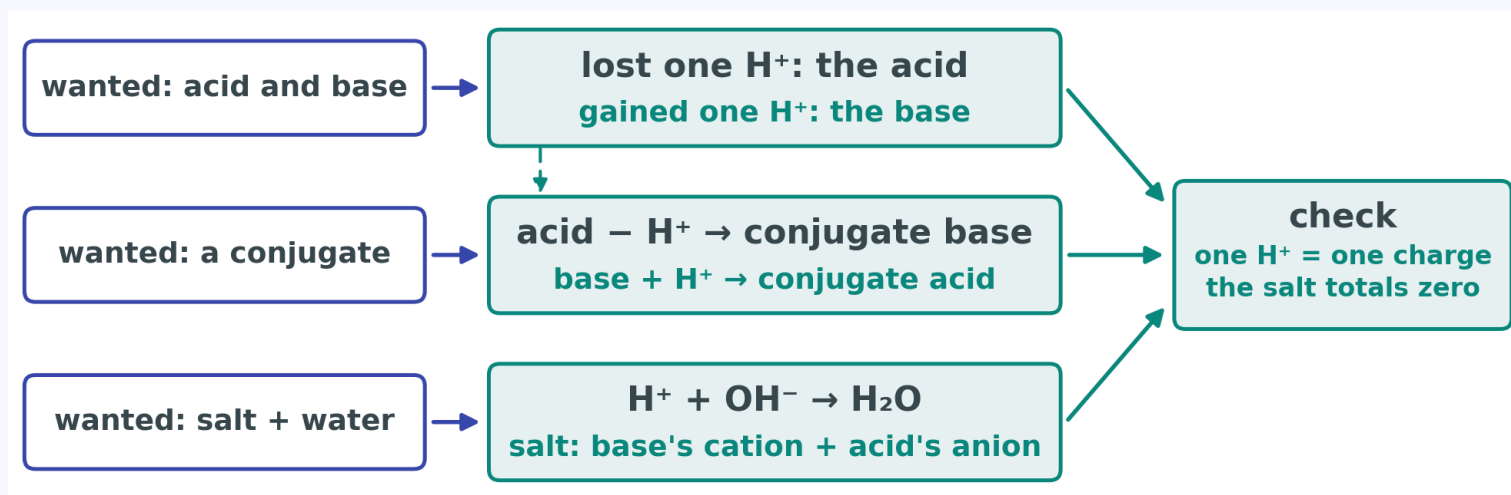
Change one H and the charge by one, together.



each H removed takes a $1+$ with it: $1-$ becomes $2-$ · each H added brings a $1+$: $1-$ becomes 0

The method

1. **Track the proton.** Which species lost an H^+ ? Which gained?
2. **Label donor and acceptor.** Donor = acid, acceptor = base.
3. **Predict the products.** Base's cation + acid's anion = the salt; $\text{H}^+ + \text{OH}^- = \text{water}$.
4. **Balance and check.**





Guided example: green apples



H: $6 + 2 = 3 + 5$ ✓ · wanted: the acid, the base, the conjugate acid, the conjugate base

Malic acid, $\text{H}_2\text{C}_4\text{H}_4\text{O}_5$, gives green apples their tartness. It hands one H^+ to water. Label all four species.

Match each reactant to the product it becomes: same atoms, one H different.

✓ Guided example: solution



wanted: acid, base, conjugate acid, conjugate base

Step 1 · Track the proton



charge: $0 \rightarrow 1-$ and $0 \rightarrow 1+$ · one H^+ moved from $\text{H}_2\text{C}_4\text{H}_4\text{O}_5$ to H_2O

Step 2 · Label donor and acceptor

Name the conjugates

acid $\text{H}_2\text{C}_4\text{H}_4\text{O}_5 \rightarrow \text{HC}_4\text{H}_4\text{O}_5^-$, its conjugate base · base $\text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+$, its conjugate acid

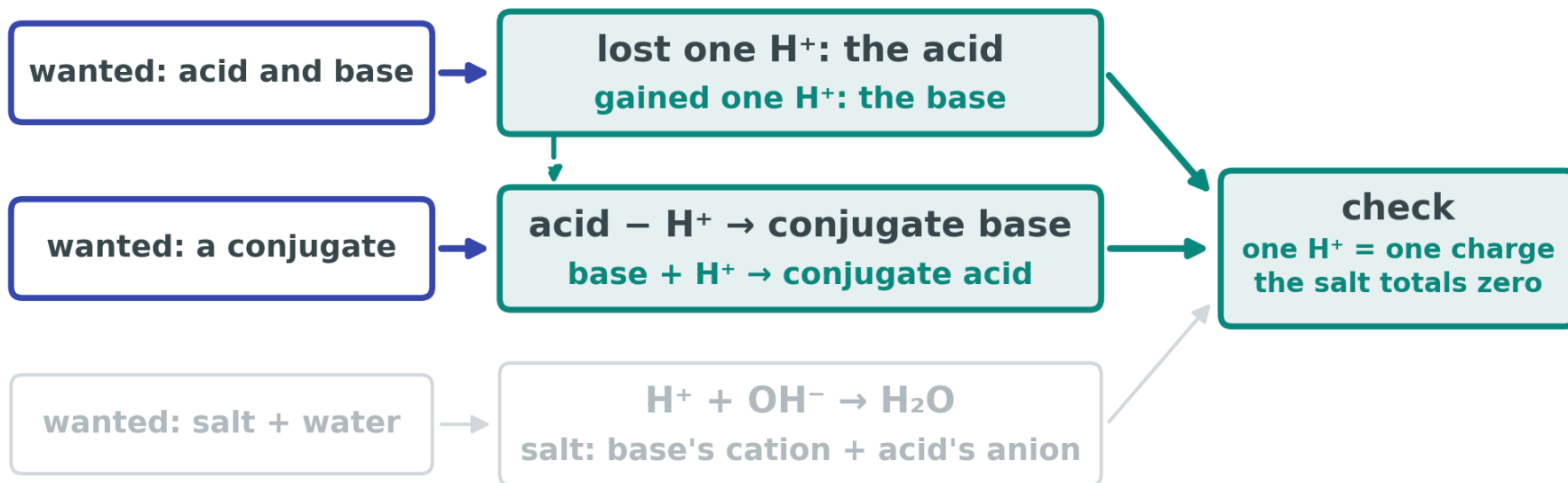
pairs: $\text{H}_2\text{C}_4\text{H}_4\text{O}_5/\text{HC}_4\text{H}_4\text{O}_5^-$ and $\text{H}_2\text{O}/\text{H}_3\text{O}^+$ · each pair differs by one H^+ and one charge

 **Sense check:** Read backward, $\text{HC}_4\text{H}_4\text{O}_5^-$ takes an H^+ : a base. H_3O^+ gives one up: an acid. The conjugate labels fit. ✓

✓ Guided example: the route on the map



found: acid $\text{H}_2\text{C}_4\text{H}_4\text{O}_5$ · base H_2O · conjugate acid H_3O^+ · conjugate base $\text{HC}_4\text{H}_4\text{O}_5^-$



 **Sense check:** The top lane gave the labels. The dashed arrow carries them down: each label's partner sits across the $\rightleftharpoons$. ✓

Practice 1

What is the conjugate base of HPO_4^{2-} ?



✓ Practice 1: answer B



H: $1 - 1 = 0$ · charge: $2- \text{ minus one } 1+ = 3-$

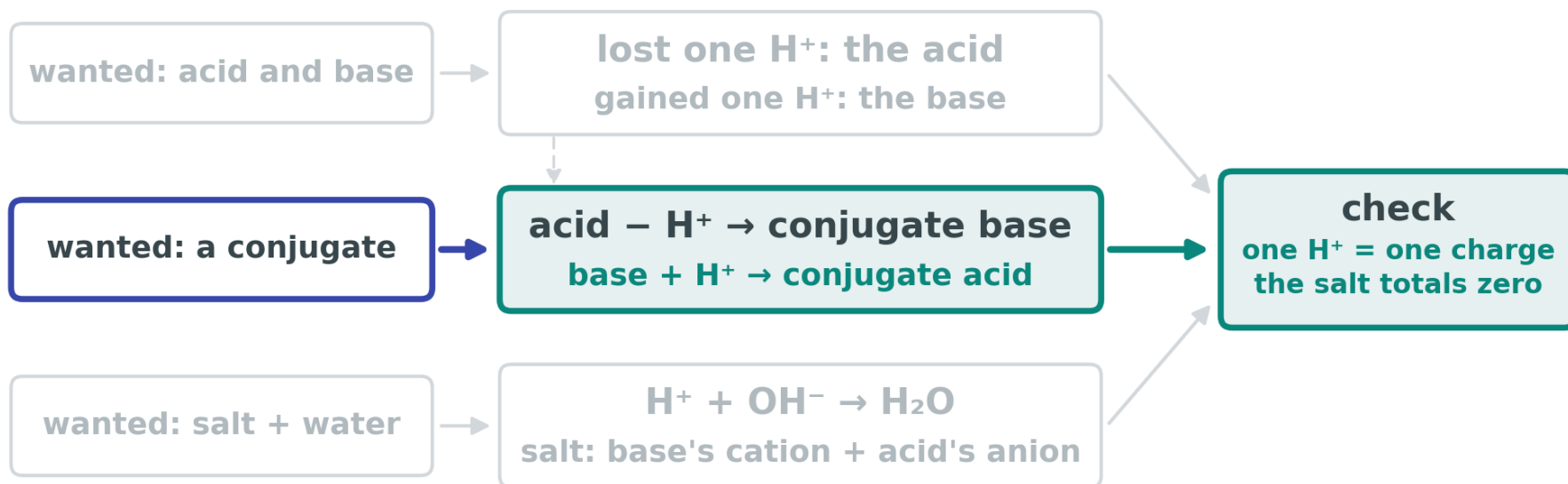
A added an H^+ instead of removing one: H_2PO_4^- is the conjugate acid. C removed the H but kept the $2-$ charge; the H^+ takes its $1+$ with it. D lowered the charge but left the H in place.

🧠 **Sense check:** A conjugate base has one H fewer and one more negative charge than its acid. ✓

✓ Practice 1: the route on the map



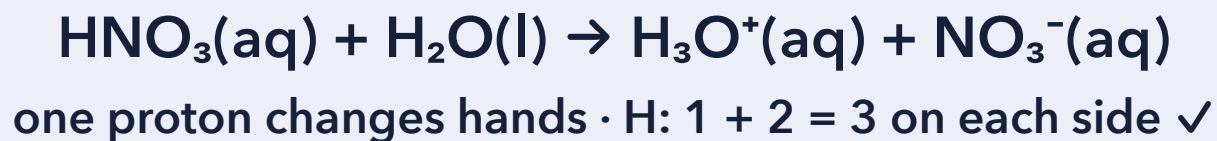
given: one formula, no reaction · found: the conjugate base PO_4^{3-}



🧠 **Sense check:** A formula given alone needs no labeling first: the conjugate lane applies directly. ✓



Worked example 1: nitric acid in water



Nitric acid ionizes in water. Identify the Brønsted-Lowry acid and the Brønsted-Lowry base.

✓ Worked example 1: solution

Step 1 • Track the proton

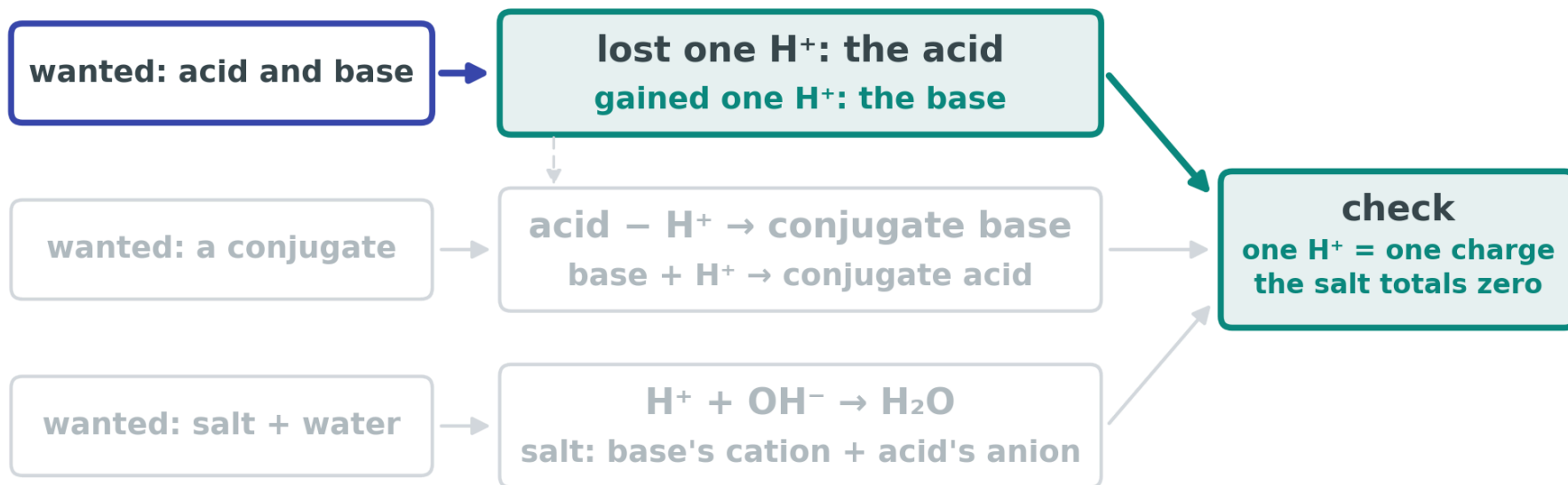
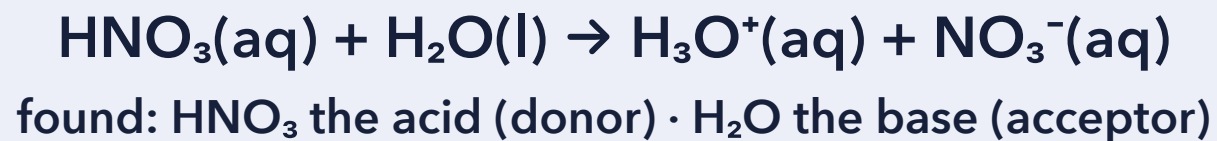
$\text{HNO}_3 \rightarrow \text{NO}_3^-$, one H^+ lighter • $\text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+$, one H^+ heavier

H check: $1 + 2 = 3$ before and after ✓

Step 2 • Label donor and acceptor

🧠 **Sense check:** The acid ends one H smaller; the base ends one H larger. The products record the transfer: H_3O^+ carries the proton, NO_3^- is the donor's leftover.

✓ Worked example 1: the route on the map



🧠 **Sense check:** Only the acid and the base were wanted: the top lane alone. ✓



Worked example 2: ammonia in water



no OH^- anywhere inside $\text{NH}_3 \cdot \text{H}$: $3 + 2 = 5$ on each side ✓

Ammonia contains no hydroxide, yet its solution turns litmus blue. Identify the donor and the acceptor.

✓ Worked example 2: solution

Step 1 • Track the proton

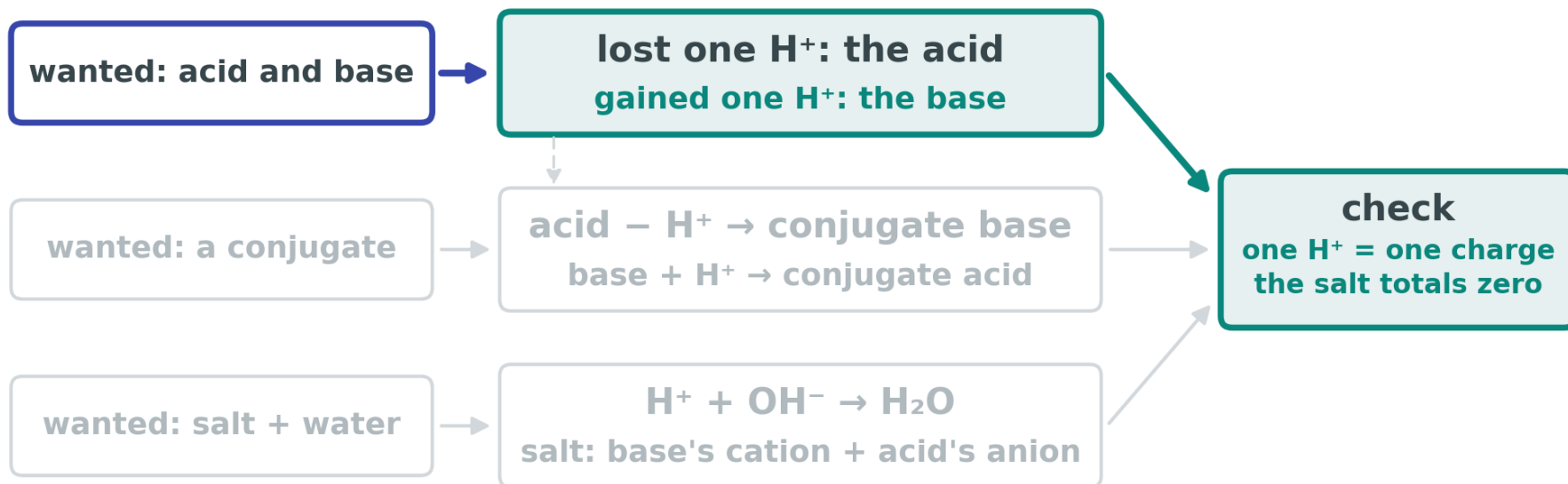
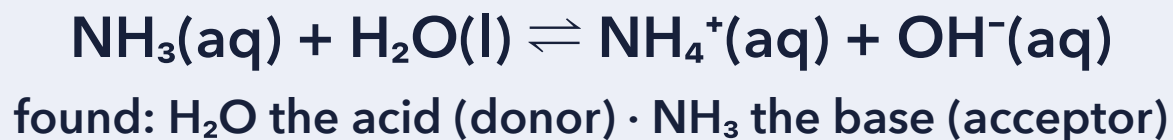
$\text{NH}_3 \rightarrow \text{NH}_4^+$, one H^+ heavier • $\text{H}_2\text{O} \rightarrow \text{OH}^-$, one H^+ lighter

H check: $3 + 2 = 5$ before and after ✓

Step 2 • Label donor and acceptor

🧠 **Sense check:** The OH^- that turns litmus blue appears because water gave up a proton. A base needs no OH^- of its own.

✓ Worked example 2: the route on the map



 **Sense check:** The same top lane. Here water lands on the acid side: the label depends on the reaction. ✓



Practice 2



$$\text{H: } 0 + 2 = 1 + 1 \checkmark$$

Which two species form a conjugate acid-base pair?

- A. SO_3^{2-} and HSO_3^{-}
- B. SO_3^{2-} and H_2O
- C. HSO_3^{-} and OH^{-}
- D. H_2O and HSO_3^{-}

✓ Practice 2: answer A

$\text{SO}_3^{2-} \rightarrow \text{HSO}_3^-$: one H^+ gained · $\text{H}_2\text{O} \rightarrow \text{OH}^-$: one H^+ lost
pairs: $\text{SO}_3^{2-}/\text{HSO}_3^-$ (answer A) and $\text{H}_2\text{O}/\text{OH}^-$ · charge: $2- \rightarrow 1-$ and $0 \rightarrow 1-$

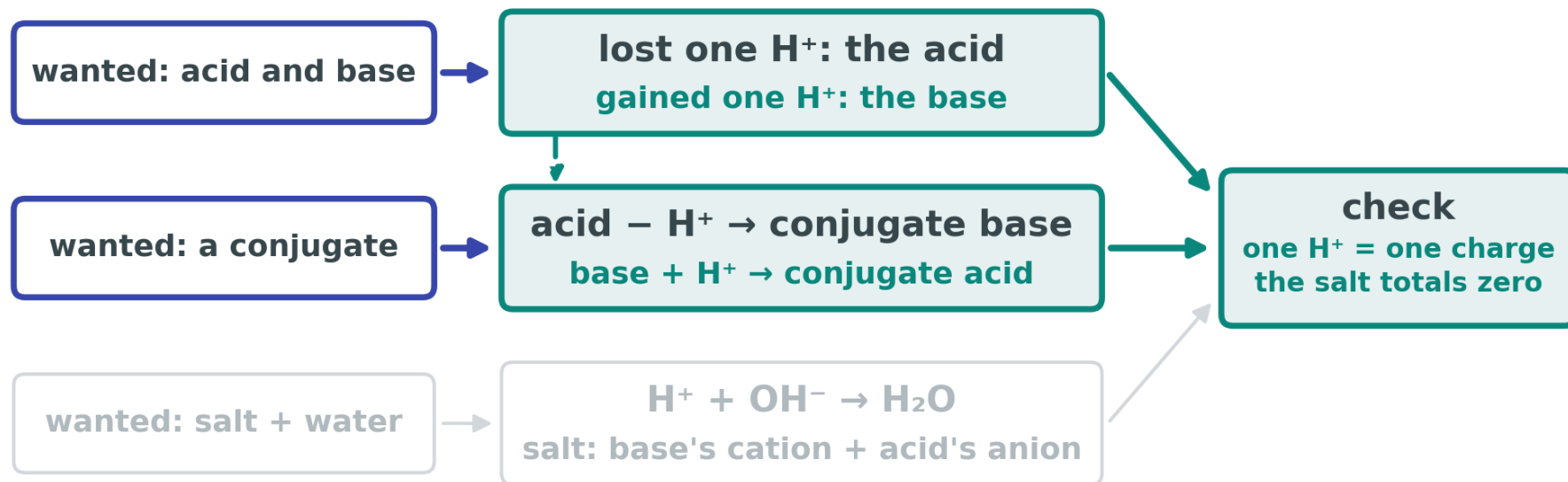
B paired the two reactants: the acid and the base react with each other, and neither becomes the other. C paired the two products. D paired the two species that hold the H^+ , the acid before and the conjugate acid after: two different species.

🧠 **Sense check:** A conjugate pair is one species before the transfer and the same species after: one H^+ apart, one on each side. ✓

✓ Practice 2: the route on the map



found: base SO_3^{2-} · acid H_2O · pairs $\text{SO}_3^{2-}/\text{HSO}_3^-$ and $\text{H}_2\text{O}/\text{OH}^-$



 **Sense check:** Labels first, then each partner across the $\rightleftharpoons$. The second pair, $\text{H}_2\text{O}/\text{OH}^-$, was not among the choices.

✓

Neutralization: acid + base

acid + base $\rightarrow$ salt + water

$H^+ + OH^-$ join as H_2O · the salt = the base's cation + the acid's anion

Mix the two families and both property sets vanish. In chemistry a **salt** is any cation-anion compound left behind, not only table salt: KBr, $CaCl_2$, and K_2SO_4 all qualify.



Worked example 3: predict the products

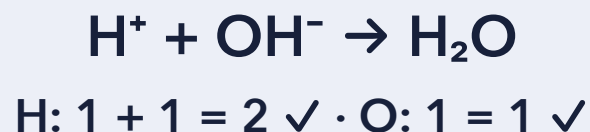


given: the acid HCl and the base NaOH · wanted: the products, balanced

Hydrochloric acid meets sodium hydroxide. Predict both products and balance the equation.

✓ Worked example 3: solution

Step 1 • Track the proton

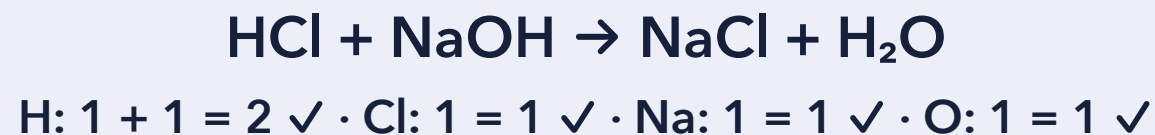


Step 2 • Label donor and acceptor

Step 3 • Predict the products

leftover ions: Na^+ from the base · Cl^- from the acid
 1+ and 1– pair one to one: the salt is NaCl

Step 4 • Balance and check

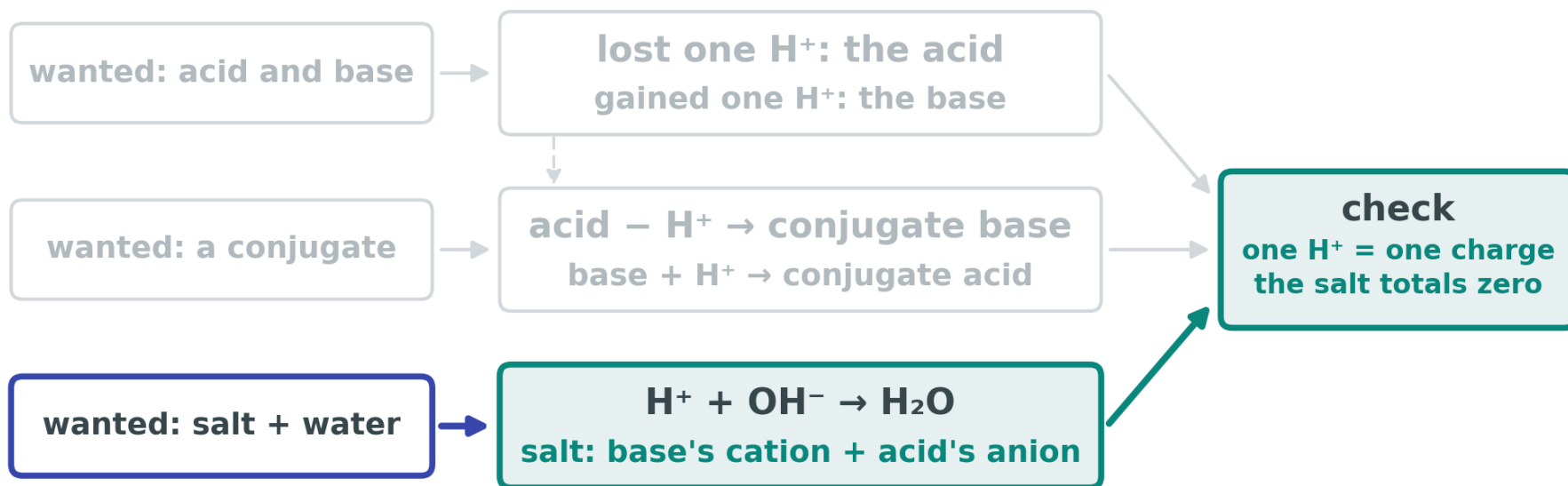


🧠 **Sense check:** Sour gone, slippery gone: a neutral salt and water remain.

✓ Worked example 3: the route on the map



found: $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$ · salt NaCl from Na^+ and Cl^-



🧠 **Sense check:** Products were wanted, so the bottom lane: water from $\text{H}^+ + \text{OH}^-$, the salt from the leftover ions. ✓

Your turn: sulfuric acid and potassium hydroxide



SO_4^{2-} carries 2- · K^+ carries 1+ · H_2SO_4 can donate 2 H^+

step	question	answer
1 · Track the proton	how many H^+ does the acid donate?	_____
2 · Label donor and acceptor	which species donates?	_____
3 · Predict the products	the salt from K^+ and SO_4^{2-} ?	_____ + water
4 · Balance and check	coefficients on KOH and H_2O ?	_____

Complete the four steps.



two H^+ donated, so two OH^- needed · $\text{H}: 2 + 2 = 4 \checkmark$ · $\text{O}: 4 + 2 = 6 \checkmark$ · $\text{K}: 2 = 2 \checkmark$ · $\text{S}: 1 = 1 \checkmark$

⚠ Where this goes wrong

"A base must contain OH." $\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-$: ammonia accepts a proton, and the OH^- appears from water. Proton acceptor is the wider definition, and it covers NH_3 .

"Salt means table salt." A salt is any cation-anion compound a neutralization leaves behind: KBr , MgCl_2 , and K_2SO_4 are all salts. NaCl is one example, not the definition.

Pairing salt ions without checking charge. K^+ with SO_4^{2-} written KSO_4 totals $1 - 2 = -1$, not neutral. Two K^+ cancel the $2-$: K_2SO_4 , with $2(1+) + (2-) = 0$.

Counting H^+ and H_3O^+ as different ions. Same species: the proton rides on a water molecule. HCl in water makes two ions, H_3O^+ and Cl^- , never three.



Practice 3



NO_3^- carries 1- · Ca^{2+} carries 2+

Nitric acid neutralizes calcium hydroxide. Which products form?

- A. CaNO_3 and H_2O
- B. $\text{Ca}(\text{NO}_3)_2$ and H_2
- C. $\text{Ca}(\text{NO}_3)_2$ and H_2O
- D. $\text{Ca}(\text{NO}_2)_2$ and H_2O

✓ Practice 3: answer C



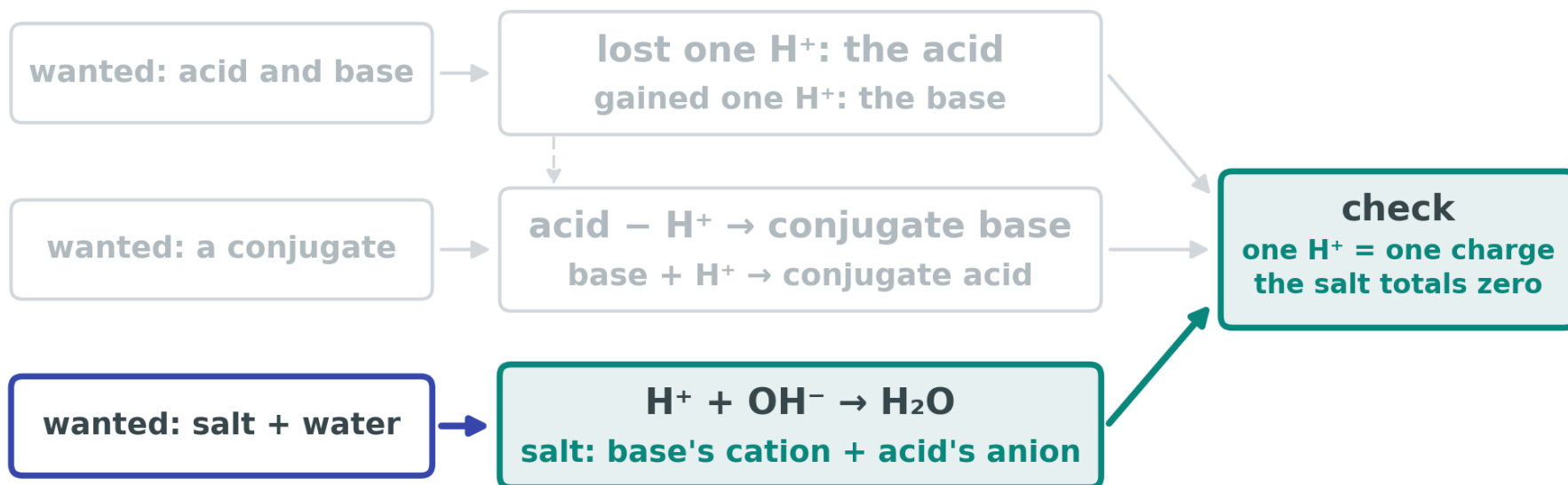
A pairs Ca^{2+} with a single NO_3^- : the charge total $2 - 1 = +1$ is not zero, so two nitrates are needed, in parentheses. B makes H_2 gas: that is the acid + active metal reaction; here H^+ meets OH^- and leaves as water. D swaps in nitrite, NO_2^- : the acid supplied nitrate, NO_3^- .

🧠 **Sense check:** The salt keeps the ions that did not become water, paired until the total charge is zero.

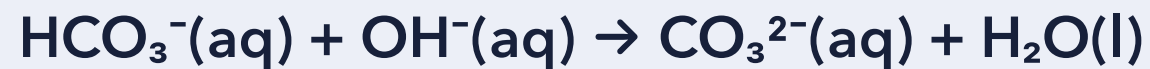
✓ Practice 3: the route on the map



found: $2 \text{H}^+ + 2 \text{OH}^- \rightarrow 2 \text{H}_2\text{O}$ · salt $\text{Ca}(\text{NO}_3)_2$: $(2+) + 2(1-) = 0$



🧠 **Sense check:** The bottom lane again. The check box caught the charge: one Ca^{2+} needs two NO_3^- . ✓

 Practice 4

$$\text{H: } 1 + 1 = 0 + 2 \checkmark$$

Which species is the conjugate base in this reaction?

- A. HCO_3^-
- B. OH^-
- C. H_2O
- D. CO_3^{2-}

✓ Practice 4: answer D

$\text{HCO}_3^- \rightarrow \text{CO}_3^{2-}$: one H^+ lost · $\text{OH}^- \rightarrow \text{H}_2\text{O}$: one H^+ gained
acid HCO_3^- · base OH^- · conjugate base CO_3^{2-} (answer D) · conjugate acid H_2O

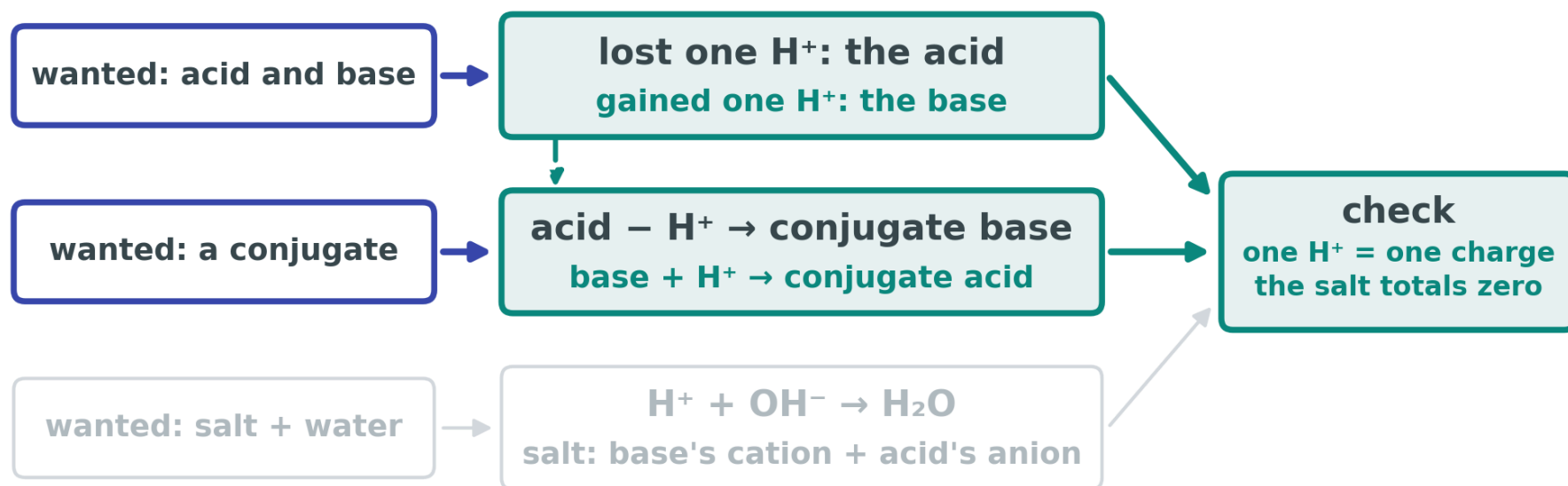
A named the acid itself; its conjugate base is what it becomes. B named the base, a reactant. C swapped the roles, reading HCO_3^- as the base; here OH^- pulls the H^+ off HCO_3^- , so H_2O is the conjugate acid.

 **Sense check:** HCO_3^- gives up an H^+ here. Toward an acid it takes one and becomes H_2CO_3 : one species, either role. ✓

✓ Practice 4: the route on the map



found: acid HCO_3^- · base OH^- · conjugate base CO_3^{2-} · conjugate acid H_2O



🧠 **Sense check:** Both reactants carry H. The top lane decides which one lost it; the conjugate lane follows. ✓

 Practice 5

H: 1 + 3 = 4 on each side ✓

Read the reaction right to left. In the reverse direction, which species acts as the Brønsted-Lowry acid?

- A. HCN
- B. CN^-
- C. NH_3
- D. NH_4^+

✓ Practice 5: answer D



$\text{NH}_4^+ \rightarrow \text{NH}_3$, one H^+ lighter: the donor, the acid (answer D) · $\text{CN}^- \rightarrow \text{HCN}$, one H^+ heavier: the base

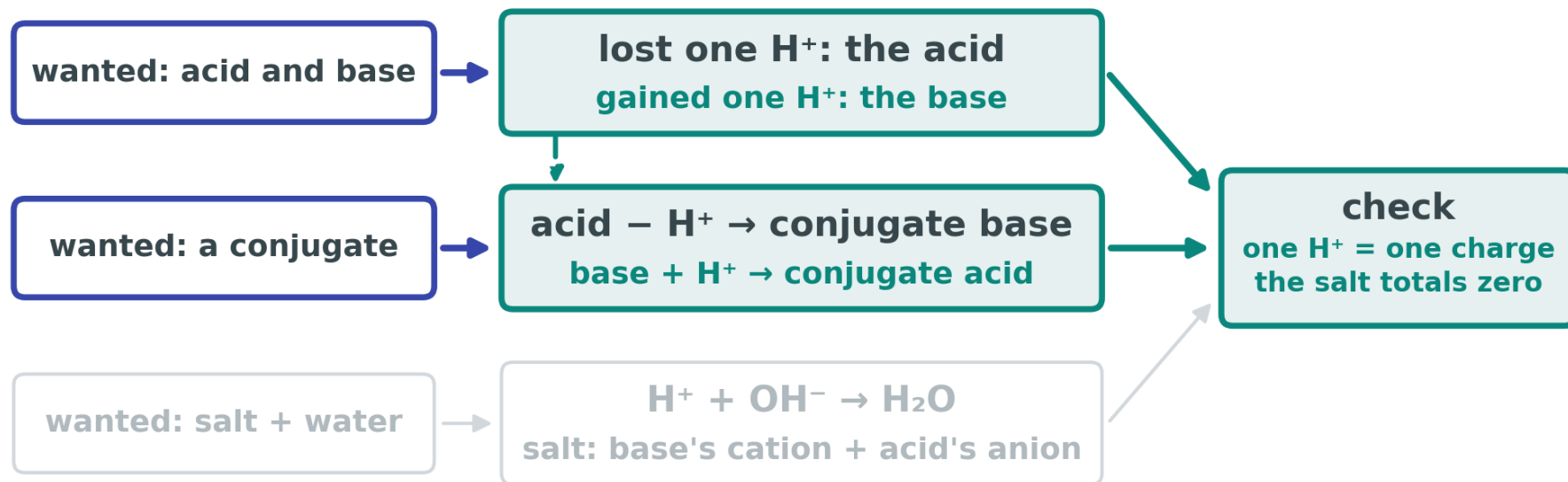
A kept the forward roles: HCN donates left to right, but read right to left it is a product, rebuilt when CN^- takes a proton. B swapped donor and acceptor: CN^- gains the H^+ , which makes it the reverse base. C is the forward base; in reverse NH_3 is a product, left behind when NH_4^+ gives up its proton.

 **Sense check:** Each conjugate pair trades roles across the $\rightleftharpoons$: HCN/CN^- and $\text{NH}_4^+/\text{NH}_3$. The reverse acid is the forward base's conjugate, NH_4^+ .

✓ Practice 5: the route on the map



forward: acid HCN · base NH₃ · conjugate acid NH₄⁺ · conjugate base CN⁻



 **Sense check:** Forward labels first, then their partners. Read right to left, the conjugate acid NH₄⁺ does the donating. ✓

Check yourself

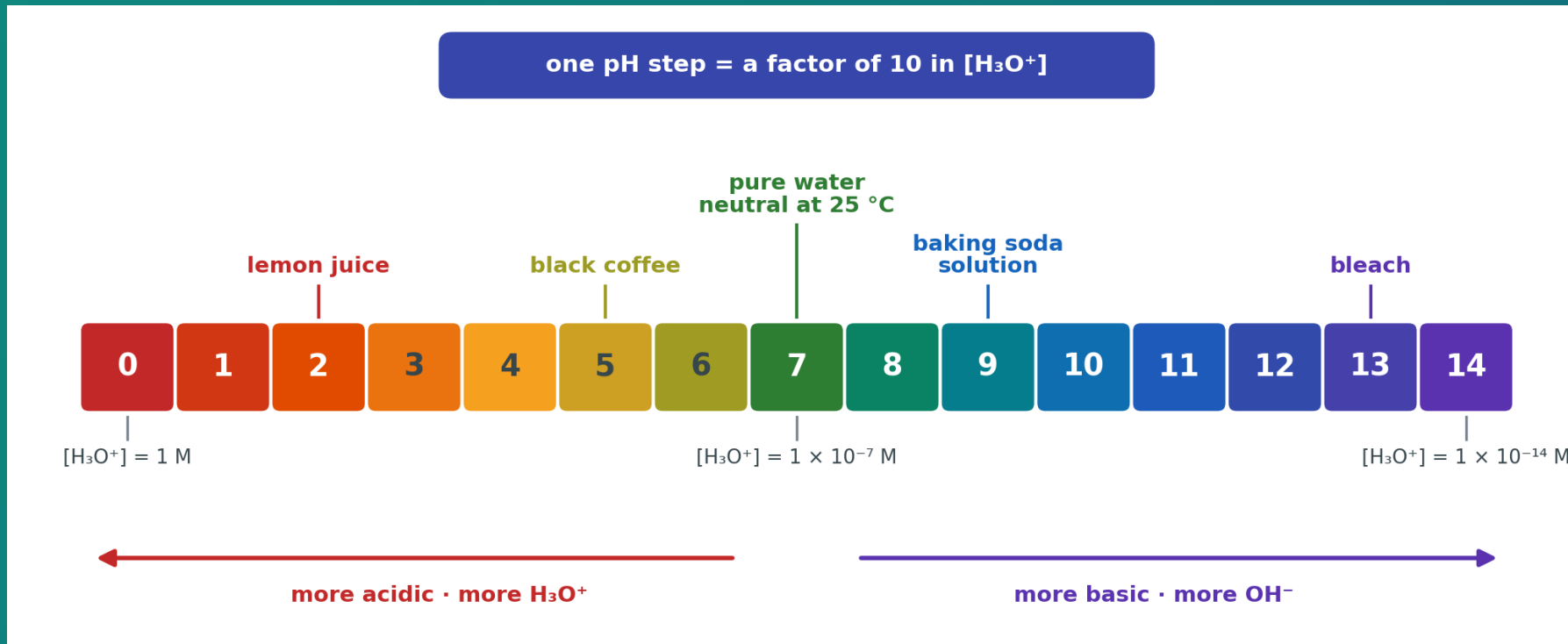
1. In $\text{HF} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{F}^-$, identify the donor, the acceptor, and both conjugate pairs.
2. Predict the products and balance: $\text{HBr} + \text{Ba}(\text{OH})_2$.

A balanced neutralization carries a mole ratio between acid and base, and that ratio drives titration volume calculations. How much H_3O^+ an acid actually delivers is the next number: the pH scale.

3 • The pH Scale

Place any solution on the pH ladder (acidic below 7, neutral 7 at 25 °C, basic above 7), read a whole-number pH straight from $[\text{H}_3\text{O}^+]$ written as a power of ten and run the read in reverse, and compare two solutions by factors of ten.

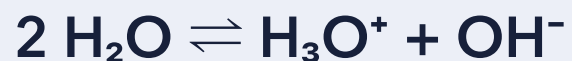
The number on the bottle



Shampoo labels, pool test strips, and soil kits all report pH. One number places lemon juice, black coffee, baking soda, and bleach on the same 0 to 14 ladder.

Every water solution holds both ions

Water itself makes both: a few molecules trade a proton. Both H_3O^+ and OH^- are present in every water solution, and they see-saw: more of one always means less of the other.



acidic = H_3O^+ ahead · basic = OH^- ahead · neutral = an exact tie

The ion product of water

$$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14} \text{ (at 25 } ^\circ\text{C)}$$

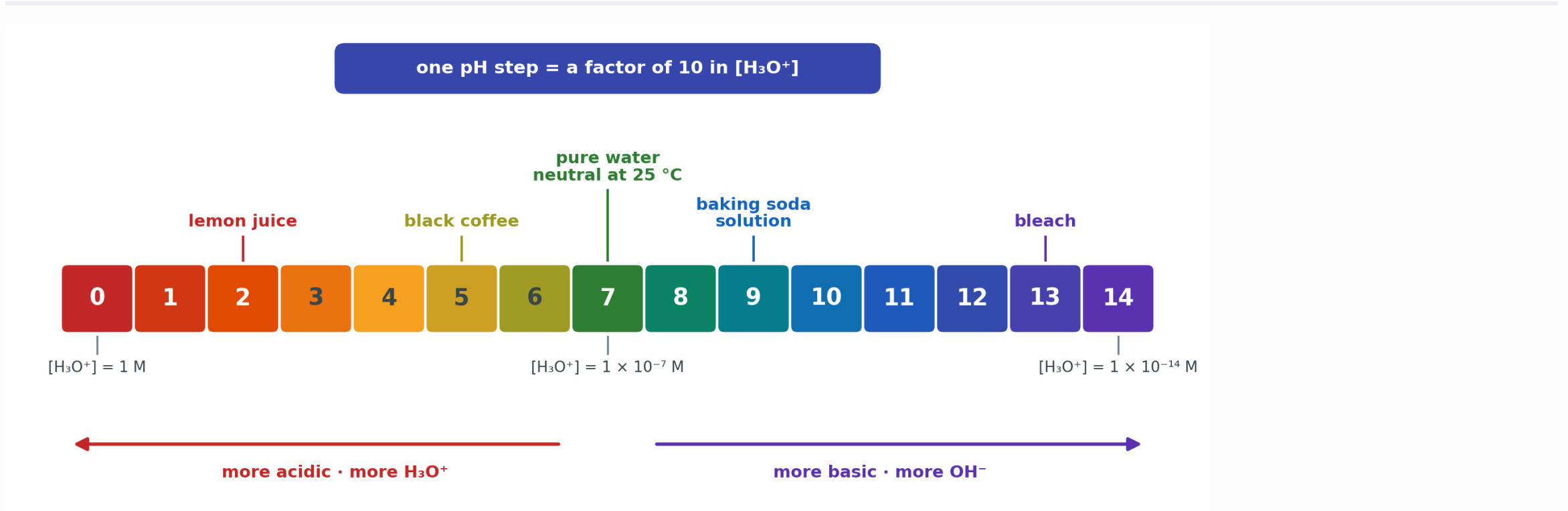
$$\text{pure water: } [\text{H}_3\text{O}^+] = [\text{OH}^-] = 1.0 \times 10^{-7} \text{ M} \cdot (1.0 \times 10^{-7})(1.0 \times 10^{-7}) = 1.0 \times 10^{-14}$$

The product of the two concentrations is fixed. Raise one and the other falls, so either concentration sets the other.

$$[\text{H}_3\text{O}^+] = [\text{OH}^-]: \text{neutral} \cdot [\text{H}_3\text{O}^+] > [\text{OH}^-]: \text{acidic} \cdot [\text{H}_3\text{O}^+] < [\text{OH}^-]: \text{basic}$$

$$\text{at 25 } ^\circ\text{C: neutral at } [\text{H}_3\text{O}^+] = 1.0 \times 10^{-7} \text{ M} \cdot \text{acidic above it} \cdot \text{basic below it}$$

The pH ladder: 0 to 14



pH places a solution on the see-saw: below 7 acidic (H_3O^+ ahead), 7 neutral at 25 °C (a tie), above 7 basic (OH^- ahead).

Each pH step is a factor of ten

The scale is compact because each step multiplies by ten. Two solutions one pH unit apart differ tenfold in H_3O^+ ; three units apart, a thousandfold.

pH 2 vs pH 5: 3 steps apart

$10 \times 10 \times 10 = 1000 \times$ the H_3O^+ · steps add, concentrations multiply

Reading pH from $[\text{H}_3\text{O}^+]$

Write $[\text{H}_3\text{O}^+]$ as 1×10^{-n} M. The pH is n , the exponent's size. A smaller concentration carries a bigger n , so pH rises as acidity falls.

$$[\text{H}_3\text{O}^+] = 1 \times 10^{-5} \text{ M} \rightarrow \text{pH } 5 \cdot [\text{H}_3\text{O}^+] = 1 \times 10^{-11} \text{ M} \rightarrow \text{pH } 11$$

$$1 \times 10^{-n} \text{ M} \leftrightarrow \text{pH } n \cdot \text{pure water at } 25^\circ\text{C}: 1 \times 10^{-7} \text{ M} \leftrightarrow \text{pH } 7$$



The method: pH from powers of ten

1. Write $[\text{H}_3\text{O}^+]$ as 1×10^{-n} M.
2. Read the pH: $\text{pH} = n$.
3. Place it: below 7 acidic, 7 neutral, above 7 basic.

Reversed, pH n means $[\text{H}_3\text{O}^+] = 1 \times 10^{-n}$ M.



Worked example 1: black coffee

black coffee: $[\text{H}_3\text{O}^+] = 1 \times 10^{-5} \text{ M}$

wanted: pH · acidic, neutral, or basic?

An analysis of black coffee reports the hydronium concentration directly. Find the pH and place the coffee on the ladder.

✓ Worked example 1: solution

Step 1 • Write $[\text{H}_3\text{O}^+]$ as $1 \times 10^{-n} \text{ M}$

$$[\text{H}_3\text{O}^+] = 1 \times 10^{-5} \text{ M}$$

coefficient 1 · exponent $-5 \cdot n = 5$

Step 2 • Read the pH: $\text{pH} = n$

$$[\text{H}_3\text{O}^+] = 1 \times 10^{-5} \text{ M} \rightarrow \text{pH} = 5$$

the pH is the exponent's size, sign dropped

Step 3 • Place it: below 7 acidic, 7 neutral, above 7 basic

pH 5 → acidic
5 sits below 7 · H_3O^+ ahead of OH^-

 **Sense check:** Coffee sits $7 - 5 = 2$ steps below neutral: $10 \times 10 = 100$ times the H_3O^+ of pure water.



Worked example 2: household ammonia

household ammonia cleaner: pH 11

wanted: $[\text{H}_3\text{O}^+]$ · acidic, neutral, or basic?

The label reports a pH, not a concentration. Run the read in reverse to recover $[\text{H}_3\text{O}^+]$.

✓ Worked example 2: solution

Reversed: pH n means $[\text{H}_3\text{O}^+] = 1 \times 10^{-n} \text{ M}$

$$\text{pH } 11 \rightarrow [\text{H}_3\text{O}^+] = 1 \times 10^{-11} \text{ M}$$

whole-number pH $\leftrightarrow$ coefficient 1 $\cdot$ exponent = -11

Place it: below 7 acidic, 7 neutral, above 7 basic

pH 11 $\rightarrow$ basic

11 sits above 7 $\cdot$ OH^- ahead, yet H_3O^+ never reaches zero

 **Sense check:** A pH of 11 sits $11 - 7 = 4$ steps above water's 7: far less H_3O^+ than pure water, so the see-saw tips well toward OH^- .

With your calculator: $\text{pH} = -\log[\text{H}_3\text{O}^+]$

The log button reads the exponent for you. Enter the concentration, press log, flip the sign. Reversed, ten to the $-\text{pH}$ rebuilds the concentration.

$$\text{pH} = -\log[\text{H}_3\text{O}^+] \cdot -\log(1 \times 10^{-9}) = 9$$

enter 1 EE 9 +/- · whole-power concentrations return whole-number pH

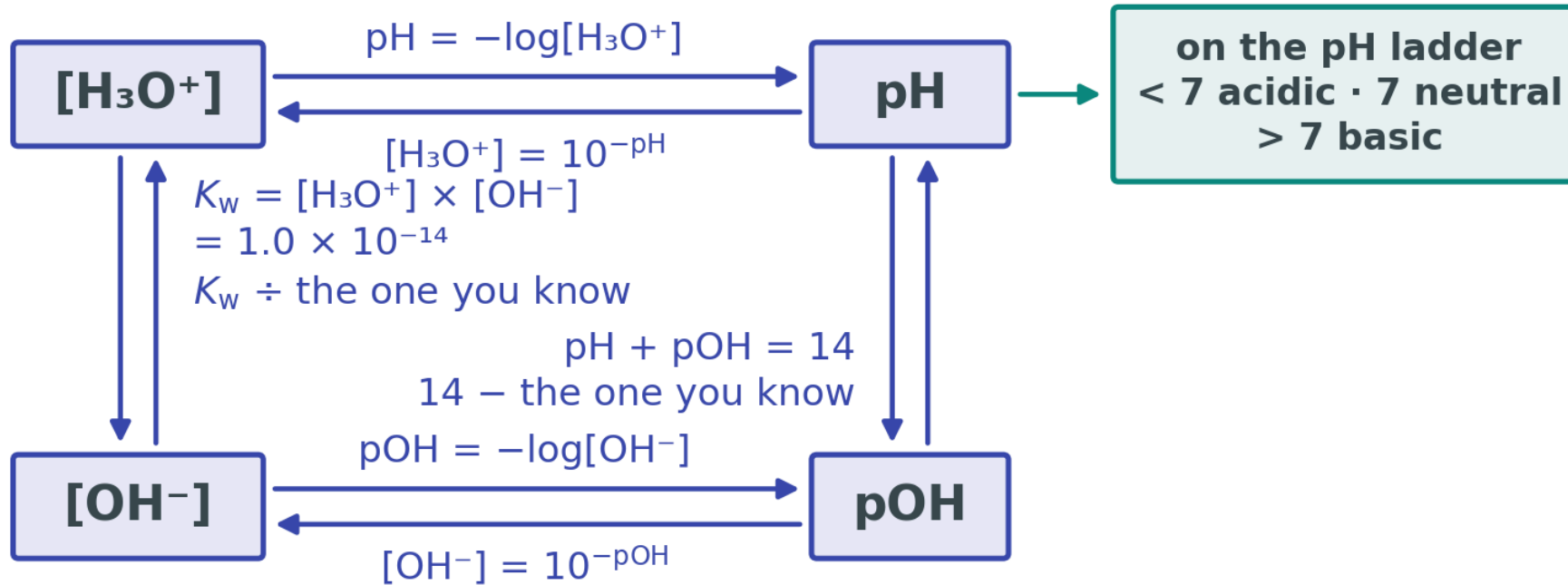
The companion number: pOH

OH^- gets its own reading, pOH, on the same kind of 0 to 14 ladder. One line connects the two, so either number sets the other.

$$\text{pH} + \text{pOH} = 14 \text{ (at } 25^\circ\text{C)}$$

$\text{pH } 3 \rightarrow \text{pOH} = 14 - 3 = 11$ · low pH pairs with high pOH: the same see-saw

The conversion chart



$[H_3O^+]$, $[OH^-]$, pH and pOH describe one solution; any one sets the other three. The top edge is the method; the bottom edge repeats it for OH^- . K_w joins the concentrations, 14 the p-numbers.

Guided example: seawater

seawater: $[\text{OH}^-] = 1 \times 10^{-6} \text{ M}$

$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$ · wanted: $[\text{H}_3\text{O}^+]$ and pH · acidic, neutral, or basic?

A seawater analysis reports the hydroxide concentration. Find $[\text{H}_3\text{O}^+]$ and the pH, then place the sample on the ladder.

Plan the route first: $[\text{OH}^-]$ sits in the bottom-left corner of the chart and pH in the top right. K_w crosses the left edge; $-\log$ runs along the top.

✓ Guided example: solution

seawater: $[\text{OH}^-] = 1 \times 10^{-6} \text{ M}$

$K_w = [\text{H}_3\text{O}^+][\text{OH}^-] = 1.0 \times 10^{-14}$ · wanted: $[\text{H}_3\text{O}^+]$ and pH

Step 1 · Write $[\text{H}_3\text{O}^+]$ as $1 \times 10^{-n} \text{ M}$

$$[\text{H}_3\text{O}^+] = \frac{1.0 \times 10^{-14}}{1 \times 10^{-6}} = 1 \times 10^{-8} \text{ M}$$

Step 2 · Read the pH: $\text{pH} = n$

$[\text{H}_3\text{O}^+] = 1 \times 10^{-8} \text{ M} \rightarrow \text{pH} = 8$

$n = 8$ · the exponent's size, sign dropped

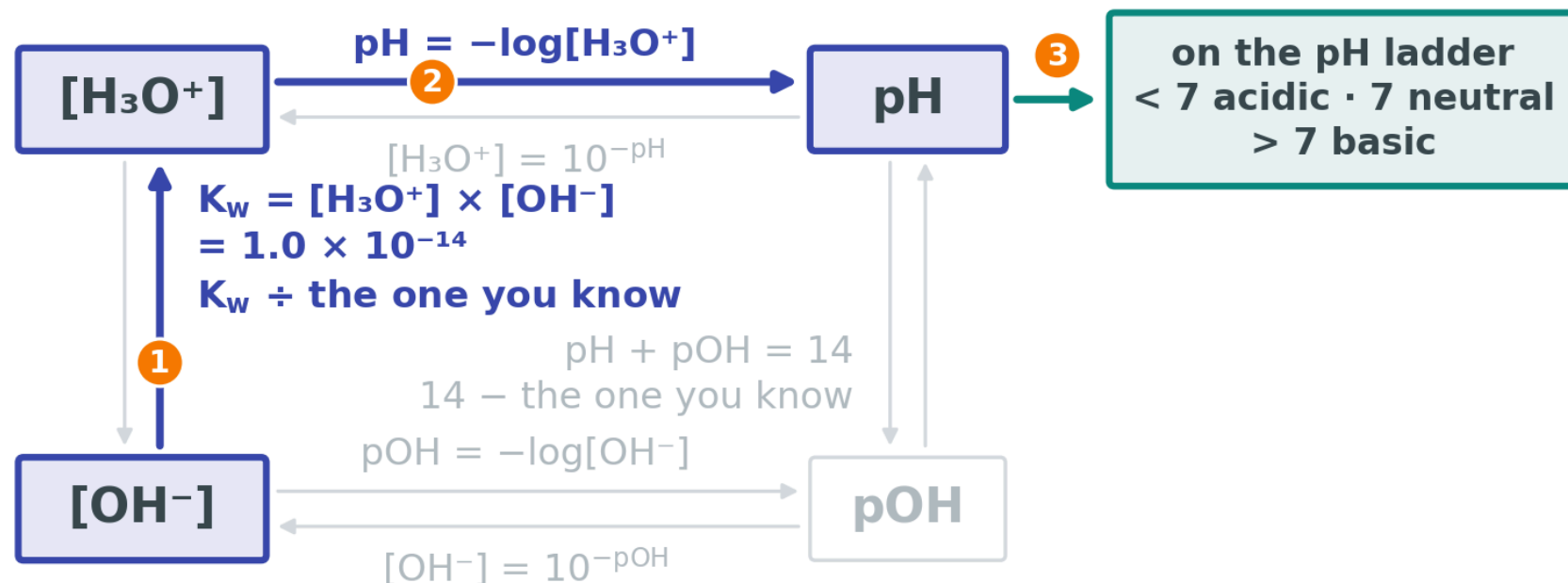
Step 3 · Place it: below 7 acidic, 7 neutral, above 7 basic

 **Sense check:** pH 8 sits above 7: basic. The pOH route agrees: $\text{pOH} = 6$, and $14 - 6 = 8$. ✓

✓ Guided example: the route on the map

seawater: $[\text{OH}^-] = 1 \times 10^{-6} \text{ M}$

given: $[\text{OH}^-]$ · found: $[\text{H}_3\text{O}^+] = 1 \times 10^{-8} \text{ M}$ · pH 8 · basic



🧠 **Sense check:** Up the left edge with K_w , along the top with $-\log$, then onto the ladder. ✓



Worked example 3: tomato juice

tomato juice: $[\text{H}_3\text{O}^+] = 5.0 \times 10^{-5} \text{ M}$

coefficient 5.0, not 1 · wanted: pH · acidic, neutral, or basic?

A coefficient other than 1 puts the pH between two whole numbers. Find it with the log key and report the right number of decimal places.

✓ Worked example 3: solution

tomato juice: $[\text{H}_3\text{O}^+] = 5.0 \times 10^{-5} \text{ M}$

2 significant figures · wanted: pH

Bracket it between two powers of ten

$$\text{pH} = -\log[\text{H}_3\text{O}^+]$$

$$\text{pH} = -\log(5.0 \times 10^{-5}) = 4.301$$

Decimal places in the pH = significant figures in $[\text{H}_3\text{O}^+]$

$5.0 \times 10^{-5} \text{ M} \rightarrow \text{pH } 4.30 \rightarrow \text{acidic}$

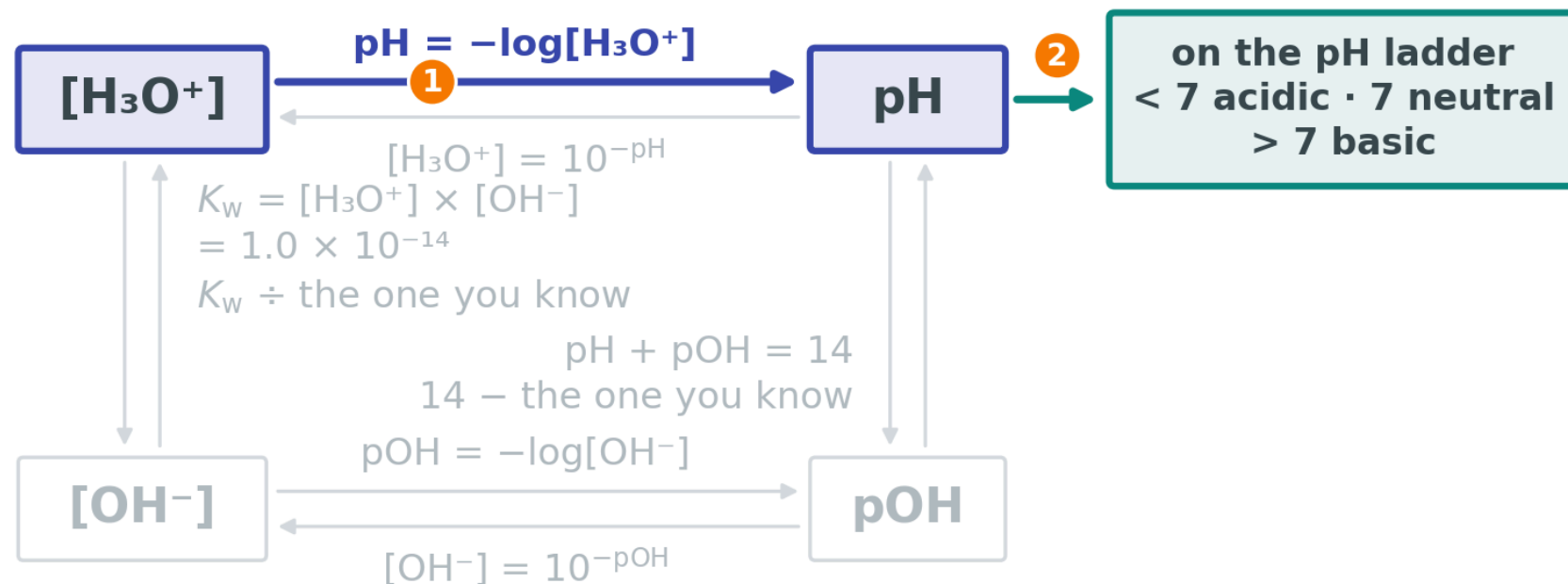
2 significant figures $\leftrightarrow$ 2 decimal places · the 4 only marks the power of ten · below 7

 **Sense check:** 4.30 falls between 4 and 5, as bracketed. Run it backward: $10^{-4.30} = 5.0 \times 10^{-5} \text{ M}$, the starting concentration. ✓

✓ Worked example 3: the route on the map

tomato juice: $[\text{H}_3\text{O}^+] = 5.0 \times 10^{-5} \text{ M}$

given: $[\text{H}_3\text{O}^+]$ · found: pH 4.30 · acidic



🧠 **Sense check:** One edge, then the ladder. A coefficient other than 1 only adds decimals. ✓

Your turn: vinegar

Vinegar measures $[\text{H}_3\text{O}^+] = 1 \times 10^{-3} \text{ M}$. Fill each blank, then check.

step	value
exponent n	_____
pH	_____
acidic, neutral, or basic	_____

$$[\text{H}_3\text{O}^+] = 1 \times 10^{-3} \text{ M} \rightarrow \text{pH } 3 \rightarrow \text{acidic}$$

$$n = 3 \cdot \text{pH} = n = 3 \cdot 3 \text{ below } 7 \cdot \text{pOH} = 14 - 3 = 11$$

⚠ Where this goes wrong

"pH 4 is twice as acidic as pH 8." The steps multiply. Four steps means $10 \times 10 \times 10 \times 10 = 10,000$ times the H_3O^+ , never 2 times.

Reading the ladder backward. pH climbs as H_3O^+ falls. pH 2 holds more H_3O^+ than pH 6, so the lower pH is the more acidic one.

"pH 0 means nothing is dissolved." pH 0 means $[\text{H}_3\text{O}^+] = 1 \times 10^0 \text{ M} = 1 \text{ M}$: the crowded, strongly acidic end of the ladder.

"A basic solution has no H_3O^+ ." Both ions live in every water solution. At pH 11 there is still $1 \times 10^{-11} \text{ M}$ H_3O^+ ; OH^- simply outnumbers it.

Practice 1

A drain cleaner sample measures $[\text{H}_3\text{O}^+] = 1 \times 10^{-12} \text{ M}$. What is its pH?

- A. 12
- B. -12
- C. 2
- D. 7

✓ Practice 1 · answer: A

$$[\text{H}_3\text{O}^+] = 1 \times 10^{-12} \text{ M} \rightarrow \text{pH } 12: \text{basic (answer A)}$$

$$1 \times 10^{-n} \text{ M} \leftrightarrow \text{pH } n \cdot 12 \text{ above } 7 \rightarrow \text{basic}$$

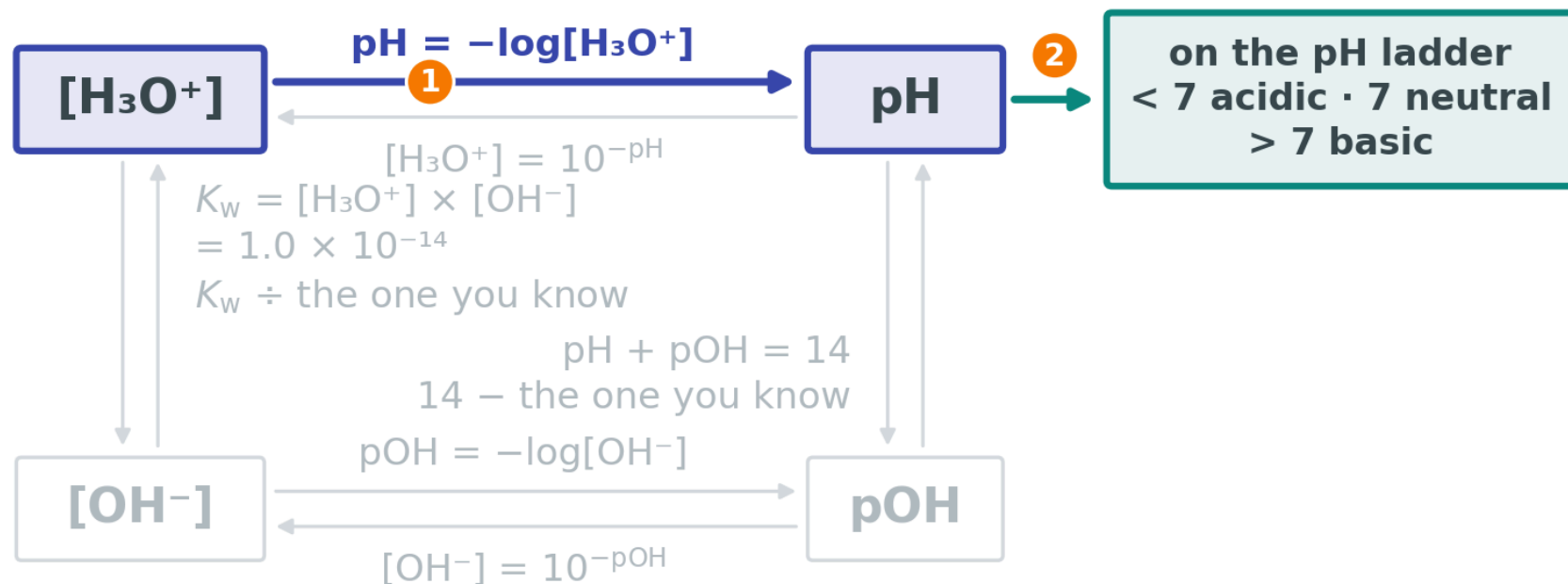
A: the exponent's size is the pH. B keeps the exponent's sign: $\text{pH} = -\log(10^{-12}) = 12$, positive. C is the pOH: $14 - 12 = 2$. D assumes a tiny $[\text{H}_3\text{O}^+]$ means neutral; 10^{-12} sits $12 - 7 = 5$ steps below water's 10^{-7} , which is 100,000 times less H_3O^+ than neutral.

 **Sense check:** Less H_3O^+ than pure water always lands above 7, never at it.

✓ Practice 1: the route on the map

drain cleaner: $[\text{H}_3\text{O}^+] = 1 \times 10^{-12} \text{ M}$

given: $[\text{H}_3\text{O}^+]$ · found: pH 12 · basic



🧠 **Sense check:** One edge: $-\log$ along the top. A basic solution still gets its pH from $[\text{H}_3\text{O}^+]$. ✓

 Practice 2: from pH to $[\text{OH}^-]$

hand soap solution: pH 9
measured at 25 °C

What is the soap solution's $[\text{OH}^-]$, in M?

- A. 1×10^{-9}
- B. 1×10^{-5}
- C. 1×10^{-23}
- D. 1×10^5

✓ Practice 2 · answer: B

hand soap solution: pH 9

$$\text{pOH} = 14 - 9 = 5 \cdot [\text{OH}^-] = 1 \times 10^{-5} \text{ M (answer B)}$$

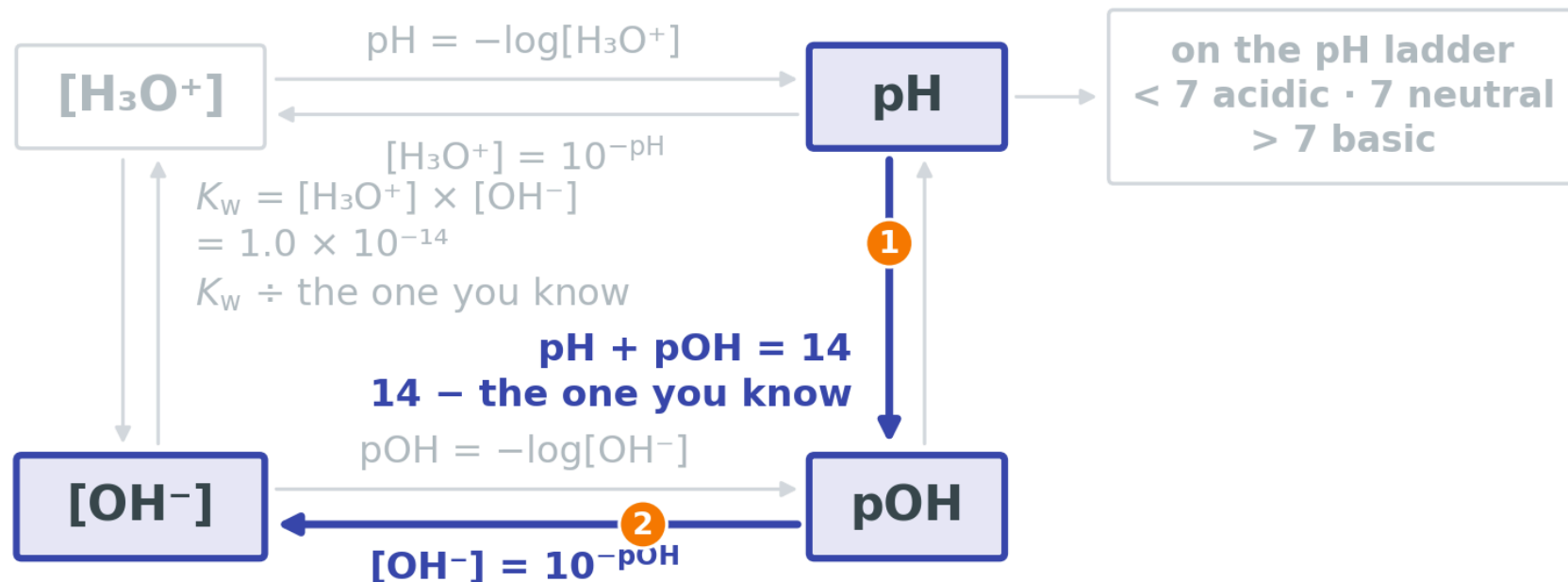
B: $14 - \text{pH}$ gives pOH 5, and pOH 5 means $[\text{OH}^-] = 1 \times 10^{-5} \text{ M}$. A rebuilt $[\text{H}_3\text{O}^+]$ from the pH: $1 \times 10^{-9} \text{ M}$ is the hydronium, not the hydroxide. C multiplied by K_w instead of dividing: $(1.0 \times 10^{-14})(1 \times 10^{-9}) = 1 \times 10^{-23}$. D lost the minus sign: pOH 5 means 10^{-5} , not 10^5 .

 **Sense check:** K_w checks it: $(1 \times 10^{-9})(1 \times 10^{-5}) = 1 \times 10^{-14}$. Above pH 7, OH^- outnumber H_3O^+ . ✓

✓ Practice 2: the route on the map

hand soap solution: pH 9

given: pH • found: pOH 5 • $[\text{OH}^-] = 1 \times 10^{-5} \text{ M}$



🧠 **Sense check:** Down the right edge with $14 - \text{pH}$, then along the bottom with ten to the $-\text{pOH}$. ✓



Practice 3: a pH with decimals

grapefruit juice: $[\text{H}_3\text{O}^+] = 6.3 \times 10^{-4} \text{ M}$
measured at 25 °C

What is the pH of the grapefruit juice?

- A. 4
- B. -3.20
- C. 10.80
- D. 3.20

✓ Practice 3 · answer: D

grapefruit juice: $[\text{H}_3\text{O}^+] = 6.3 \times 10^{-4} \text{ M}$

$\text{pH} = -\log(6.3 \times 10^{-4}) = 3.20$ (answer D) · 2 significant figures $\leftrightarrow$ 2 decimal places · acidic

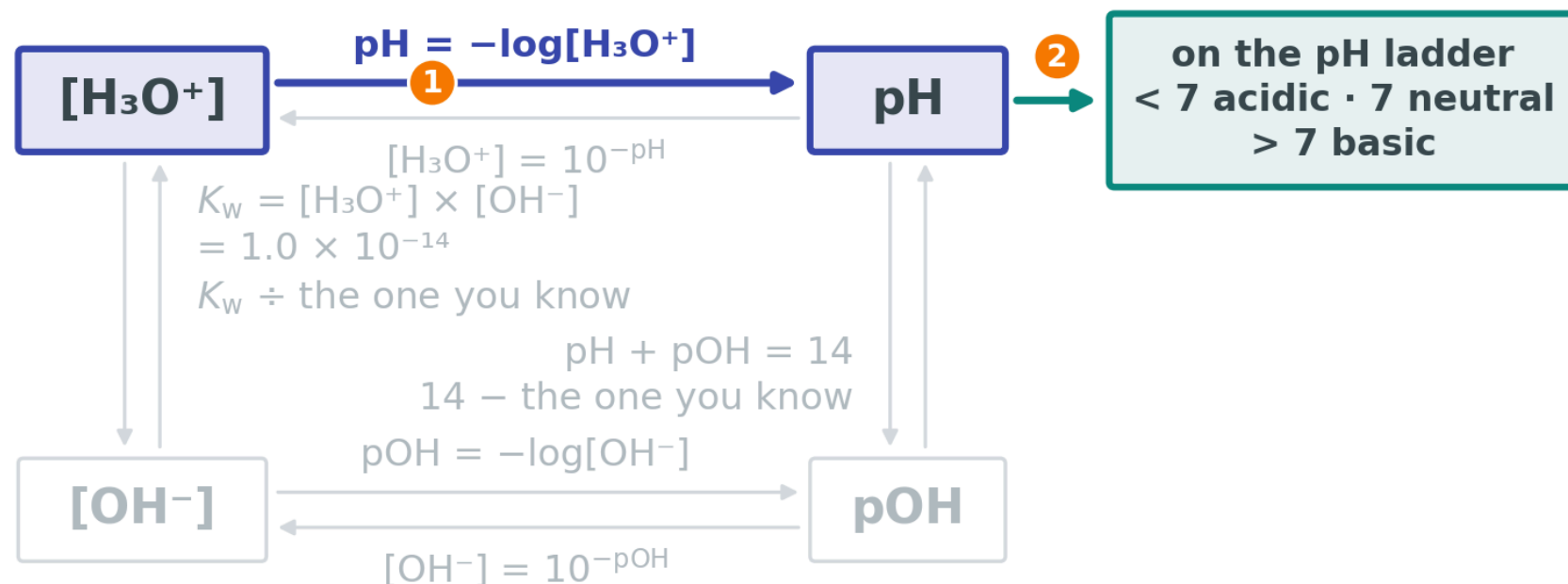
D: the log key gives 3.2007, and 6.3 carries two significant figures, so the pH keeps two decimal places. A read the exponent alone, as if $[\text{H}_3\text{O}^+]$ were $1 \times 10^{-4} \text{ M}$; 6.3 times that much H_3O^+ pulls the pH below 4. B skipped the minus in $-\log$: $\log(6.3 \times 10^{-4}) = -3.20$. C reported the pOH: $14 - 3.20 = 10.80$.

 **Sense check:** $6.3 \times 10^{-4} \text{ M}$ lies between $1 \times 10^{-4} \text{ M}$ (pH 4) and $1 \times 10^{-3} \text{ M}$ (pH 3), and 3.20 falls between them. ✓

✓ Practice 3: the route on the map

grapefruit juice: $[\text{H}_3\text{O}^+] = 6.3 \times 10^{-4} \text{ M}$

given: $[\text{H}_3\text{O}^+]$ · found: pH 3.20 · acidic



🧠 **Sense check:** One edge, then the ladder. The coefficient 6.3 adds the decimals. ✓

Practice 4: from $[\text{OH}^-]$ to pH

laundry detergent solution: $[\text{OH}^-] = 4.0 \times 10^{-3} \text{ M}$
measured at 25 °C

What is the pH of the detergent solution?

- A. 11.60
- B. 2.40
- C. 11
- D. 16.40

✓ Practice 4 · answer: A

laundry detergent solution: $[\text{OH}^-] = 4.0 \times 10^{-3} \text{ M}$

$$\text{pOH} = -\log(4.0 \times 10^{-3}) = 2.40 \cdot \text{pH} = 14.00 - 2.40 = 11.60 \text{ (answer A)}$$

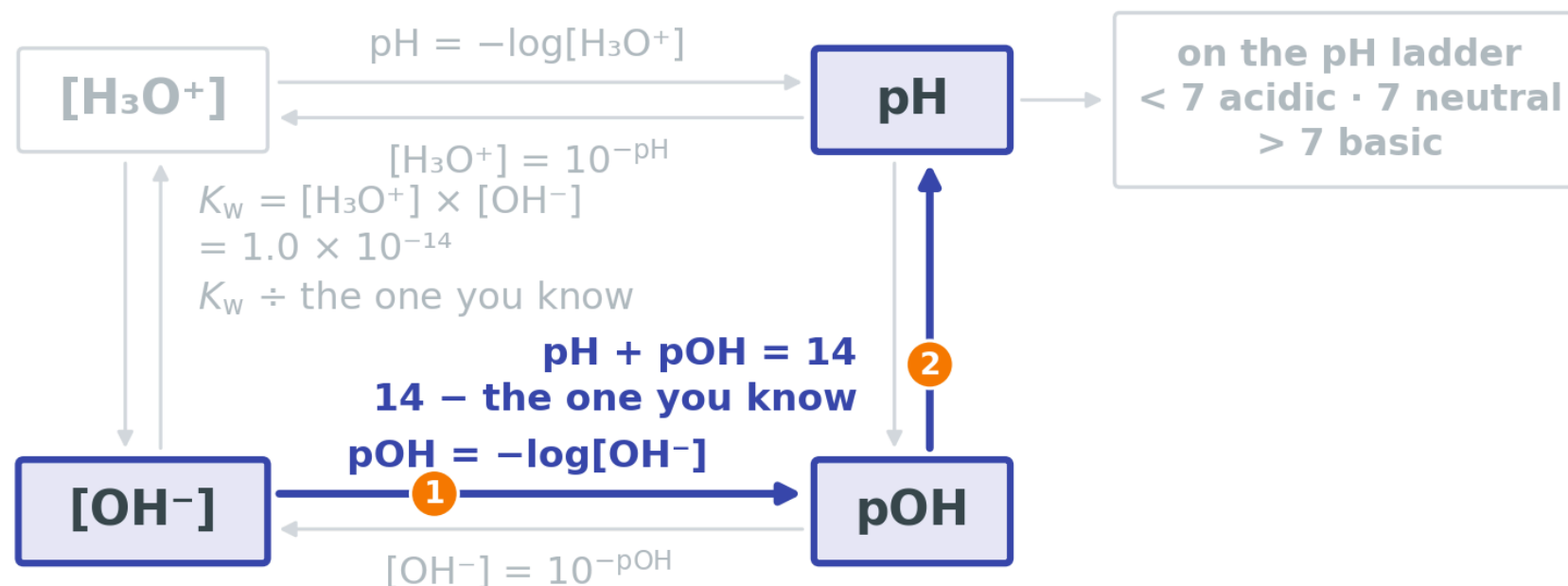
A: two moves, and 4.0 carries two significant figures, so both p-numbers keep two decimals. B stopped at the pOH: 2.40. C read the exponent alone: pOH 3, then $14 - 3 = 11$, ignoring the 4.0. D added: $14 + 2.40 = 16.40$, the same number K_w gives when multiplied instead of divided.

 **Sense check:** The K_w route agrees: $[\text{H}_3\text{O}^+] = 1.0 \times 10^{-14} \div 4.0 \times 10^{-3} = 2.5 \times 10^{-12} \text{ M}$, and $-\log$ gives 11.60. ✓

✓ Practice 4: the route on the map

laundry detergent solution: $[\text{OH}^-] = 4.0 \times 10^{-3} \text{ M}$

given: $[\text{OH}^-]$ · found: pOH 2.40 · pH 11.60



🧠 **Sense check:** Along the bottom with $-\log$, then up the right edge with $14 - \text{pOH}$. ✓



Worked example 4: comparing two solutions

lemon juice: pH 2 · black coffee: pH 5
which holds more H_3O^+ ? by what factor?

Two acidic drinks, three pH steps apart. Decide which side holds more H_3O^+ , then turn the pH gap into a factor.

✓ Worked example 4: solution

Lower pH, more H_3O^+

pH gap: $5 - 2 = 3$ steps
lower pH $\rightarrow$ more H_3O^+ $\rightarrow$ lemon juice

Each pH step is a factor of ten

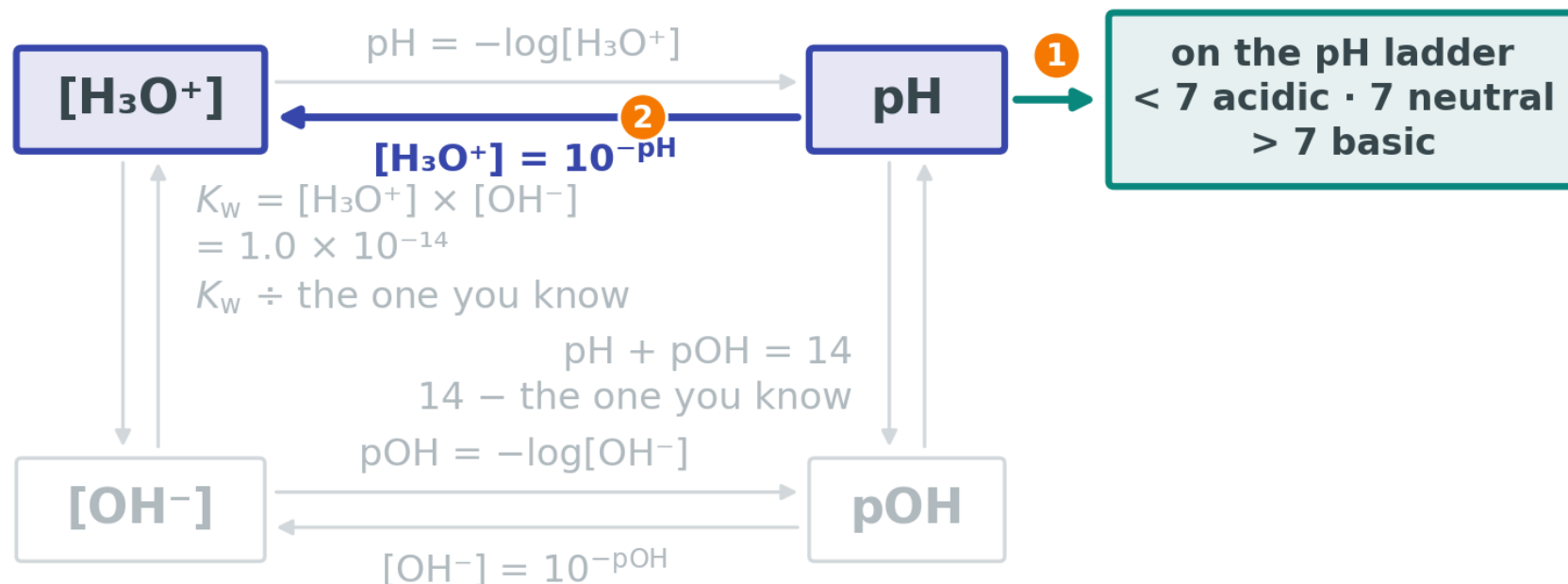
factor = $10 \times 10 \times 10 = 1000$
[H_3O^+]: $1 \times 10^{-2} \text{ M}$ vs $1 \times 10^{-5} \text{ M}$ · lemon juice holds 1000 times the H_3O^+

🧠 **Sense check:** Three whole steps means three factors of ten: the answer is 10^3 , never 3.

✓ Worked example 4: the route on the map

lemon juice: pH 2 · black coffee: pH 5

found: $[\text{H}_3\text{O}^+]$ $1 \times 10^{-2} \text{ M}$ vs $1 \times 10^{-5} \text{ M}$ · lemon juice holds 1000 times the H_3O^+



🧠 **Sense check:** The ladder picks the more acidic drink; the top edge, run backward, gives the factor. ✓



Practice 5

garden-soil extract: pH 9 · rainwater: $[\text{H}_3\text{O}^+] = 1 \times 10^{-4} \text{ M}$ · cleaning solution: pOH 3
all three at 25 °C

Which order runs from the most H_3O^+ to the least?

- A. cleaner > rain > soil
- B. cleaner > soil > rain
- C. rain > soil > cleaner
- D. soil > rain > cleaner

✓ Practice 5 · answer: C

rain: $1 \times 10^{-4} \text{ M} \rightarrow \text{pH } 4$ · soil: pH 9 · cleaner: $\text{pH} = 14 - 3 = 11$

lowest pH holds the most H_3O^+ · rain > soil > cleaner (answer C)

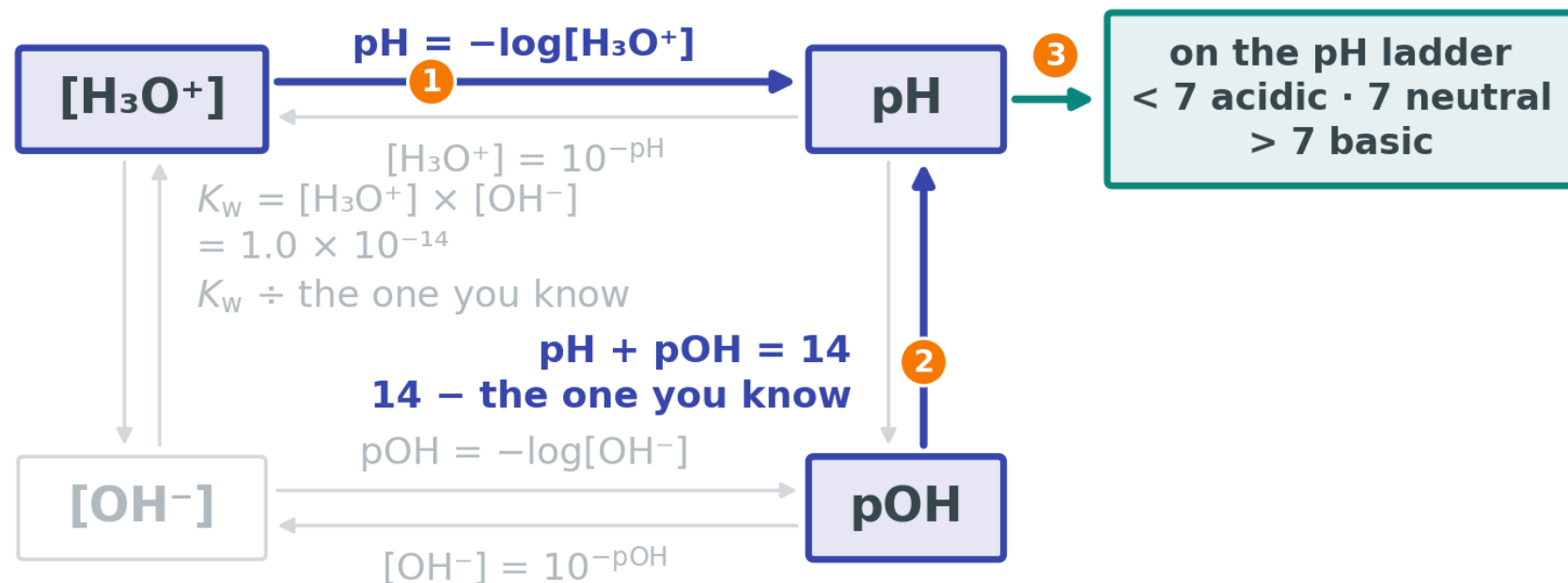
C: every reading on the pH ladder first, then lowest to highest. A read the cleaner's pOH 3 as a pH; $\text{pH} = 14 - 3 = 11$ puts it last. B ranks by the pH values backward: highest pH first means least H_3O^+ first. D treated the rain's 10^{-4} M as OH^- : $14 - 4 = 10$ puts rain below soil; an H_3O^+ concentration reads straight as pH 4.

 **Sense check:** Three different readings, one ladder: convert each to pH before any comparison.

✓ Practice 5: the route on the map

rain: $[\text{H}_3\text{O}^+] = 1 \times 10^{-4} \text{ M}$ · soil: pH 9 · cleaner: pOH 3

found: pH 4 · pH 9 · pH 14 – 3 = 11 · rain > soil > cleaner



🧠 **Sense check:** Rain moves along the top, the cleaner up the right edge; one ladder then ranks all three. ✓



Check yourself

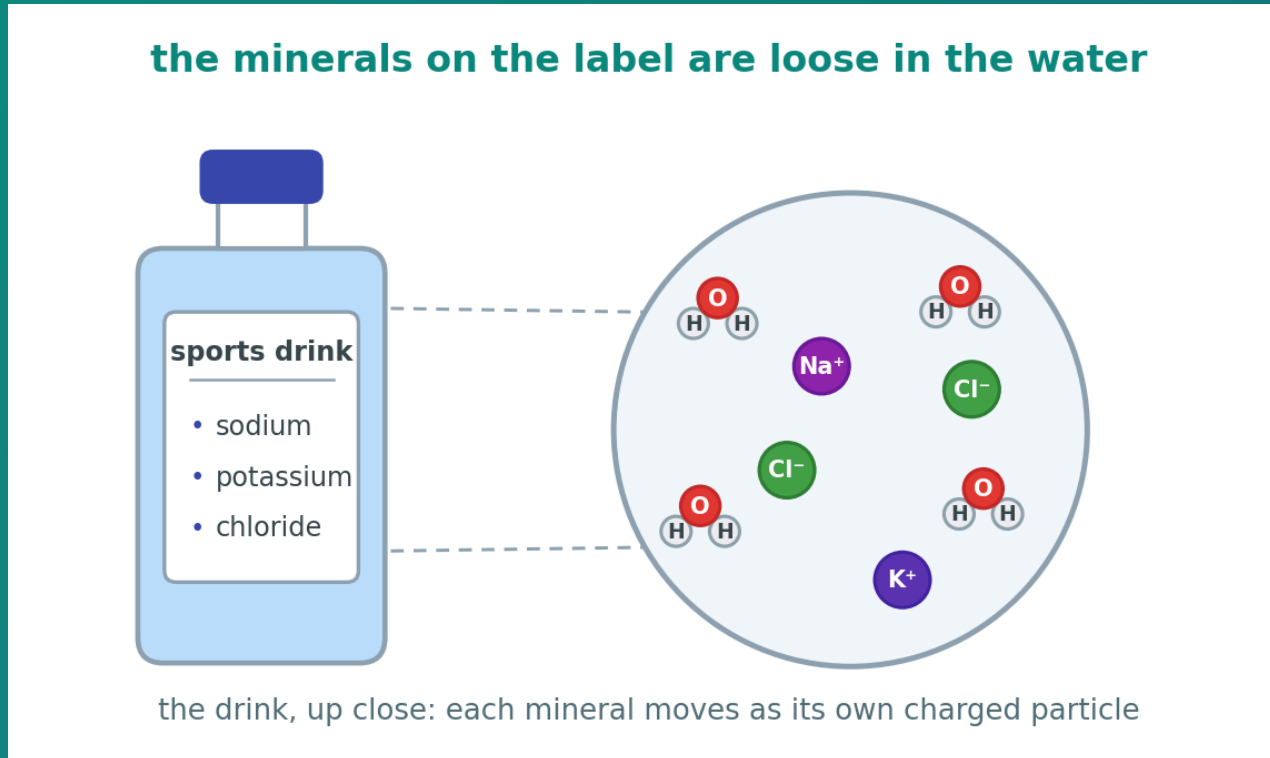
1. Milk of magnesia measures pH 10. Acidic or basic? Write $[\text{H}_3\text{O}^+]$ and $[\text{OH}^-]$ as powers of ten.
2. Orange juice measures pH 3; milk measures pH 6. Which holds more H_3O^+ , and by what factor?

A strong acid ionizes completely and drives the pH far down; a weak acid barely ionizes and leaves it higher. The ions a dissolved substance releases also carry current: electrolytes come next, then titration, where a measured volume of base finds an acid's concentration.

4 · Electrolytes & Dissociation

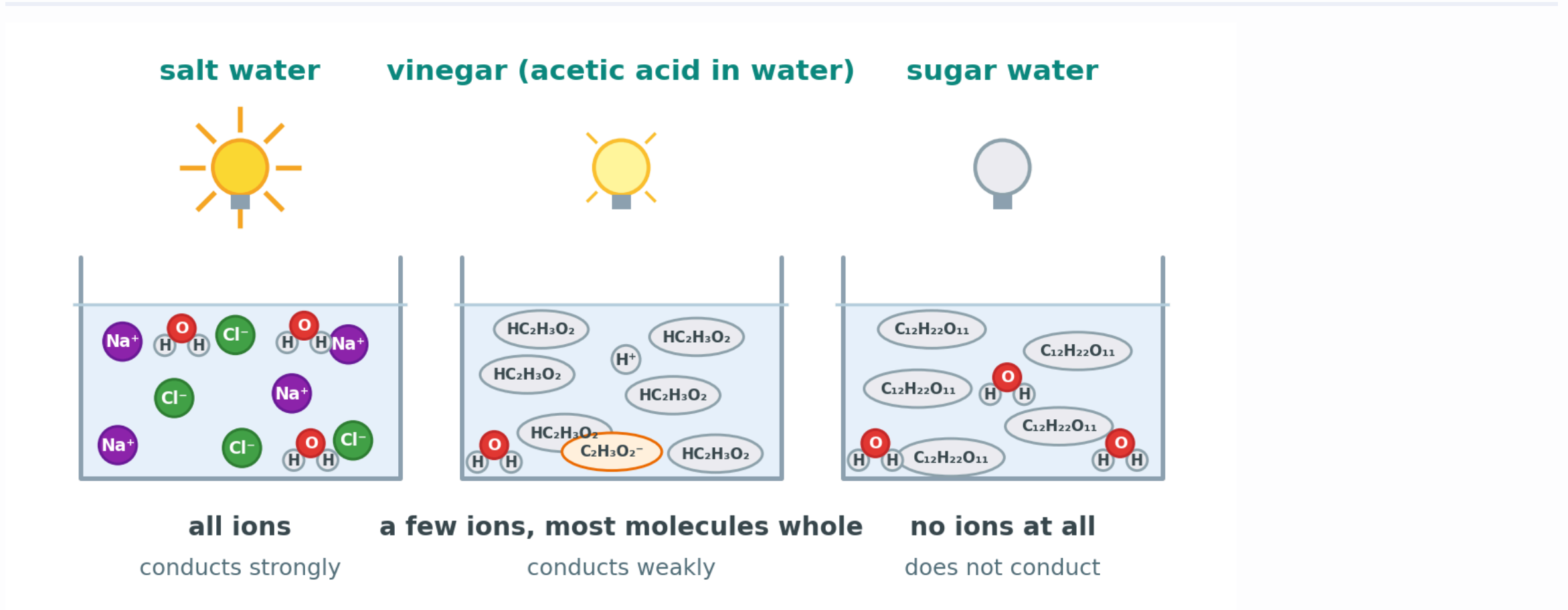
Classify a solute as a strong electrolyte, a weak electrolyte, or a nonelectrolyte from its compound type, and write its dissociation equation with the right ions, coefficients, and charge sum.

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

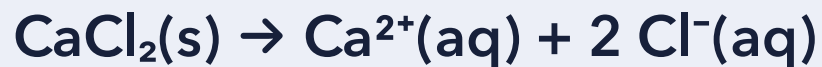
other molecular compounds: sugar · ethanol; no ions, no conduction

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



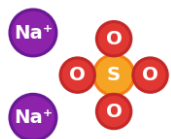
1 + 2 = 3 ions per formula unit · charge: (2+) + 2(1-) = 0

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

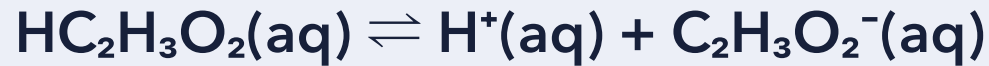


the S-O bonds do not break:
sulfate travels with its own 2- charge



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: $(1+) + (1-) = 0$



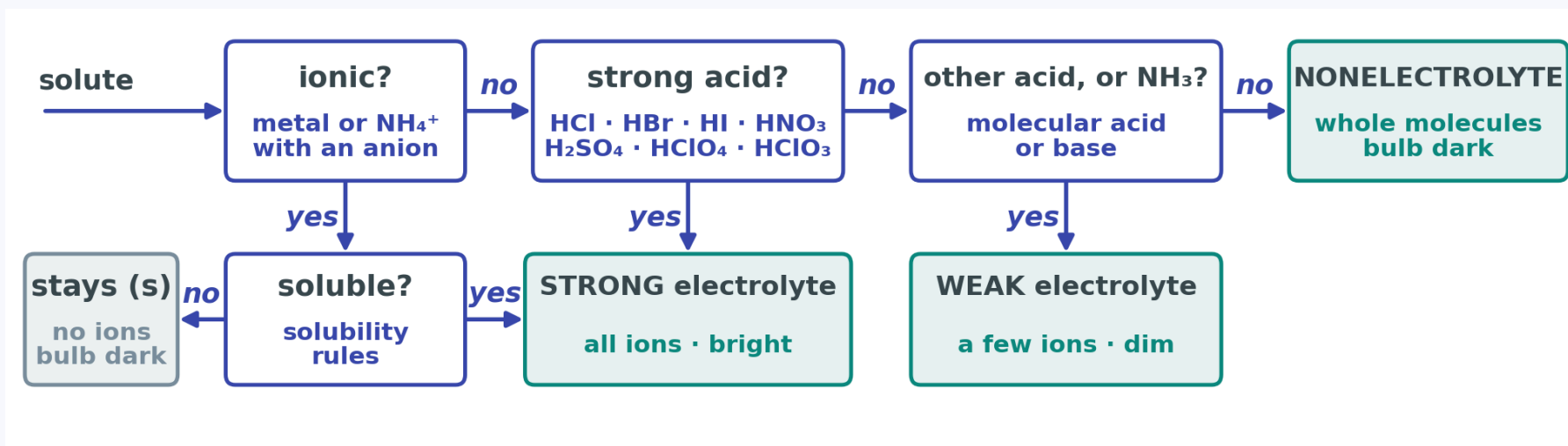
a weak base: only a few molecules react · charge: $(1+) + (1-) = 0$

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

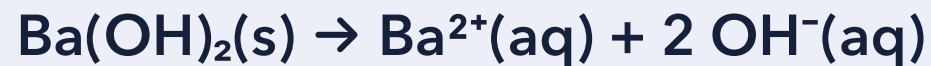
Step 3 • Check the charge sum

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

 **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?

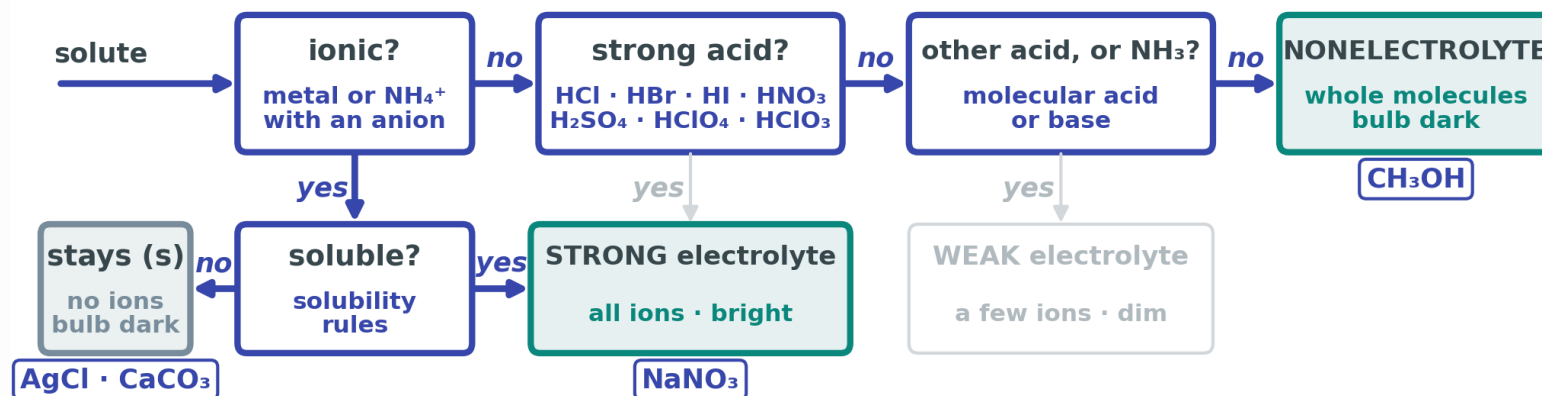
- A. AgCl
- B. CH_3OH
- C. NaNO_3
- D. CaCO_3

✓ 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

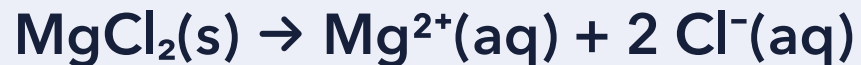
Step 1 · Classify the solute

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

$\text{Na}_2\text{CO}_3 \cdot \text{NH}_3 \cdot \text{C}_2\text{H}_5\text{OH}$
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

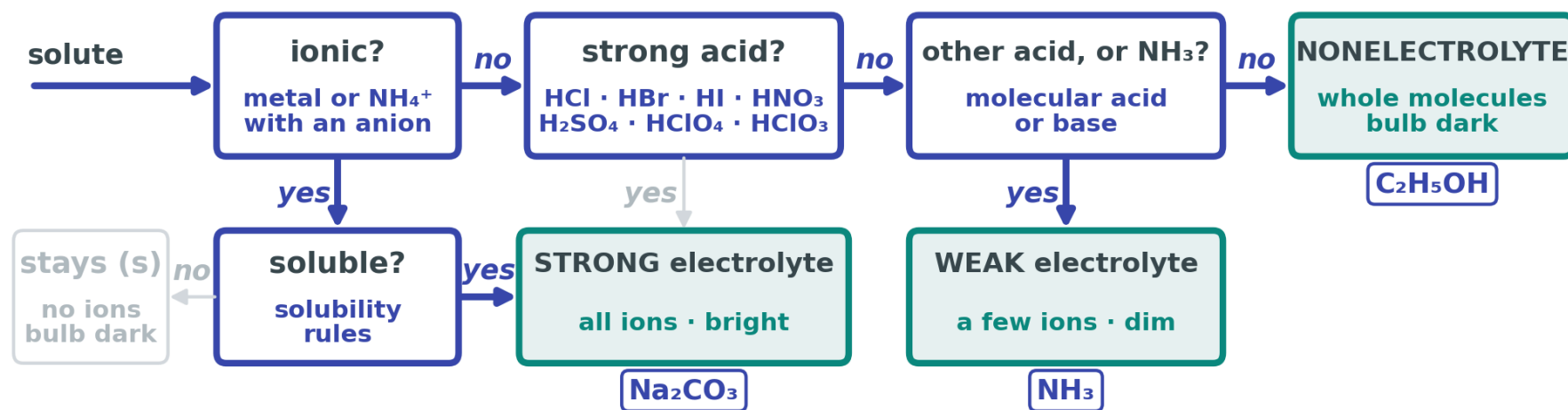
0 ions · the OH is covalently bonded, not OH^-

 **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

$\text{Mg}(\text{NO}_3)_2(\text{s})$ dissolved in water
 given: a soluble ionic compound · nitrate: NO_3^-

step	work	result
1 · classify the solute	soluble ionic compound	_____ electrolyte
2 · write what water makes	$\text{Mg}(\text{NO}_3)_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \underline{\hspace{1cm}}$	ions per formula unit: _____
3 · check the charge sum	$(2+) + 2(1-)$	= _____

Complete the classification and the equation.

$\text{Mg}(\text{NO}_3)_2(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2 \text{NO}_3^-(\text{aq})$
 strong electrolyte · $1 + 2 = 3$ ions · charge: $(2+) + 2(1-) = 0$ · each nitrate leaves whole

Drill: three dissociation equations



all three: soluble ionic $\rightarrow$ strong electrolytes $\cdot$ wanted: each equation, ion count, charge sum

solid	dissociation	ions	charge sum
$\text{K}_2\text{S}(\text{s})$	$2 \text{K}^+(\text{aq}) + \text{S}^{2-}(\text{aq})$	$2 + 1 = \underline{\hspace{1cm}}$	$2(1+) + (2-) = \underline{\hspace{1cm}}$
$(\text{NH}_4)_2\text{SO}_4(\text{s})$	$2 \underline{\hspace{1cm}}(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$	$2 + 1 = 3$	$2(1+) + (2-) = 0$
$\text{Al}(\text{NO}_3)_3(\text{s})$	$\text{Al}^{3+}(\text{aq}) + \underline{\hspace{1cm}}$	$1 + 3 = \underline{\hspace{1cm}}$	$(3+) + 3(1-) = 0$

Complete the table.



every charge sum is 0 $\cdot$ both polyatomic ions travel whole: NH_4^+ and SO_4^{2-}

⚠ 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 3K^+ 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?

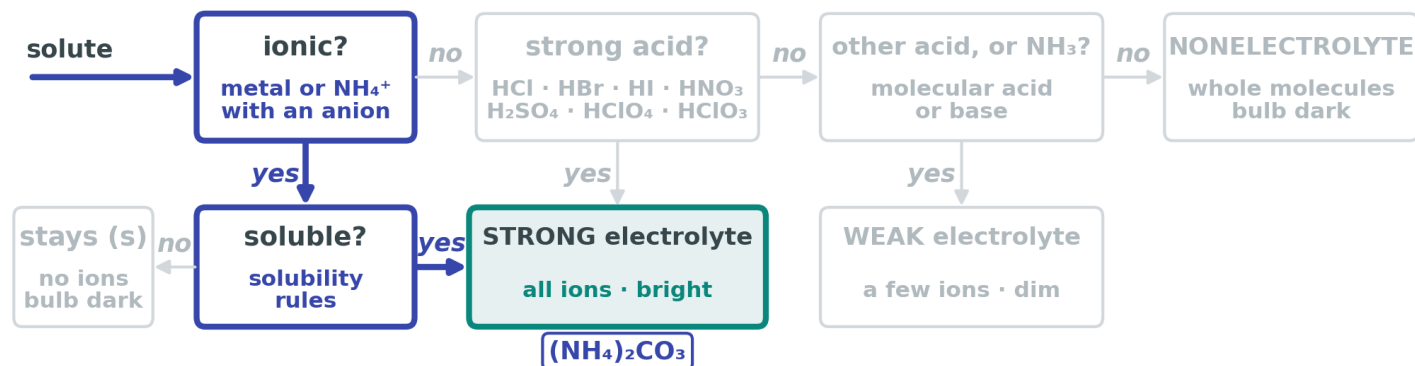
- A. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightleftharpoons 2 \text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- B. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{CO}_3^{2-}(\text{aq})$
- C. $(\text{NH}_4)_2\text{CO}_3(\text{s}) \rightarrow (\text{NH}_4)_2^{2+}(\text{aq})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

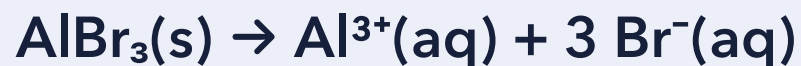


M = mol per liter of solution

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

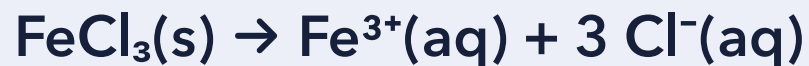
0.15 M FeCl_3 dissolved in water

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 ✓.



Worked example 4: two acids

HNO_3 and $\text{HC}_2\text{H}_3\text{O}_2$, each dissolved in water

given: two molecular acids · wanted: each class + what each solution contains

Nitric acid and acetic acid both dissolve freely, in any proportion. A common first attempt: both are acids, so both ionize completely. Test it.

✓ Worked example 4: solution

HNO_3 and $\text{HC}_2\text{H}_3\text{O}_2$, each dissolved in water

A common first attempt

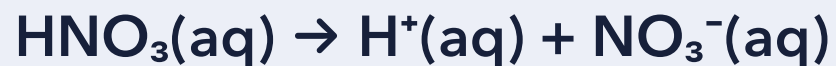
both acids $\rightarrow$ all ions?

the strong-acid list: $\text{HCl} \cdot \text{HBr} \cdot \text{HI} \cdot \text{HNO}_3 \cdot \text{H}_2\text{SO}_4 \cdot \text{HClO}_4 \cdot \text{HClO}_3$; $\text{HC}_2\text{H}_3\text{O}_2$ is not on it ✕

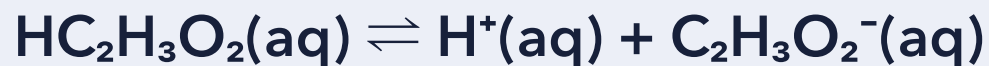
Step 1 · Classify the solute

Step 2 · Write what water makes

Step 3 · Check the charge sum



every molecule ionizes · $1 + 1 = 2$ ions · charge: $(1+) + (1-) = 0$



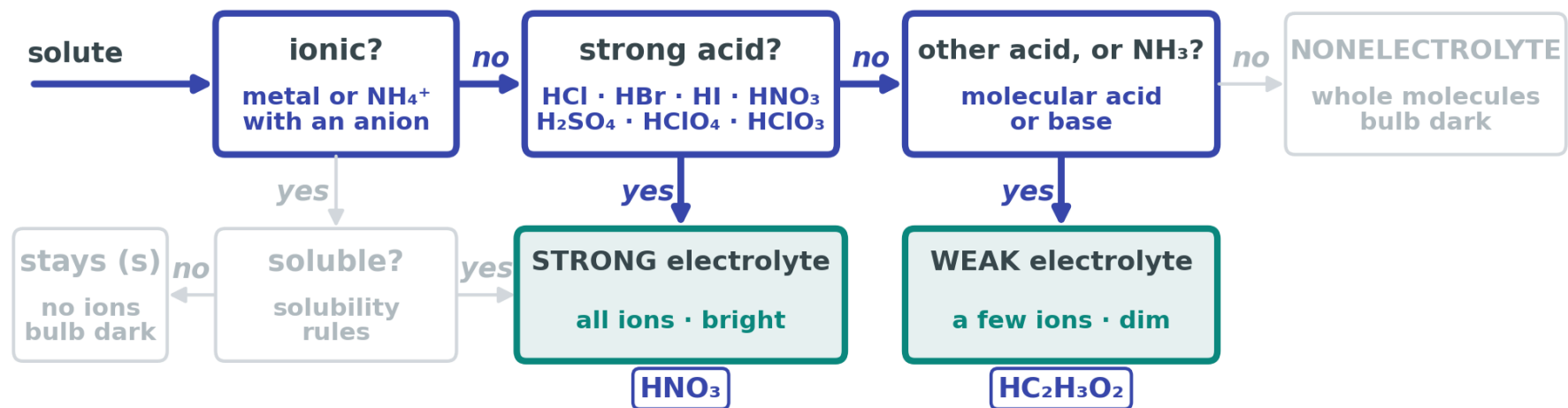
a few molecules ionize, the rest stay whole · charge: $(1+) + (1-) = 0$

🧠 **Sense check:** Both conduct, not equally: HNO_3 all ions, $\text{HC}_2\text{H}_3\text{O}_2$ mostly whole molecules: a dim bulb. ✓

✓ Worked example 4: the route on the chart

HNO_3 and $\text{HC}_2\text{H}_3\text{O}_2$

HNO_3 : not ionic, on the strong-acid list · $\text{HC}_2\text{H}_3\text{O}_2$: not ionic, off the list, another acid



🧠 **Sense check:** Both acids skip the solubility question. The strong-acid list alone splits them: one exit bright, one dim. ✓

Take-home: dissolving is not ionizing

HNO_3 : on the strong-acid list

dissolves freely and ionizes completely: all ions in solution

$\text{HC}_2\text{H}_3\text{O}_2$: not on the list

dissolves just as freely, barely ionizes: mostly whole molecules

Solubility measures how much dissolves. Electrolyte strength measures what the dissolved substance becomes. An acid is a strong electrolyte only if it is on the memorized list; every other acid is weak.



Extra practice



perchloric acid · hydrofluoric acid · sucrose · sodium fluoride · equal concentrations

Each solution is tested with a light-bulb conductivity tester. Which solution lights the bulb only dimly?

- A. HF
- B. HClO_4
- C. $\text{C}_{12}\text{H}_{22}\text{O}_{11}$
- D. NaF

✓ Extra practice: answer A



an acid off the strong list: weak electrolyte · a few molecules ionize · charge: $(1+) + (1-) = 0$

B is on the strong-acid list (HCl, HBr, HI, HNO₃, H₂SO₄, HClO₄, HClO₃): every molecule ionizes, and the bulb glows bright. C is molecular and neither acid nor base: sucrose dissolves as whole molecules, and the bulb stays dark. D shares fluorine with HF but is a soluble ionic compound: $\text{NaF} \rightarrow \text{Na}^{\text{+}} + \text{F}^{-}$ dissociates completely, a bright bulb.

 **Sense check:** Four solutes, three classes: bright (HClO₄, NaF), dim (HF), dark (sucrose). The compound type decides, not the elements it contains.

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?

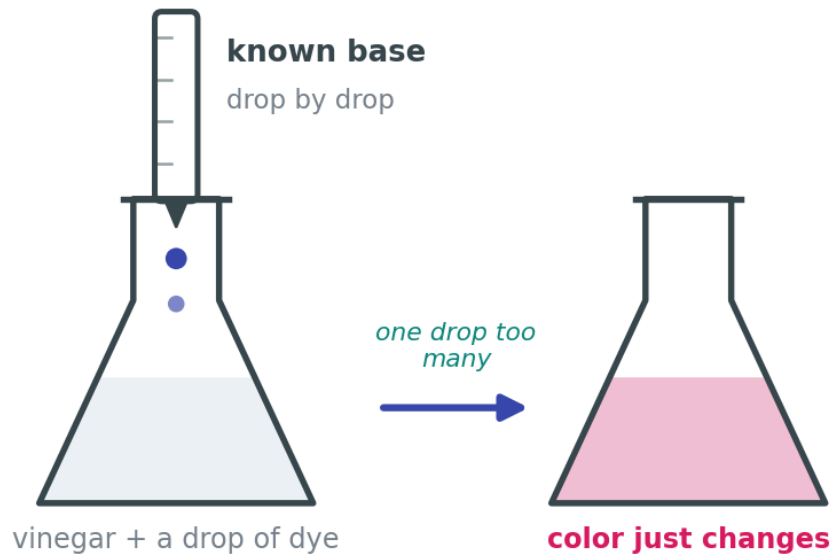
Every (aq) compound in a reaction equation is shorthand for these separated ions. Which new pairings leave the water, and which ions only watch, is exactly what the solubility rules and the net ionic equation track. The **acids and bases** among these solutes get their own strong and weak lists, and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

5 • Titration Calculations

Find an unknown acid concentration from a titration by counting the titrant's millimoles, dividing out the balanced equation's base-to-acid ratio, and dividing by the acid's volume; the milliliters cancel.

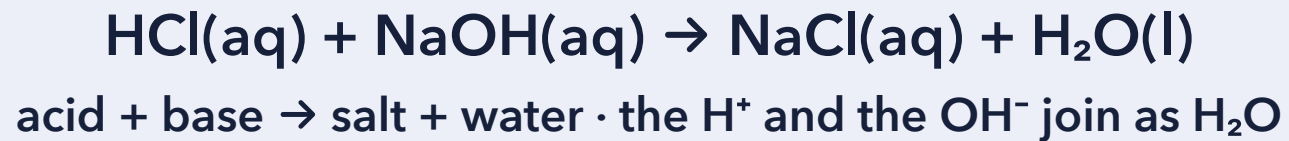
Reading the acid in vinegar

Count the base you added, and you know the acid.



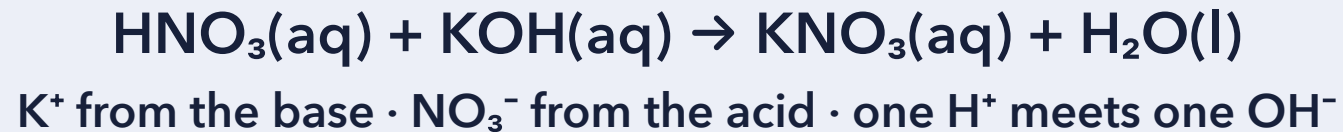
Add a drop of dye to vinegar, then drip in a known base until the color just changes. The base you used measures the acid.

Acid plus base makes salt and water



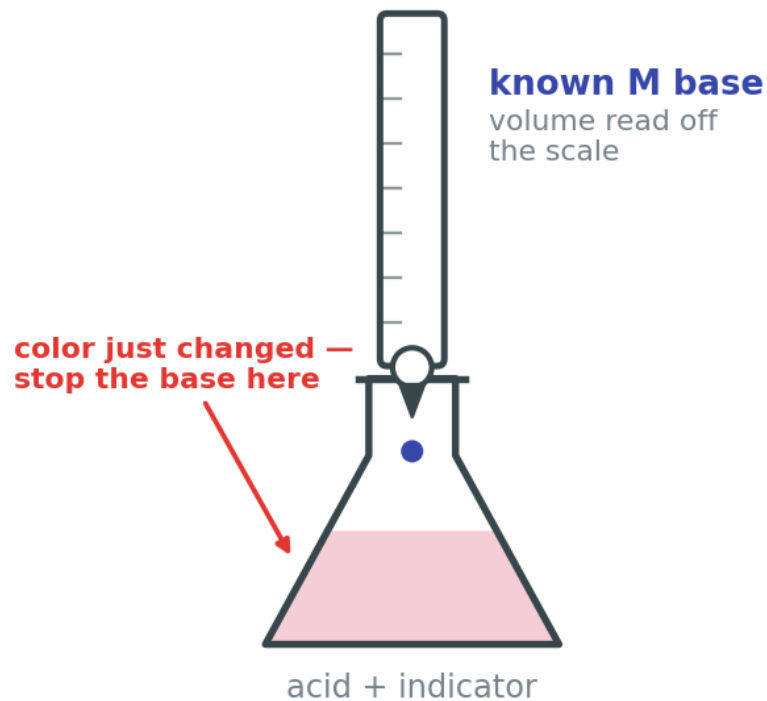
An acid and a base neutralize each other. Each H^+ from the acid meets one OH^- from the base. The ions left over form a salt.

Complete it: $\text{HNO}_3(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow ?$



The equivalence point

The base exactly neutralizes the acid.



at the color change
moles OH^- added
=
moles H^+ available

Add a known base to an acid until an indicator flips; this addition is a titration. At the flip, the equivalence point, moles of OH^- added equal moles of H^+ available.

End point and equivalence point

equivalence point: moles of H^+ = moles of OH^-

end point: the indicator changes color · a good indicator changes within one drop of the equivalence point

The equivalence point cannot be seen. The indicator's color change, the end point, marks it. The buret reading at the end point is the volume the calculation uses.

Molarity is a conversion factor

0.250 M NaOH = 0.250 mol per 1 L = 0.250 mmol per 1 mL
mol and L both shrink by 1000 to mmol and mL · the ratio stays 0.250

$$\frac{0.250 \text{ mmol NaOH}}{1 \text{ mL}} \text{ or } \frac{1 \text{ mL}}{0.250 \text{ mmol NaOH}} \cdot \text{pick the one that cancels the given unit}$$

Molarity links volume and moles, either way up. How many millimoles of NaOH are in **12.00 mL** of 0.250 M NaOH?

$$12.00 \text{ mL} \times \frac{0.250 \text{ mmol NaOH}}{1 \text{ mL}}$$

= **3.00 mmol NaOH** · in liters: $0.01200 \text{ L} \times 0.250 \text{ mol/L} = 0.00300 \text{ mol}$, the same amount

Equal millimoles in a 1:1 reaction

$$0.200 \text{ M} \times 25.00 \text{ mL} = 5.00 \text{ mmol}$$

molarity $\times$ volume, with volume in mL, counts millimoles

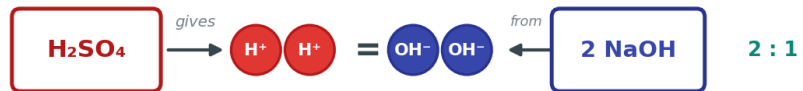
$$M_{\text{acid}} \cdot V_{\text{acid}} = M_{\text{base}} \cdot V_{\text{base}}$$

1 : 1 acid to base $\cdot$ both volumes in mL, so the mL cancel

Moles equal molarity times volume. With volume in milliliters, that product counts millimoles. When an acid and base react one-to-one, their millimoles are equal.

Polyprotic acids need the mole ratio

Each acidic H needs one OH⁻.



The balanced equation sets the base-to-acid ratio.

$$M_{\text{acid}} = M_{\text{base}} \cdot V_{\text{base}} \div (\text{ratio} \cdot V_{\text{acid}})$$

ratio = base units per acid unit · the mL cancel, so no liter step

A diprotic acid gives two H⁺ per unit; a triprotic gives three. Each H⁺ takes one OH⁻, so the balanced equation's coefficients set the base-to-acid ratio.

memory hook: count the H's written first

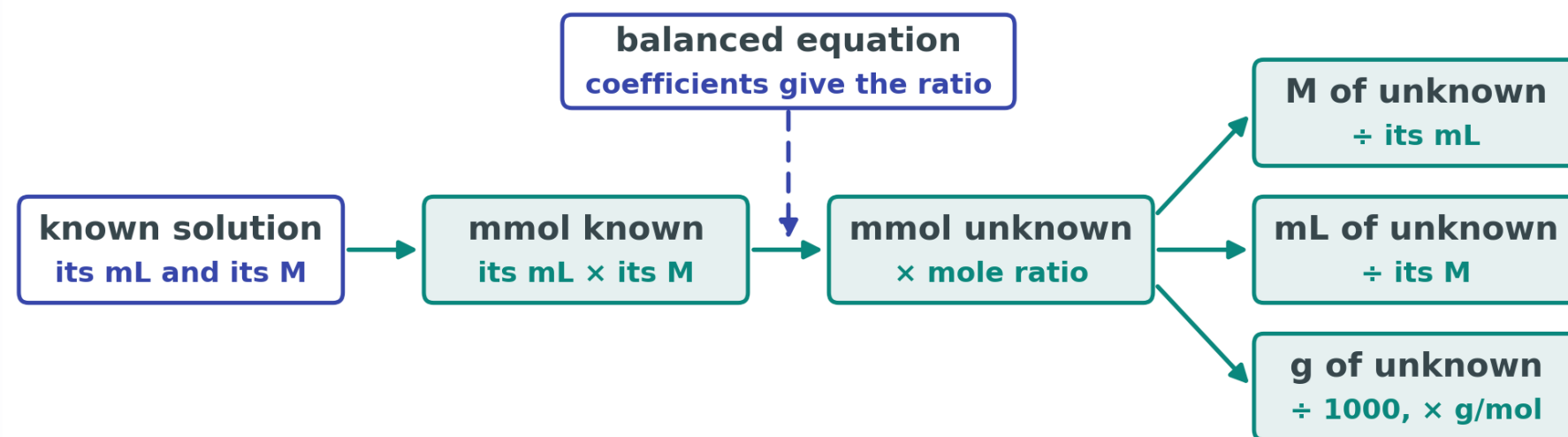
HCl 1 · H₂SO₄ 2 · H₃PO₄ 3 · that many NaOH per acid



The method

1. **Moles of the known solution:** $\text{molarity} \times \text{mL}$ gives millimoles.
2. **Apply the mole ratio:** cross to the other substance with the balanced equation.
3. **Divide to finish:** by its volume for a molarity, or by its molarity for a volume.

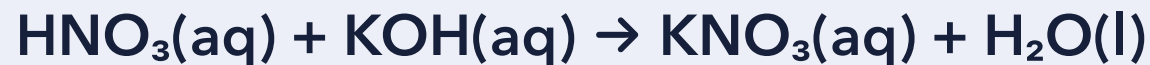
The route through a titration problem



Start from the solution whose molarity and volume are both known. The balanced equation carries its millimoles across. The wanted quantity picks the exit.



Guided example: a KOH solution

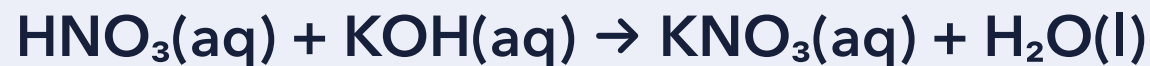


given: 15.00 mL KOH titrated by 18.60 mL of 0.100 M HNO_3 · wanted: M of the KOH

A **15.00 mL** sample of potassium hydroxide solution is titrated with **0.100 M HNO_3** . The indicator changes color after **18.60 mL** of acid. Find the molarity of the KOH.

Name the known solution first: the one with both its molarity and its volume given.

✓ Guided example: solution



given: 15.00 mL KOH · 18.60 mL of 0.100 M HNO_3 · wanted: M of the KOH

Step 1 · Moles of the known solution

$$18.60 \text{ mL acid} \times \frac{0.100 \text{ mmol HNO}_3}{1 \text{ mL acid}} = 1.86 \text{ mmol HNO}_3$$

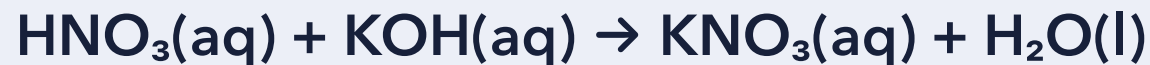
Step 2 · Apply the mole ratio

Step 3 · Divide to finish

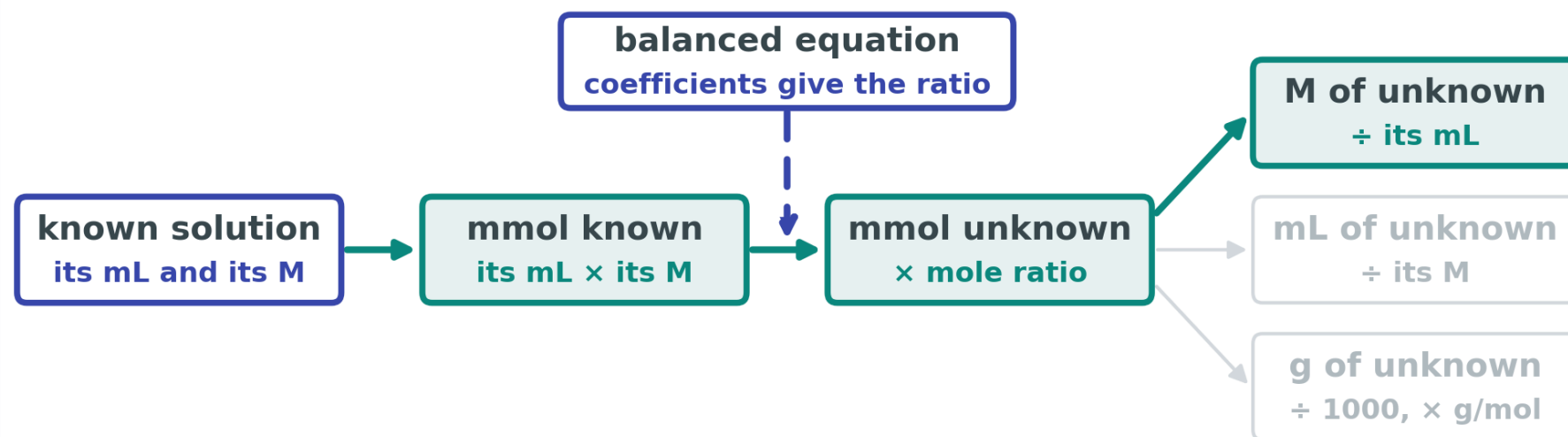
$$M = \frac{1.86 \text{ mmol KOH}}{15.00 \text{ mL base}} = 0.124 \text{ M KOH}$$

 **Sense check:** It took more acid (18.60 mL) than there was base (15.00 mL), so the base is more concentrated than the acid's 0.100 M: 0.124 M ✓

✓ Guided example: the route on the map



given: 18.60 mL of 0.100 M HNO_3 · 15.00 mL KOH · found: 0.124 M KOH



 **Sense check:** The known solution is the acid. Its 1.86 mmol cross the 1 : 1 ratio, and the KOH's own 15.00 mL give the molarity. ✓



Worked example 1: a one-to-one titration



given: 20.00 mL HCl titrated by 25.00 mL of 0.200 M NaOH · wanted: M of the HCl

A **20.00 mL** sample of hydrochloric acid of unknown concentration is titrated with **0.200 M NaOH**. The indicator changes color after **25.00 mL** of base. Find the concentration of the acid.

Set it up: the base's millimoles, the 1:1 ratio, then divide by the acid's volume.

✓ Worked example 1: solution



given: 20.00 mL HCl · 25.00 mL of 0.200 M NaOH · wanted: M of the HCl

Step 1 · Moles of the known solution

$$25.00 \text{ mL base} \times \frac{0.200 \text{ mmol NaOH}}{1 \text{ mL base}} = 5.00 \text{ mmol NaOH}$$

Step 2 · Apply the mole ratio

Step 3 · Divide to finish

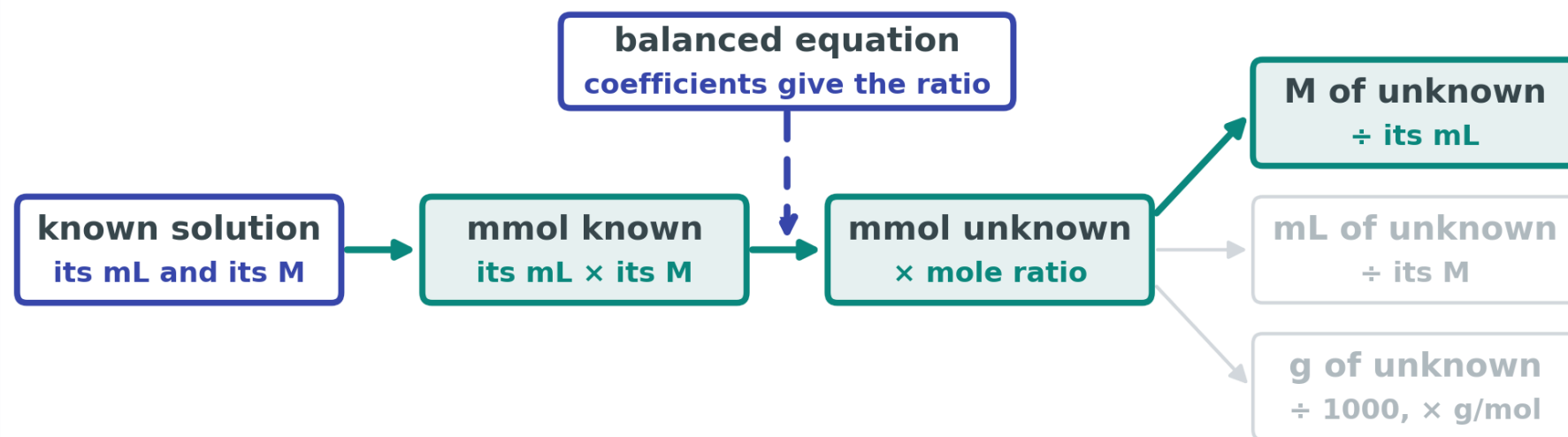
$$M = \frac{5.00 \text{ mmol HCl}}{20.00 \text{ mL acid}} = 0.250 \text{ M HCl}$$

 **Sense check:** The base's 25.00 mL slightly topped the acid's 20.00 mL at 0.200 M, so the acid runs a little higher: 0.250 M ✓

✓ Worked example 1: the route on the map



given: 25.00 mL of 0.200 M NaOH · 20.00 mL HCl · found: 0.250 M HCl

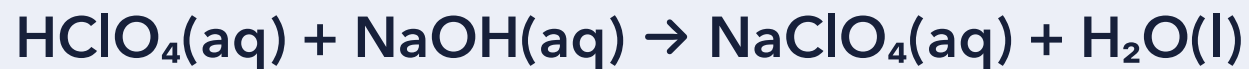


🧠 **Sense check:** Here the base in the buret is the known solution. Same chain, same exit: ÷ the acid's own 20.00 mL.





Practice 1

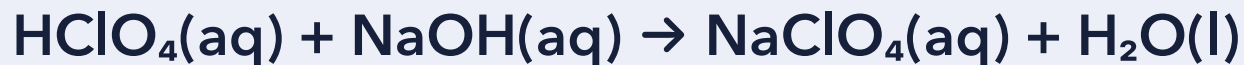


titrant 0.100 M NaOH · sample 16.00 mL perchloric acid

A **16.00 mL** sample of perchloric acid needs **22.40 mL of 0.100 M NaOH** to reach the end point. What is the molarity of the HClO_4 ?

- A. 0.0714
- B. 0.000140
- C. 0.0583
- D. 0.140

✓ Practice 1 answer: D



given: 16.00 mL HClO_4 · 22.40 mL of 0.100 M NaOH · wanted: M of the HClO_4

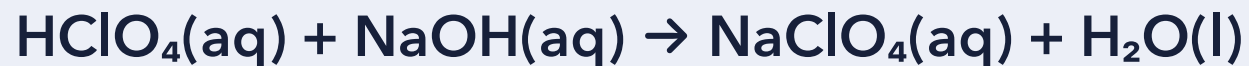
$$22.40 \text{ mL base} \times \frac{0.100 \text{ mmol NaOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol HClO}_4}{1 \text{ mmol NaOH}}$$

= 2.24 mmol HClO_4 , then $\div$ 16.00 mL acid = **0.140 M · answer D**

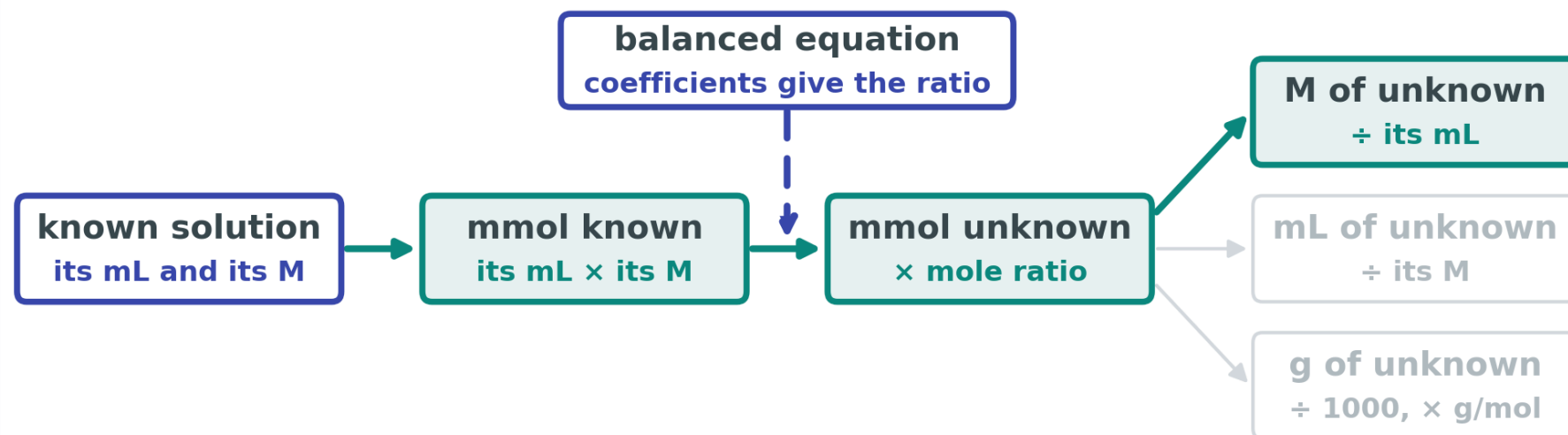
A swapped the volumes: $0.100 \times 16.00 \div 22.40 = 0.0714 \text{ M}$. B put the base's volume in liters but left the acid's in mL: $0.100 \times 0.02240 \div 16.00 = 0.000140$. C divided by the total volume in the flask: $2.24 \div 38.40 = 0.0583 \text{ M}$.

 **Sense check:** More base than acid by volume, so the acid is more concentrated than the base's 0.100 M:
0.140 M ✓

✓ Practice 1: the route on the map



given: 22.40 mL of 0.100 M NaOH · 16.00 mL HClO₄ · found: 0.140 M HClO₄



🧠 **Sense check:** The molarity exit divides by the acid's own 16.00 mL, never by the 38.40 mL of mixture in the flask. ✓



Worked example 2: a diprotic acid



given: 20.00 mL H_2SO_4 titrated by 32.00 mL of 0.250 M NaOH · wanted: M of the H_2SO_4

A **20.00 mL** sample of sulfuric acid is titrated with **0.250 M NaOH**, and the indicator changes color after **32.00 mL** of base. Sulfuric acid is diprotic: each unit gives two H^+ . Find its concentration.

A tempting shortcut: carry the base's millimoles straight to the acid's volume. Test it against the balanced equation.

✓ Worked example 2: solution



given: 20.00 mL H_2SO_4 · 32.00 mL of 0.250 M NaOH · wanted: M of the H_2SO_4

Step 1 · Moles of the known solution

The tempting shortcut

Carry the base's millimoles straight to the acid's volume, as if the ratio were one:

$$M = \frac{8.00 \text{ mmol NaOH}}{20.00 \text{ mL acid}} = 0.400 \text{ M} \times$$

 **Sense check:** Each H_2SO_4 gives two H^+ , so those 8.00 mmol OH^- neutralized only half as many acid units. ✗

✓ Worked example 2: the mole ratio



given: 20.00 mL H_2SO_4 · 32.00 mL of 0.250 M NaOH · wanted: M of the H_2SO_4

Step 2 · Apply the mole ratio

Step 3 · Divide to finish

$$32.00 \text{ mL base} \times \frac{0.250 \text{ mmol NaOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol H}_2\text{SO}_4}{2 \text{ mmol NaOH}}$$

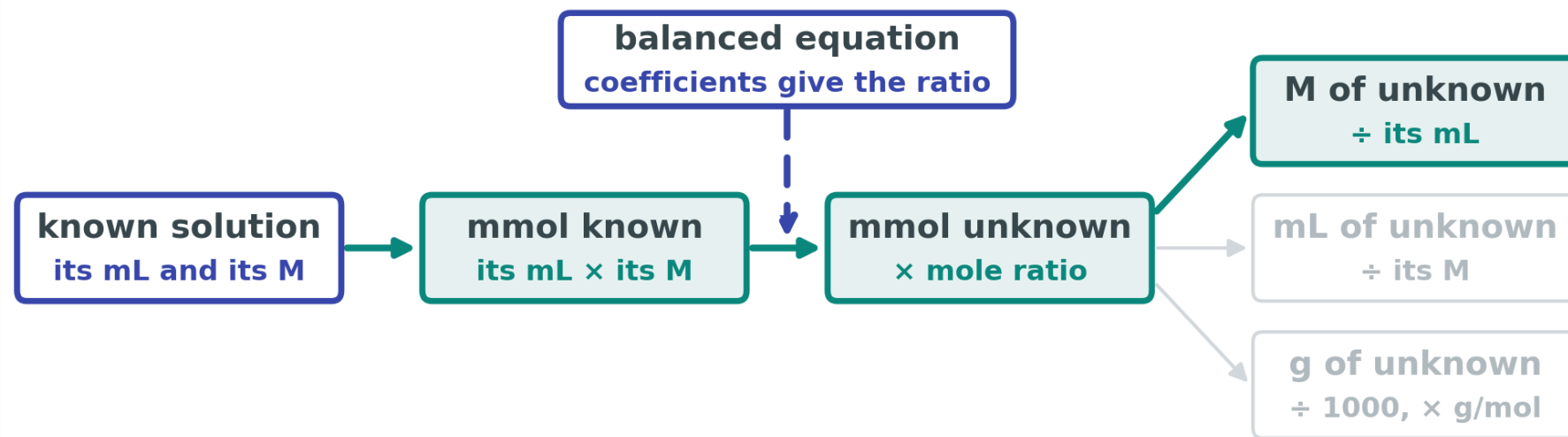
= 4.00 mmol H_2SO_4 , then $\div$ 20.00 mL acid = **0.200 M H_2SO_4**

 **Sense check:** The 2:1 ratio halves the acid's millimoles, so its concentration is half the shortcut's guess: 0.200 M, not 0.400 M ✓

✓ Worked example 2: the route on the map



given: 32.00 mL of 0.250 M NaOH · 20.00 mL H₂SO₄ · found: 0.200 M H₂SO₄



 **Sense check:** The same route as a 1 : 1 titration. Only the ratio step changes: 1 H₂SO₄ per 2 NaOH halves 8.00 mmol to 4.00 mmol. ✓

Take-home: a polyprotic acid is not 1:1



given: 32.00 mL of 0.250 M NaOH · 20.00 mL H₂SO₄

$$M = \frac{8.00 \text{ mmol NaOH}}{20.00 \text{ mL acid}} = 0.400 \text{ M} \times \cdot \text{counts each H}_2\text{SO}_4 \text{ as one H}^+$$

$$32.00 \text{ mL base} \times \frac{0.250 \text{ mmol NaOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol H}_2\text{SO}_4}{2 \text{ mmol NaOH}} \div 20.00 \text{ mL acid} = \mathbf{0.200 \text{ M} \checkmark}$$

A diprotic acid feeds two H⁺, a triprotic three. The balanced equation's ratio divides the base's millimoles before the volume does. Skip it and every diprotic answer comes out doubled.

Your turn: sulfuric acid and KOH



given: 40.00 mL of 0.150 M KOH · 25.00 mL H_2SO_4 · wanted: M of the H_2SO_4

It takes **40.00 mL of 0.150 M KOH** to titrate **25.00 mL of H_2SO_4** . Fill the molarity, the 2:1 ratio, and the acid's volume, then compute:

$$40.00 \text{ mL base} \times \frac{\text{_____ mmol KOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol H}_2\text{SO}_4}{\text{_____ mmol KOH}}$$

$$= \text{_____ mmol H}_2\text{SO}_4, \text{ then } \div \text{_____ mL acid} = \text{_____ M}$$

$$40.00 \text{ mL base} \times \frac{0.150 \text{ mmol KOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol H}_2\text{SO}_4}{2 \text{ mmol KOH}}$$

$$= 3.00 \text{ mmol H}_2\text{SO}_4, \text{ then } \div 25.00 \text{ mL acid} = \mathbf{0.120 \text{ M H}_2\text{SO}_4}$$

⚠ Where this goes wrong



given: 32.00 mL of 0.250 M NaOH · 20.00 mL H₂SO₄ · correct: 8.00 mmol NaOH → 4.00 mmol H₂SO₄ → 0.200 M

Treating the diprotic acid as 1:1. 8.00 mmol ÷ 20.00 mL = 0.400 M, double the truth. Each H₂SO₄ gives two H⁺, so divide the base's millimoles by 2 first.

Multiplying by the ratio instead of dividing. 2 × 8.00 ÷ 20.00 = 0.800 M. Each acid unit uses up two OH⁻, so there are fewer acid units than base units: the 2 divides.

Swapping the two volumes. Pairing 0.250 M with 20.00 mL gives 0.250 × 20.00 ÷ 2 ÷ 32.00 = 0.0781 M. Each molarity multiplies its own solution's volume.



Practice 2



titrant 0.125 M NaOH · sample 18.00 mL oxalic acid

It takes **28.80 mL of 0.125 M NaOH** to reach the color change while titrating **18.00 mL of oxalic acid**. What is the molarity of the oxalic acid?

- A. 1.80
- B. 0.100
- C. 0.200
- D. 0.400

✓ Practice 2 answer: B



given: 18.00 mL $\text{H}_2\text{C}_2\text{O}_4$ · 28.80 mL of 0.125 M NaOH · wanted: M of the $\text{H}_2\text{C}_2\text{O}_4$

$$28.80 \text{ mL base} \times \frac{0.125 \text{ mmol NaOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol H}_2\text{C}_2\text{O}_4}{2 \text{ mmol NaOH}}$$

= 1.80 mmol $\text{H}_2\text{C}_2\text{O}_4$, then $\div$ 18.00 mL acid = **0.100 M · answer B**

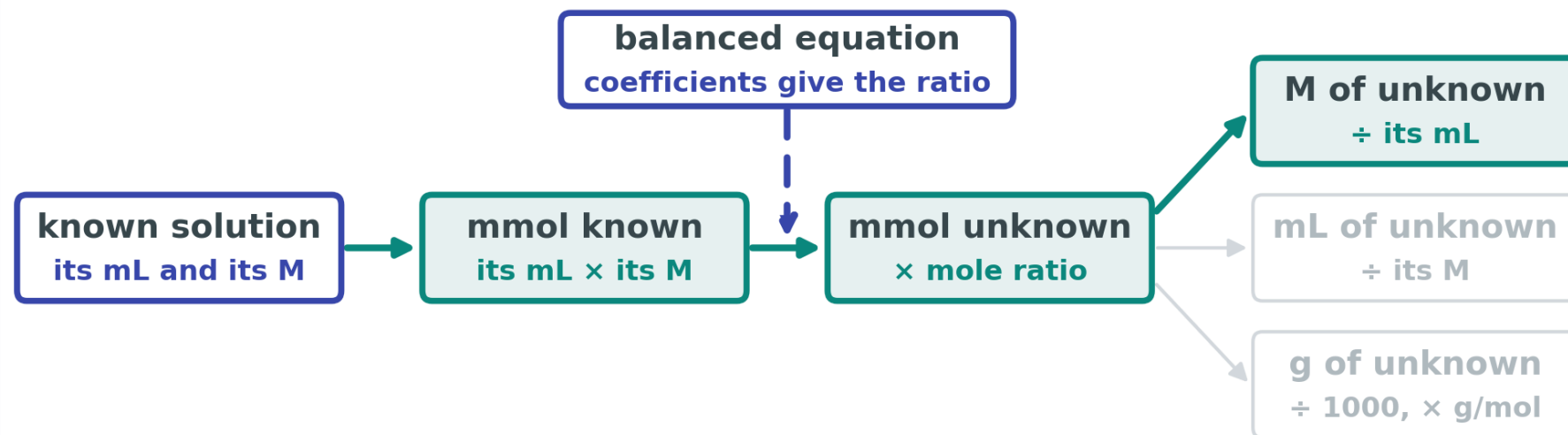
A stopped at 1.80 mmol of oxalic acid, before dividing by its 18.00 mL. C ignored the 2:1 ratio: $3.60 \div 18.00 = 0.200 \text{ M}$. D multiplied by the ratio: $2 \times 3.60 \div 18.00 = 0.400 \text{ M}$.

 **Sense check:** Two NaOH per oxalic acid, so the acid holds half the base's 3.60 mmol: 1.80 mmol in 18.00 mL is 0.100 M ✓

✓ Practice 2: the route on the map



given: 28.80 mL of 0.125 M NaOH · 18.00 mL $\text{H}_2\text{C}_2\text{O}_4$ · found: 0.100 M $\text{H}_2\text{C}_2\text{O}_4$



 **Sense check:** 3.60 mmol NaOH cross the 2 : 1 ratio as 1.80 mmol $\text{H}_2\text{C}_2\text{O}_4$. The acid's own 18.00 mL finish the molarity. ✓



Worked example 3: volume of base for a triprotic acid



given: 25.00 mL of 0.0600 M H_3PO_4 · titrant 0.150 M NaOH · wanted: mL of NaOH

A **25.00 mL** sample of **0.0600 M phosphoric acid** is titrated with **0.150 M NaOH**.

Phosphoric acid is triprotic: each unit gives three H^+ . What volume of base reaches the color change?

A common first attempt divides by 3 out of habit. Test it against the protons.

✓ Worked example 3: solution



given: 25.00 mL of 0.0600 M H_3PO_4 · 0.150 M NaOH · wanted: mL of NaOH

Step 1 · Moles of the known solution

A common first attempt

$$1.50 \text{ mmol} \div 3 = 0.500 \text{ mmol NaOH} \rightarrow 0.500 \div 0.150 = 3.33 \text{ mL} \times$$

 **Sense check:** Each H_3PO_4 carries three H^+ , and each H^+ takes one OH^- . The base's millimoles are three times the acid's, not a third. $\times$

✓ Worked example 3: the mole ratio



given: 25.00 mL of 0.0600 M H_3PO_4 · 0.150 M NaOH · wanted: mL of NaOH

Step 2 · Apply the mole ratio

Step 3 · Divide to finish

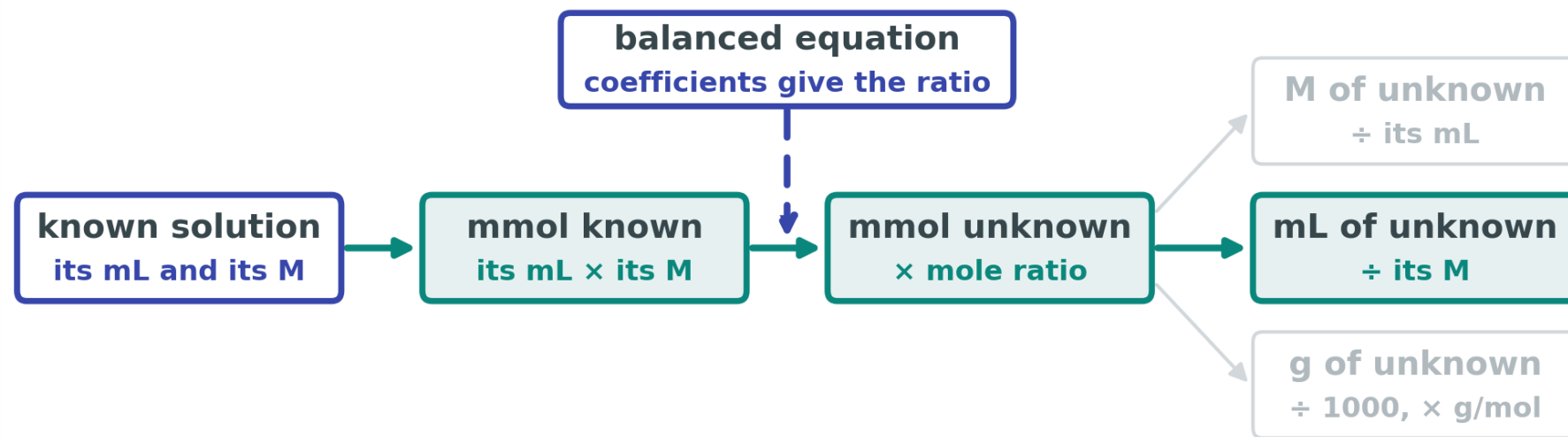
$$1.50 \text{ mmol } \text{H}_3\text{PO}_4 \times \frac{3 \text{ mmol NaOH}}{1 \text{ mmol } \text{H}_3\text{PO}_4} \times \frac{1 \text{ mL base}}{0.150 \text{ mmol NaOH}} = 30.0 \text{ mL NaOH}$$

🧠 **Sense check:** 4.50 mmol of NaOH at 0.150 mmol per mL takes 30.0 mL, nine times the 3.33 mL guess ✓

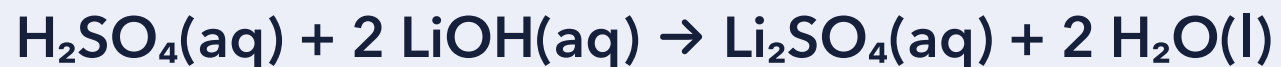
✓ Worked example 3: the route on the map



given: 25.00 mL of 0.0600 M H_3PO_4 · 0.150 M NaOH · found: 30.0 mL NaOH



 **Sense check:** The acid is the known solution. The ratio triples 1.50 mmol to 4.50 mmol NaOH, and the volume exit divides by the base's 0.150 M. ✓

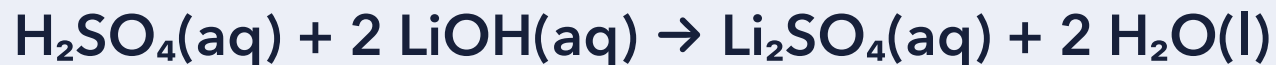
 Practice 3

titrant 0.300 M H_2SO_4 · sample 30.00 mL of 0.120 M LiOH

A spacecraft's CO_2 scrubber runs on lithium hydroxide solution. What volume of **0.300 M H_2SO_4** , in mL, neutralizes **30.00 mL of 0.120 M LiOH**?

- A. 12.0
- B. 24.0
- C. 6.00
- D. 15.0

✓ Practice 3 answer: C



given: 30.00 mL of 0.120 M LiOH · 0.300 M H₂SO₄ · wanted: mL of H₂SO₄

$$30.00 \text{ mL base} \times \frac{0.120 \text{ mmol LiOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol H}_2\text{SO}_4}{2 \text{ mmol LiOH}}$$

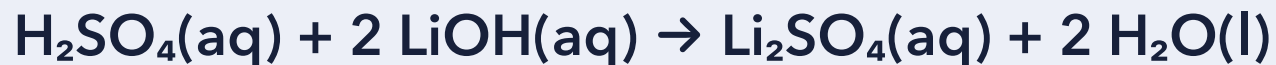
= 1.80 mmol H₂SO₄, then ÷ 0.300 mmol per mL acid = **6.00 mL · answer C**

A ignored the 2 : 1 ratio: 3.60 ÷ 0.300 = 12.0 mL. B multiplied by the ratio: 2 × 3.60 ÷ 0.300 = 24.0 mL. D divided by the base's molarity instead of the acid's: 1.80 ÷ 0.120 = 15.0 mL.

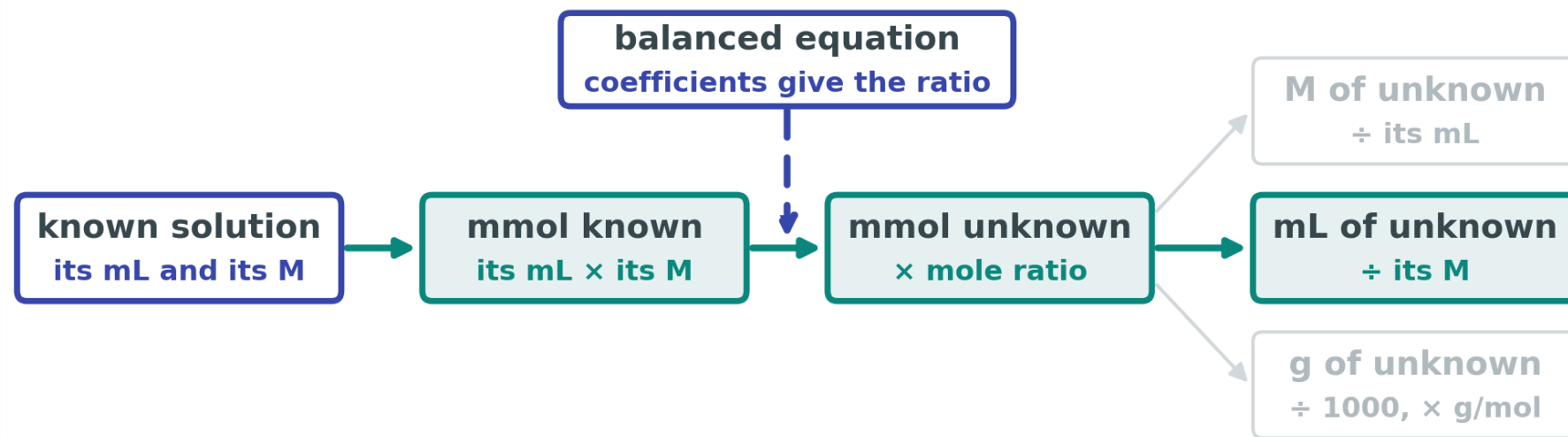
 **Sense check:** The acid is 2.5 times as concentrated, and each H₂SO₄ takes two LiOH: 30.00 mL ÷ 2.5 ÷ 2 = 6.00 mL

✓

✓ Practice 3: the route on the map



given: 30.00 mL of 0.120 M LiOH · 0.300 M H₂SO₄ · found: 6.00 mL H₂SO₄



 **Sense check:** The base is the known solution this time. The ratio halves 3.60 mmol to 1.80 mmol, and the volume exit divides by the acid's own 0.300 M. ✓



Practice 4



given: 26.40 mL of 0.120 M NaOH · citric acid 192.12 g/mol · wanted: g of citric acid

A powdered drink mix is dissolved in water, and its citric acid takes **26.40 mL of 0.120 M NaOH** to reach the color change. How many grams of citric acid did the sample hold?

- A. 0.203
- B. 0.609
- C. 1.06
- D. 203
- E. 1.83

✓ Practice 4 answer: A



26.40 mL of 0.120 M NaOH · citric acid 192.12 g/mol

$$26.40 \text{ mL base} \times \frac{0.120 \text{ mmol NaOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol acid}}{3 \text{ mmol NaOH}} = 1.056 \text{ mmol acid}$$

$$1.056 \text{ mmol} \times \frac{1 \text{ mol}}{1000 \text{ mmol}} \times \frac{192.12 \text{ g}}{1 \text{ mol}} = \mathbf{0.203 \text{ g} \cdot \text{answer A}}$$

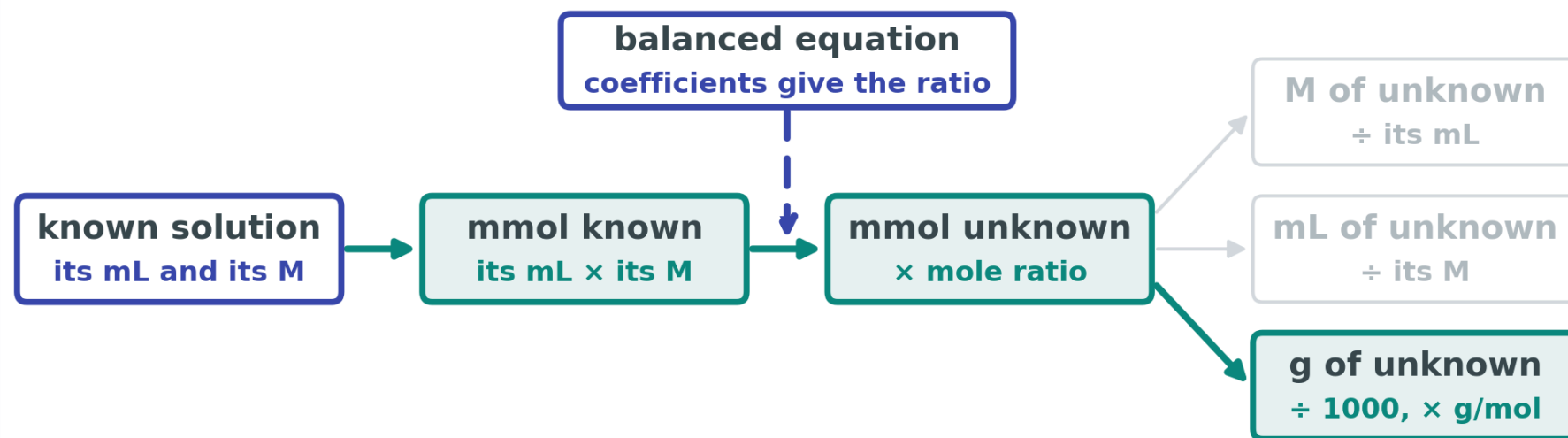
B ignored the 3:1 ratio: 3.168 mmol → 0.609 g. C stopped at 1.06 mmol, before the molar mass. D skipped mmol → mol: 1.056 × 192.12 = 203 g. E multiplied by the ratio: 9.504 mmol → 1.83 g.

 **Sense check:** 1.056 mmol is a third of 3.168: three NaOH per citric acid. 203 g would outweigh the sample. ✓

✓ Practice 4: the route on the map



given: 26.40 mL of 0.120 M NaOH · citric acid 192.12 g/mol · found: 0.203 g



🧠 **Sense check:** The grams exit: 1.056 mmol of acid is 0.001056 mol, and the molar mass turns moles into grams. ✓



Practice 5



skeleton, not yet balanced · titrant 0.05000 M HCl · sample 25.00 mL limewater

Limewater is a calcium hydroxide solution. A **25.00 mL** sample takes **18.36 mL of 0.05000 M HCl** to reach the end point. What is the molarity of the Ca(OH)_2 ?

- A. 0.03672
- B. 0.07344
- C. 0.01059
- D. 0.03404
- E. 0.01836

✓ Practice 5 answer: E



Ca: 1 = 1 ✓ · Cl: 2 = 2 ✓ · H: 4 = 4 ✓ · O: 2 = 2 ✓ · given: 18.36 mL of 0.05000 M HCl · 25.00 mL
Ca(OH)₂

$$18.36 \text{ mL acid} \times \frac{0.05000 \text{ mmol HCl}}{1 \text{ mL acid}} \times \frac{1 \text{ mmol Ca(OH)}_2}{2 \text{ mmol HCl}}$$

= 0.4590 mmol Ca(OH)₂, then ÷ 25.00 mL base = **0.01836 M · answer E**

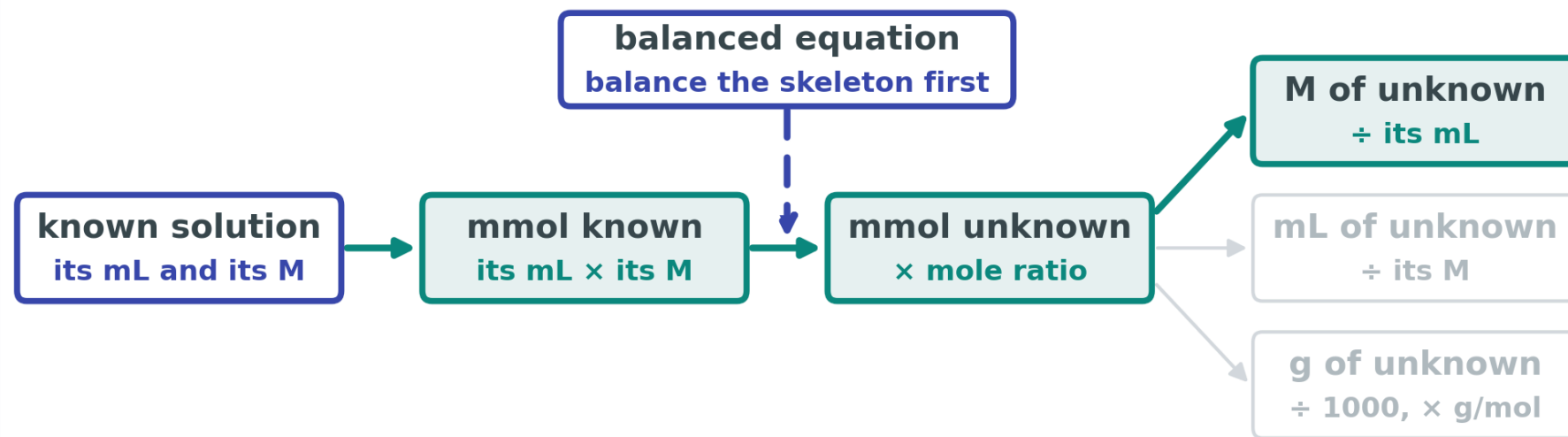
A skipped balancing and used 1 : 1: 0.9180 ÷ 25.00 = 0.03672 M. B multiplied by the ratio: 2 × 0.9180 ÷ 25.00 = 0.07344 M. C divided by the total volume: 0.4590 ÷ 43.36 = 0.01059 M. D swapped the volumes: 0.05000 × 25.00 ÷ 2 ÷ 18.36 = 0.03404 M.

 **Sense check:** Two OH⁻ per Ca(OH)₂, so the base holds half the acid's 0.9180 mmol: 0.4590 mmol in 25.00 mL is 0.01836 M ✓

✓ Practice 5: the route on the map



given: 18.36 mL of 0.05000 M HCl · 25.00 mL Ca(OH)₂ · found: 0.01836 M Ca(OH)₂



 **Sense check:** Balancing comes before the ratio step: 1 Ca(OH)₂ per 2 HCl. The chain then runs as usual and exits through the base's own 25.00 mL. ✓



Extra practice 1



titrant KOH, molarity unknown · sample 10.00 mL of 0.0450 M H_3PO_4

A new bottle of KOH solution needs **12.50 mL** to neutralize **10.00 mL of 0.0450 M H_3PO_4** .
What is the molarity of the KOH?

- A. 0.0360
- B. 0.0120
- C. 0.108
- D. 0.0600

✓ Extra practice 1 answer: C



given: 10.00 mL of 0.0450 M H_3PO_4 · 12.50 mL KOH · wanted: M of the KOH

$$10.00 \text{ mL acid} \times \frac{0.0450 \text{ mmol H}_3\text{PO}_4}{1 \text{ mL acid}} \times \frac{3 \text{ mmol KOH}}{1 \text{ mmol H}_3\text{PO}_4}$$

= 1.35 mmol KOH, then $\div$ 12.50 mL base = **0.108 M · answer C**

A ignored the 3 : 1 ratio: $0.450 \div 12.50 = 0.0360 \text{ M}$. B divided by the ratio: $0.450 \div 3 \div 12.50 = 0.0120 \text{ M}$. D divided by the total volume: $1.35 \div 22.50 = 0.0600 \text{ M}$.

 **Sense check:** The acid is the known solution. Each H_3PO_4 takes three KOH, so the base's millimoles are triple the acid's 0.450 mmol: 1.35 mmol in 12.50 mL is 0.108 M ✓



Extra practice 2



sample 0.2933 g tartaric acid, 150.09 g/mol · titrant NaOH, molarity unknown

A **0.2933 g** sample of solid tartaric acid is dissolved in water and titrated with NaOH. The color change comes after **23.90 mL** of base. What is the molarity of the NaOH?

- A. 0.6136
- B. 0.08176
- C. 3.908
- D. 0.04088
- E. 0.1635

✓ Extra practice 2 answer: E



given: 0.2933 g tartaric acid, 150.09 g/mol · 23.90 mL NaOH · wanted: M of the NaOH

$$0.2933 \text{ g} \times \frac{1 \text{ mol}}{150.09 \text{ g}} \times \frac{1000 \text{ mmol acid}}{1 \text{ mol}} \times \frac{2 \text{ mmol NaOH}}{1 \text{ mmol acid}}$$

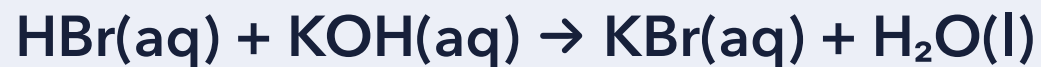
= 3.908 mmol NaOH, then ÷ 23.90 mL base = **0.1635 M · answer E**

A used NaOH's molar mass: $0.2933 \div 40.00 \times 1000 \times 2 \div 23.90 = 0.6136 \text{ M}$. B ignored the 2 : 1 ratio: $1.954 \div 23.90 = 0.08176 \text{ M}$. C stopped at 3.908 mmol NaOH, before dividing by its volume. D divided by the ratio: $1.954 \div 2 \div 23.90 = 0.04088 \text{ M}$.

 **Sense check:** Two NaOH per tartaric acid: 3.908 mmol of base, double the acid's 1.954 mmol ✓



Extra practice 3

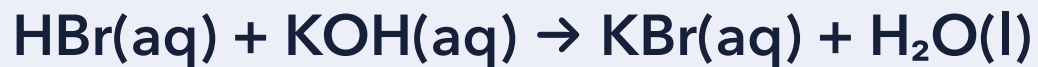


titrant 0.0250 M KOH · sample 20.00 mL hydrobromic acid

A **20.00 mL** sample of hydrobromic acid needs **12.80 mL of 0.0250 M KOH** to reach the end point. What is the pH of the HBr solution?

- A. 1.796
- B. 1.602
- C. 1.408
- D. 2.011
- E. 12.20

✓ Extra practice 3 answer: A



given: 20.00 mL HBr · 12.80 mL of 0.0250 M KOH · wanted: pH of the HBr

$$12.80 \text{ mL base} \times \frac{0.0250 \text{ mmol KOH}}{1 \text{ mL base}} \times \frac{1 \text{ mmol HBr}}{1 \text{ mmol KOH}}$$

$$= 0.320 \text{ mmol HBr} \div 20.00 \text{ mL} = 0.0160 \text{ M H}_3\text{O}^+ \cdot \text{pH} = -\log(0.0160) = \mathbf{1.796 \cdot \text{answer A}}$$

B took $-\log$ of the base's 0.0250 M: 1.602. C swapped the volumes: $0.0250 \times 20.00 \div 12.80 = 0.0391 \text{ M}$, pH 1.408. D divided by the total 32.80 mL: 0.00976 M, pH 2.011. E reported the pOH: $14.00 - 1.796 = 12.20$.

 **Sense check:** HBr is a strong acid, so $[\text{H}_3\text{O}^+] = 0.0160 \text{ M}$, between 10^{-2} and 10^{-1} M : the pH lies between 1 and 2 ✓

Check yourself

1. A 1:1 titration takes **24.0 mL of 0.150 M NaOH** to neutralize **20.0 mL of HCl**. Set up $M_{\text{acid}} = M_{\text{base}} \cdot V_{\text{base}} \div V_{\text{acid}}$ and find the HCl concentration.
2. Phosphoric acid reacts as $\text{H}_3\text{PO}_4 + 3 \text{NaOH} \rightarrow \text{Na}_3\text{PO}_4 + 3 \text{H}_2\text{O}$. Which number becomes the base-to-acid ratio in the denominator, and where does it come from?

Every calculation here counted moles with a concentration, then crossed substances with the balanced equation's ratio: the same mole-ratio bridge that drives reaction stoichiometry. A concentration is only another way to count the moles a reaction runs on.

Can you...?

- ☐ recognize acids and bases by their properties and define them by the Arrhenius and Brønsted-Lowry definitions?
- ☐ identify the Brønsted-Lowry acid, base, and conjugate pairs in a reaction, and write a species' conjugate acid or base?
- ☐ classify acids and bases as strong or weak, write their ionization with the correct arrow, and predict the products of neutralization and gas-forming reactions?
- ☐ use K_w , $\text{pH} = -\log[\text{H}_3\text{O}^+]$, pOH , and $\text{pH} + \text{pOH} = 14$ to convert among $[\text{H}_3\text{O}^+]$, $[\text{OH}^-]$, pH , and pOH and label a solution acidic, basic, or neutral?
- ☐ find an unknown acid or base concentration from titration data?

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