

Concentration: Percent, Molarity, Dilution

Preparation for General Chemistry · Dr. Karmach

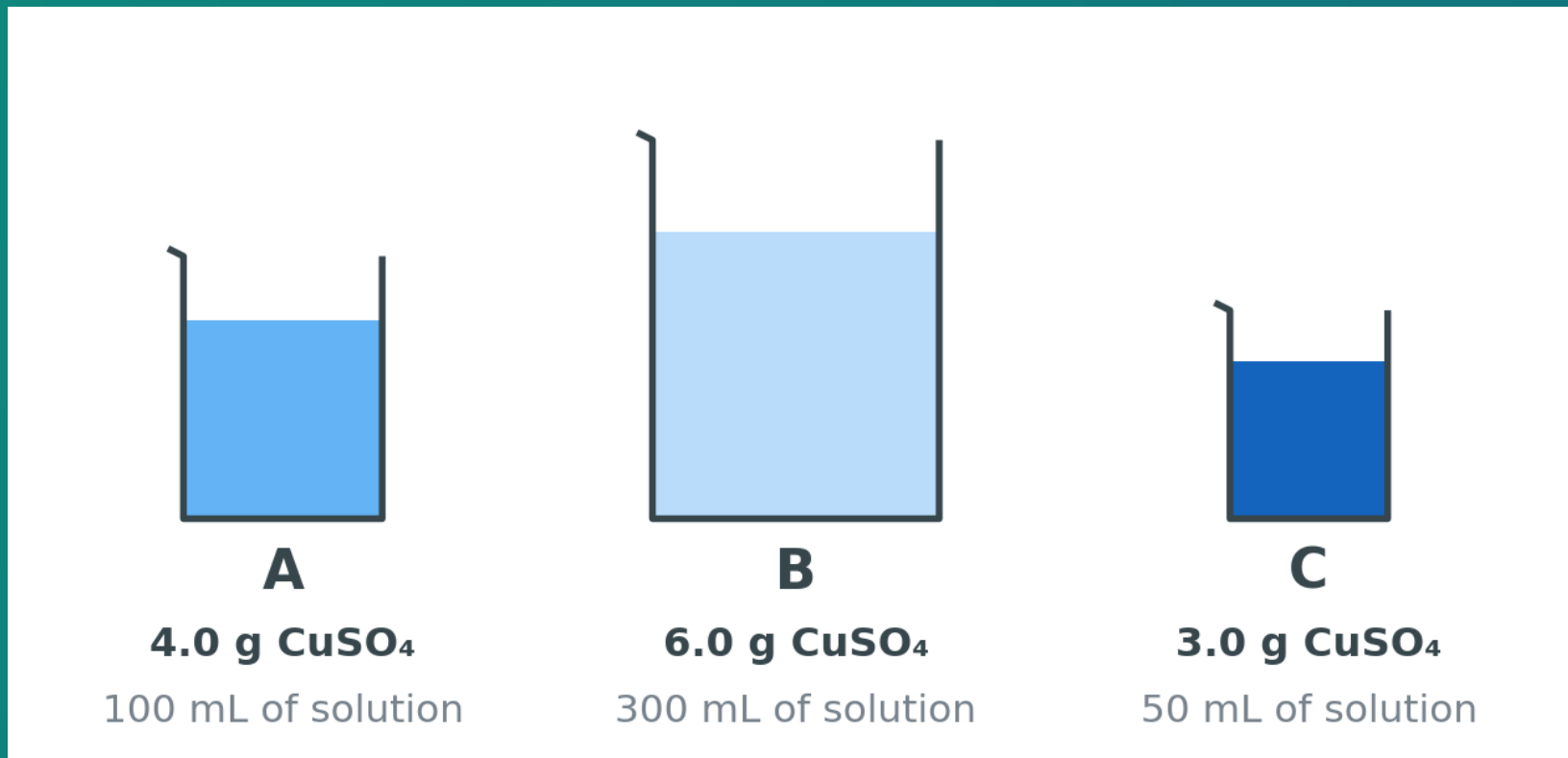
By the end of this unit, you can...

- Calculate molarity and percent concentration, use them as conversion factors, and dilute a stock solution with $M_1V_1 = M_2V_2$

1 · Concentration: Percent, Molarity, Dilution

Compute a percent or molar concentration, use either one as a conversion factor between solution and solute, and dilute a stock with $C_1V_1 = C_2V_2$, including the water to add.

Three blue solutions



Copper(II) sulfate dissolves in water as a blue solution. Beaker B holds the most salt, yet it is the palest. The color follows the salt in each milliliter, not the total.

Concentration: solute compared to solution

concentration = amount of solute ÷ amount of solution

solute: the substance dissolved · solvent: what dissolves it, usually water · solution = solute + solvent

A: 4.0 g CuSO₄ in 100 mL · B: 6.0 g in 300 mL · C: 3.0 g in 50 mL

compare each on the same footing: grams per 100 mL of solution

Rank the three beakers. Which is most concentrated, and which is most dilute?

$$A \frac{4.0 \text{ g}}{100 \text{ mL}} \quad B \frac{6.0 \text{ g}}{300 \text{ mL}} = \frac{2.0 \text{ g}}{100 \text{ mL}} \quad C \frac{3.0 \text{ g}}{50 \text{ mL}} = \frac{6.0 \text{ g}}{100 \text{ mL}}$$

C is most concentrated, with the least salt in total. B is most dilute.

Four ways to state a concentration

one pattern: solute over the whole solution; percents $\times 100$, molarity in mol per L

m/m %	v/v %	m/v %	molarity, M
$\frac{\text{g solute}}{\text{g solution}} \times 100$	$\frac{\text{mL solute}}{\text{mL solution}} \times 100$	$\frac{\text{g solute}}{\text{mL solution}} \times 100$	$\frac{\text{mol solute}}{\text{L solution}}$
seawater 3.5 g salts per 100 g	rubbing alcohol 70.0 mL per 100 mL	normal saline 0.90 g NaCl per 100 mL	stockroom acid 6.0 mol HCl per 1 L

Each one is solute over the whole solution. A percent counts parts of solute per 100 parts of solution. Molarity counts moles of solute in each liter of solution.

A concentration is an equality

0.90% (m/v) NaCl: 0.90 g NaCl = 100 mL soln · 6.0 M HCl: 6.0 mol HCl = 1 L soln
a percent's whole is 100 g or 100 mL of solution · a molarity's whole is 1 L of solution

Every equality gives a conversion factor, either way up:

$$\frac{0.90 \text{ g NaCl}}{100 \text{ mL solution}} \text{ or } \frac{100 \text{ mL solution}}{0.90 \text{ g NaCl}} \quad \frac{6.0 \text{ mol HCl}}{1 \text{ L solution}} \text{ or } \frac{1 \text{ L solution}}{6.0 \text{ mol HCl}}$$

Write it so the **given unit cancels**.



The method

1. **Name part and whole:** solute; solution = solute + solvent.
2. **Match the units:** % per 100 g or mL; M in mol per L.
3. **Write the fraction:** part over whole, or a factor canceling the given.
4. **Multiply and check.**



Worked example 1: grams from a percent label

Step 1 • Name part and whole

vinegar: 5.00% (m/v) acetic acid

part: acetic acid • whole: solution • given: 500. mL of solution • wanted: g acetic acid

A **500. mL** bottle of vinegar is **5.00% (m/v)** acetic acid. How many grams of acetic acid does it hold?

Set it up so mL of solution cancels.

✓ Worked example 1: solution

vinegar: 5.00% (m/v) acetic acid

part: acetic acid · whole: solution · given: 500. mL of solution · wanted: g acetic acid

Step 2 · Match the units

Step 3 · Write the fraction

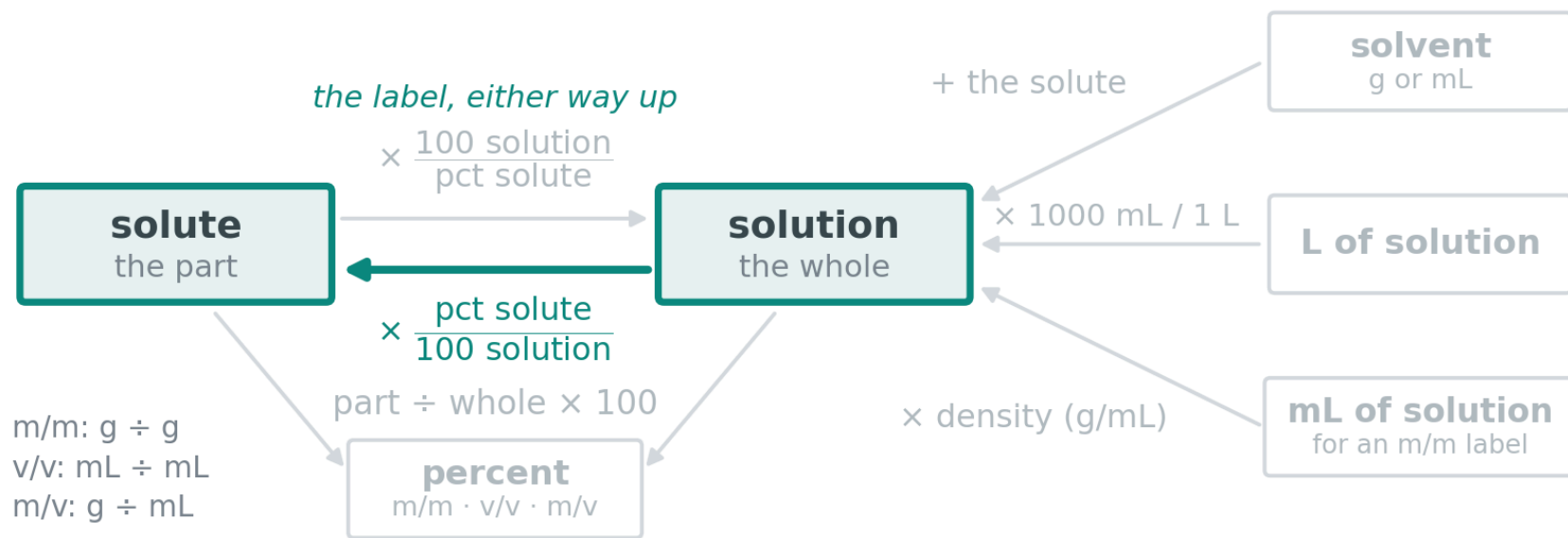
Step 4 · Multiply and check

$$500. \cancel{\text{ mL solution}} \times \frac{5.00 \text{ g acetic acid}}{100 \cancel{\text{ mL solution}}} = 25.0 \text{ g acetic acid}$$

🧠 **Sense check:** 5.00 g in every 100 mL, and the bottle holds five hundreds: 25.0 g ✓

✓ Worked example 1: the route on the map

vinegar: 5.00% (m/v) acetic acid
given: 500. mL of solution · found: 25.0 g acetic acid



🧠 **Sense check:** The given is already the label's whole, mL of solution. One move: the label factor carries solution to solute. ✓

Worked example 2: molarity from grams

Step 1 • Name part and whole

$$M = \text{mol solute} \div \text{L solution}$$

part: 34.8 g KNO_3 (101.11 g/mol) • whole: 225 mL of solution • wanted: M

What is the molarity of **225 mL** of a potassium nitrate solution that contains **34.8 g** of KNO_3 ?

Count the moves: grams to moles, mL to L, then divide.

✓ Worked example 2: solution

$$M = \text{mol solute} \div \text{L solution}$$

part: 34.8 g KNO₃ (101.11 g/mol) · whole: 225 mL of solution · wanted: M

Step 2 · Match the units

$$34.8 \text{ g KNO}_3 \times \frac{1 \text{ mol KNO}_3}{101.11 \text{ g KNO}_3} = 0.344 \text{ mol KNO}_3 \quad 225 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.225 \text{ L}$$

Step 3 · Write the fraction

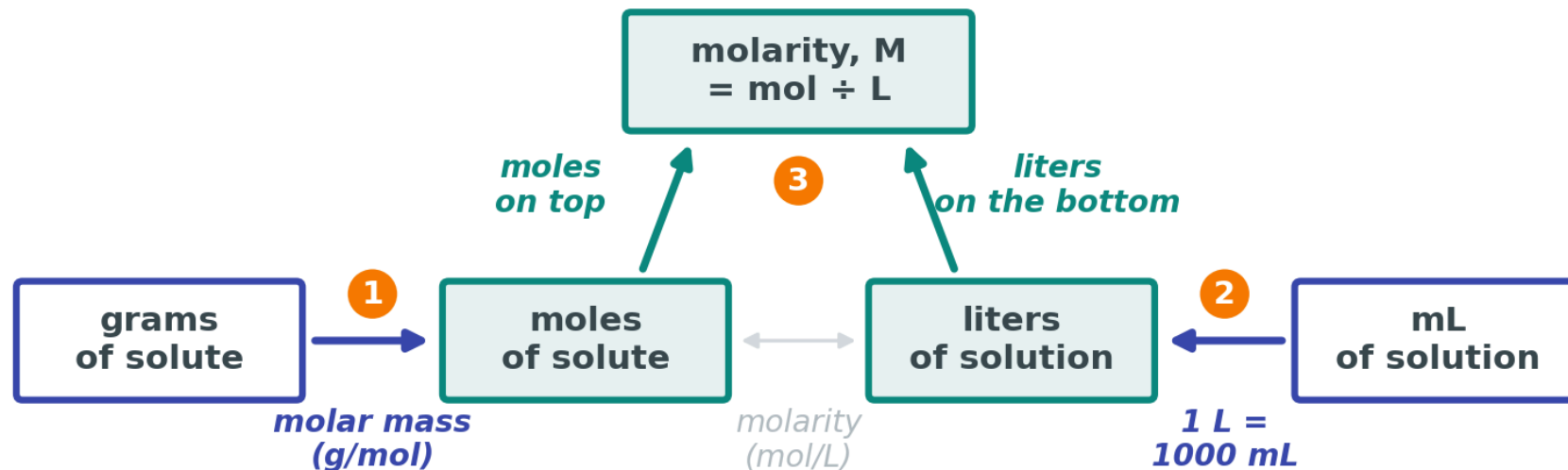
$$M = \frac{0.344 \text{ mol KNO}_3}{0.225 \text{ L soln}} = 1.53 \text{ M KNO}_3$$

 **Sense check: Step 4 · Multiply and check.** A bit under a quarter liter holds 0.344 mol, so a liter holds over four times that, over 1.38 mol: 1.53 M ✓

✓ Worked example 2: the route on the map

$$M = \text{mol solute} \div \text{L solution}$$

given: 34.8 g KNO₃ · 225 mL of solution · found: 1.53 M KNO₃



 **Sense check:** Molar mass to moles, 225 mL to 0.225 L, then divide. The label 1.53 M KNO₃ now states 1.53 mol KNO₃ = 1 L of solution. ✓

Your turn: moles from a molarity

0.400 mol NaCl = 1 L of solution

the label "0.400 M NaCl" states this equality · given: 275 mL of solution · wanted: mol NaCl

How many moles of NaCl are in **275 mL** of **0.400 M NaCl**?

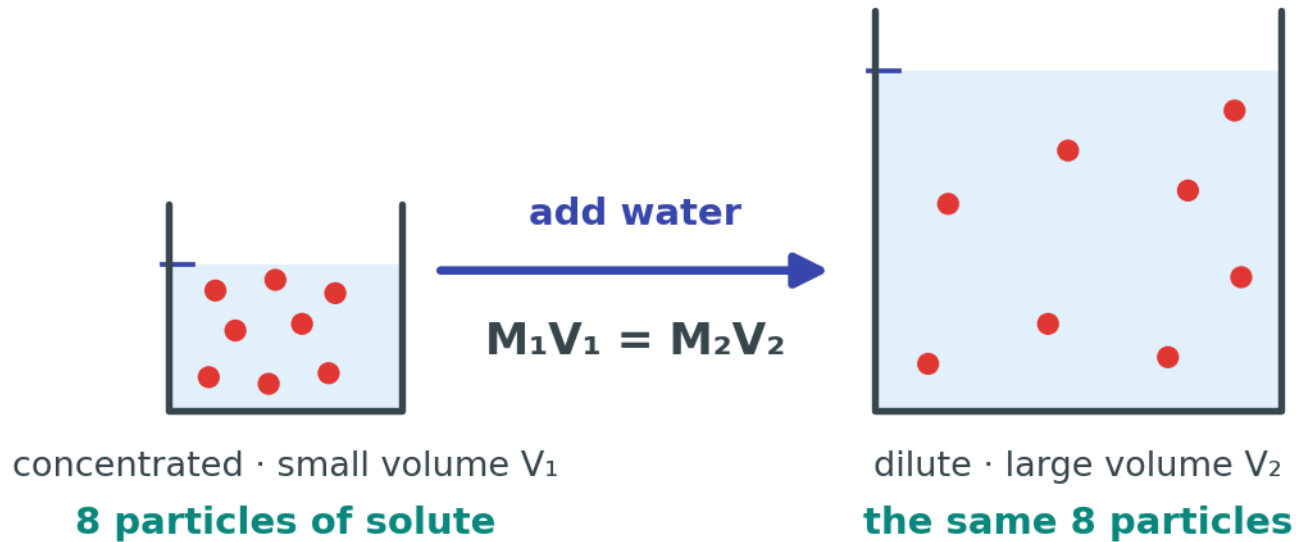
$$275 \text{ mL soln} \times \frac{1 \text{ L soln}}{\text{ } \text{mL soln}} \times \frac{\text{ } \text{mol NaCl}}{\text{ } \text{L soln}} = \text{ } \text{mol NaCl}$$

Fill each factor so the unit before it cancels, then compute.

$$275 \text{ mL soln} \times \frac{1 \text{ L soln}}{1000 \text{ mL soln}} \times \frac{0.400 \text{ mol NaCl}}{1 \text{ L soln}} = \mathbf{0.110 \text{ mol NaCl}}$$

Adding water keeps the solute

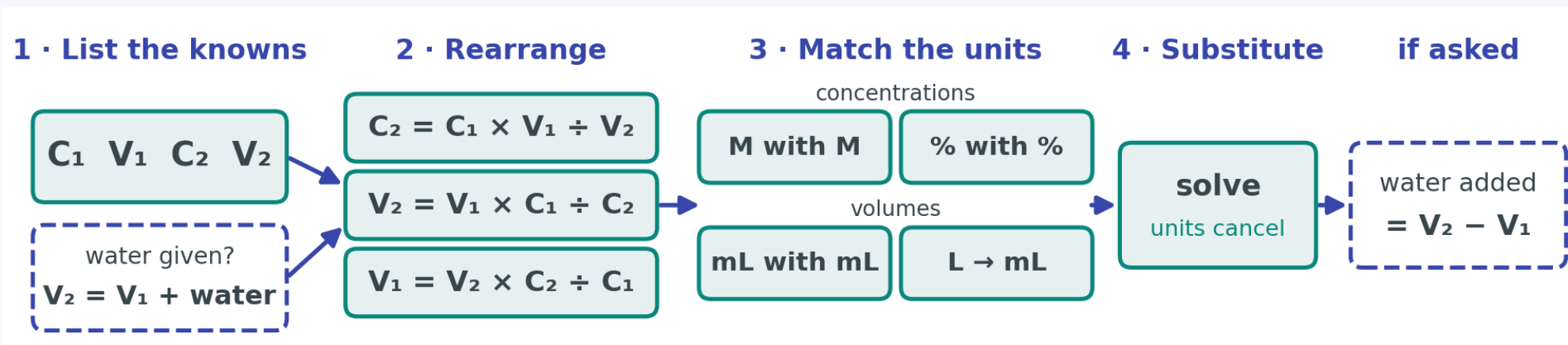
the solute is conserved — only the volume grows



Adding water spreads the solute through more liquid. No solute is added or removed, so concentration $\times$ volume stays fixed: $C_1V_1 = C_2V_2$ ($M_1V_1 = M_2V_2$ for molarity; the same for percent).

The dilution method

1. **List the knowns:** three of C_1 , V_1 , C_2 , V_2 ; mark the unknown.
2. **Rearrange** for the unknown.
3. **Match the units:** C_1 with C_2 , V_1 with V_2 .
4. **Substitute and solve;** if asked, water added = $V_2 - V_1$.





Worked example 3: a percent dilution

$$C_1V_1 = C_2V_2$$

given: 9.00% (m/v) NaOH · 10.0 mL stock · diluted to 60.0 mL · wanted: % (m/v) after

What is the percent (m/v) of a solution prepared by diluting **10.0 mL of 9.00% (m/v) NaOH** to **60.0 mL**?

The stock is "before" (1). The diluted solution is "after" (2).

✓ Worked example 3: solution

$$C_1V_1 = C_2V_2$$

given: 9.00% (m/v) NaOH · 10.0 mL stock · diluted to 60.0 mL · wanted: C_2 in % (m/v)

Step 1 · List the knowns

Step 2 · Rearrange

Step 3 · Match the units

$$C_1V_1 = C_2V_2 \rightarrow C_2 = C_1 \times \frac{V_1}{V_2}$$

Step 4 · Substitute and solve

$$C_2 = 9.00\% \times \frac{10.0 \text{ mL}}{60.0 \text{ mL}} = 1.50\% \text{ (m/v)}$$

 **Sense check:** Grams check: $10.0 \text{ mL} \times 9.00 \text{ g}/100 \text{ mL} = 0.900 \text{ g NaOH}$, and 0.900 g in 60.0 mL is 1.50 g per 100 mL ✓

✓ Worked example 3: the route on the map

$$C_1V_1 = C_2V_2$$

given: 9.00% (m/v) · 10.0 mL stock · 60.0 mL final · found: $C_2 = 1.50\%$ (m/v)

1 · List the knowns

C_1 V_1 C_2 V_2

water given?
 $V_2 = V_1 + \text{water}$

2 · Rearrange

$$C_2 = C_1 \times V_1 \div V_2$$

$$V_2 = V_1 \times C_1 \div C_2$$

$$V_1 = V_2 \times C_2 \div C_1$$

3 · Match the units

concentrations

M with M

% with %

volumes

mL with mL

L → mL

4 · Substitute

solve
units cancel

if asked

water added
 $= V_2 - V_1$

🧠 **Sense check:** The unknown is the new concentration, so $C_2 = C_1 \times V_1 \div V_2$. Percent pairs with percent, mL with mL.

✓



Worked example 4: water to add

$$M_1V_1 = M_2V_2$$

given: 750.0 mL of 3.00 M HCl · diluted to 2.50 M · wanted: mL of water added

How much water, in mL, must be added to **750.0 mL of 3.00 M HCl** to obtain a solution that is **2.50 M**?

The relation gives the total volume. The question asks for the water.

✓ Worked example 4: solution

$$M_1V_1 = M_2V_2$$

given: 750.0 mL of 3.00 M HCl · diluted to 2.50 M · wanted: mL of water added

Step 1 · List the knowns

Step 2 · Rearrange

Step 3 · Match the units

$$M_1V_1 = M_2V_2 \rightarrow V_2 = V_1 \times \frac{M_1}{M_2}$$

Step 4 · Substitute and solve

$$V_2 = 750.0 \text{ mL} \times \frac{3.00 \text{ M}}{2.50 \text{ M}} = 900. \text{ mL total} \rightarrow \text{water} = 900. - 750.0 = \mathbf{150. \text{ mL}}$$

 **Sense check:** 3.00 M down to 2.50 M is a 1.2-fold drop, so the volume grows 1.2-fold: $750.0 \times 1.2 = 900. \text{ mL}$.
Water supplies the extra 150. mL ✓

✓ Worked example 4: the route on the map

$$M_1V_1 = M_2V_2$$

given: 750.0 mL of 3.00 M · diluted to 2.50 M · found: 900. mL total · 150. mL of water

1 · List the knowns

2 · Rearrange

3 · Match the units

4 · Substitute

if asked



🧠 **Sense check:** $V_2 = V_1 \times M_1 \div M_2$ gives the total, 900. mL. The question asked for the water, so the last step subtracts the 750.0 mL of stock. ✓

⚠ Where this goes wrong

Dividing by the solvent alone. 12.0 g of NaCl in 138.0 g of water: $12.0 \div 138.0 \times 100 = 8.70\%$. The salt is part of the solution: $12.0 \div 150.0 \times 100 = 8.00\%$. Molarity also divides by the solution, never by the water poured in.

Dividing by milliliters. $0.344 \text{ mol KNO}_3 \div 225 \text{ mL} = 0.00153$, in mol/mL, 1000 times too small. Molarity is per liter: $0.344 \div 0.225 \text{ L} = 1.53 \text{ M}$.

Flipping the dilution ratio. $750.0 \text{ mL} \times (2.50 \div 3.00) = 625 \text{ mL}$, less liquid than the start. Diluting grows the volume: $750.0 \times (3.00 \div 2.50) = 900. \text{ mL}$.

Reporting the total as the water. 900. mL is the whole diluted solution. The water added is $900. - 750.0 = 150. \text{ mL}$.



Practice 1

pickling brine: 6.00% (m/m) NaCl

given: 250. g of brine · wanted: g NaCl

A **250. g** jar of pickling brine is **6.00% (m/m)** NaCl. How many grams of NaCl does it hold?

- A. 14.2
- B. 1.50×10^3
- C. 15.0
- D. 235
- E. 4.17×10^3

✓ Practice 1: answer C

6.00% (m/m): 6.00 g NaCl = 100 g brine
given: 250. g of brine, the whole solution · wanted: g NaCl

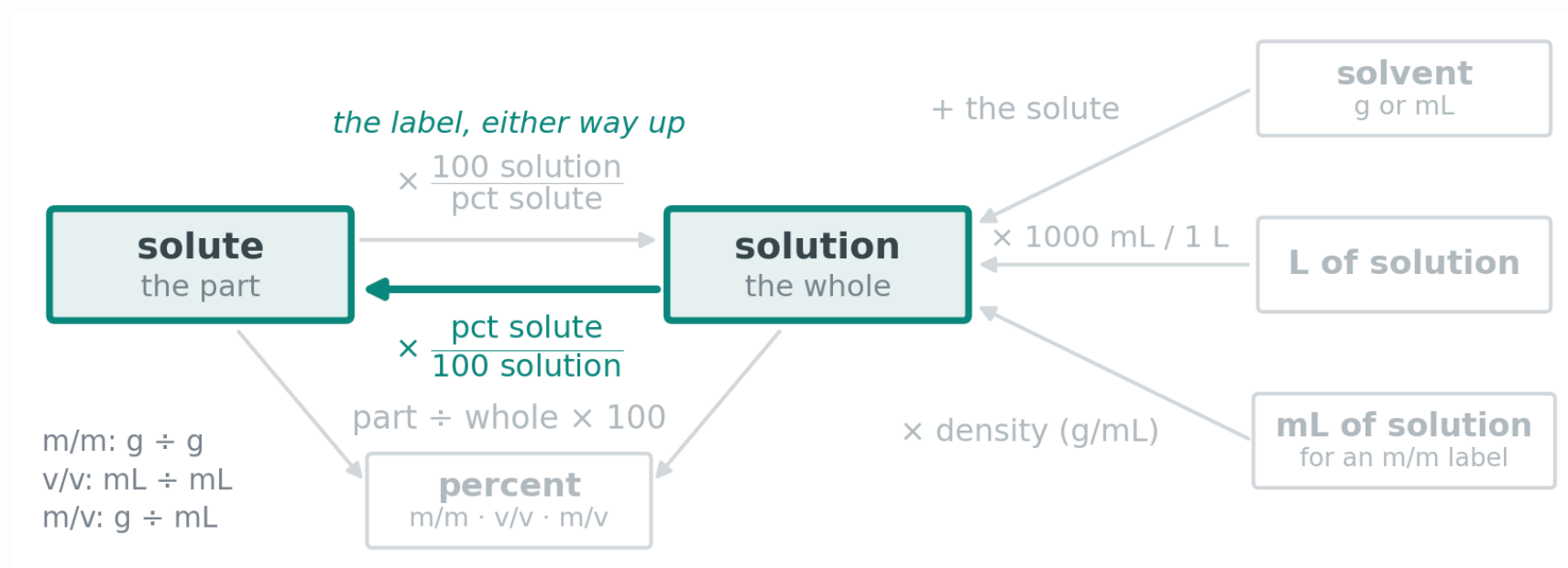
$$250. \cancel{\text{g brine}} \times \frac{6.00 \text{ g NaCl}}{100 \cancel{\text{g brine}}} = 15.0 \text{ g NaCl, answer C}$$

A read the label per 100 g of water, as if 106 g of brine held 6.00 g: $250. \times 6.00 \div 106 = 14.2$. B used the raw percent: $250. \times 6.00 = 1.50 \times 10^3$. D found the water: $250. - 15.0 = 235$. E flipped the factor: $250. \times 100 \div 6.00 = 4.17 \times 10^3$.

🧠 **Sense check:** 6.00 g in every 100 g of brine, and the jar holds two and a half hundreds: 15.0 g ✓

✓ Practice 1: the route on the map

6.00% (m/m) NaCl brine
given: 250. g of brine · found: 15.0 g NaCl



🧠 **Sense check:** The given is the whole, grams of brine. One move: the label factor carries solution to solute. ✓



Practice 2

0.200 M KOH

given: 350. mL of solution · molar mass KOH 56.11 g/mol

How many grams of KOH are dissolved in **350. mL** of **0.200 M KOH**?

- A. 3.93
- B. 98.2
- C. 3.93×10^3
- D. 11.2

✓ Practice 2: answer A

0.200 mol KOH = 1 L of solution

given: 350. mL of solution · KOH 56.11 g/mol · route: mL → L → mol → g

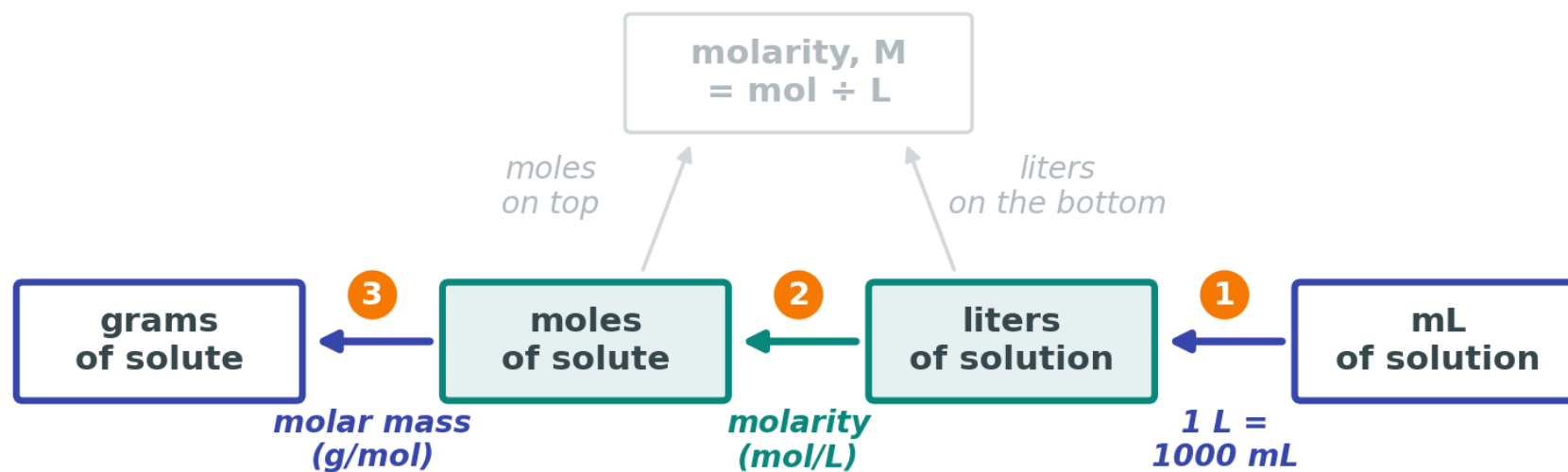
$$350. \cancel{\text{ mL soln}} \times \frac{1 \cancel{\text{ L soln}}}{1000 \cancel{\text{ mL soln}}} \times \frac{0.200 \cancel{\text{ mol KOH}}}{1 \cancel{\text{ L soln}}} \times \frac{56.11 \text{ g KOH}}{1 \cancel{\text{ mol KOH}}} = 3.93 \text{ g, answer A}$$

B flipped the molarity: $0.350 \div 0.200 \times 56.11 = 98.2$, and the units do not cancel. C skipped mL → L: $350. \times 0.200 \times 56.11 = 3.93 \times 10^3$. D used one full liter: $0.200 \times 56.11 = 11.2 \text{ g}$, the mass in 1 L.

🧠 **Sense check:** 0.350 L of 0.200 M holds 0.0700 mol, at about 56 g per mole: about 3.9 g ✓

✓ Practice 2: the route on the map

0.200 mol KOH = 1 L of solution
given: 350. mL of solution · found: 3.93 g KOH



🧠 **Sense check:** Milliliters become liters first. Then the molarity reaches moles, and the molar mass reaches grams. ✓

 Practice 3

$$M_1V_1 = M_2V_2$$

start: 200. mL of 2.40 M NaCl · target: 0.600 M

A **200. mL** portion of **2.40 M NaCl** is diluted with water to **0.600 M**. What volume of water, in mL, goes in?

- A. 800.
- B. 50.0
- C. 480.
- D. 600.

✓ Practice 3: answer D

$$M_1V_1 = M_2V_2$$

given: 200. mL of 2.40 M NaCl · diluted to 0.600 M · wanted: mL of water added

$$V_2 = 200. \text{ mL} \times \frac{2.40 \text{ M}}{0.600 \text{ M}} = 800. \text{ mL total} \rightarrow \text{water} = 800. - 200. = \mathbf{600. \text{ mL, answer D}}$$

A stopped at the total: 800. mL still counts the 200. mL of stock. B flipped the ratio: $200. \times (0.600 \div 2.40) = 50.0 \text{ mL}$, less than the start. C stopped at the solute: $200. \times 2.40 = 480. \text{ mmol of NaCl}$, not a volume.

 **Sense check:** 2.40 M down to 0.600 M is a four-fold drop, so the solution grows to four times 200. mL. Water supplies 600. mL of it ✓

✓ Practice 3: the route on the map

$$M_1V_1 = M_2V_2$$

given: 200. mL of 2.40 M · diluted to 0.600 M · found: 600. mL of water

1 · List the knowns

2 · Rearrange

3 · Match the units

4 · Substitute

if asked



🧠 **Sense check:** $V_2 = V_1 \times M_1 \div M_2$ gives the total, 800. mL. The water is the total minus the stock. ✓



Practice 4

$$M = \text{mol solute} \div L \text{ solution}$$

measured: 46.0 g glucose · 220.0 mL of water · 250.0 mL of solution

A technician stirs **46.0 g of glucose ($\text{C}_6\text{H}_{12}\text{O}_6$)** into **220.0 mL** of water. The solution that forms measures **250.0 mL**. What is its molarity?

- A. 1.16
- B. 1.02
- C. 0.255
- D. 15.7
- E. 1.02×10^{-3}

✓ Practice 4: answer B

$$M = \text{mol solute} \div \text{L solution}$$

$$\text{C}_6\text{H}_{12}\text{O}_6: 6(12.01) + 12(1.008) + 6(16.00) = 180.16 \text{ g/mol} \cdot \text{whole: } 250.0 \text{ mL} = 0.2500 \text{ L of solution}$$

$$46.0 \text{ g} \times \frac{1 \text{ mol}}{180.16 \text{ g}} = 0.2553 \text{ mol, then } \frac{0.2553 \text{ mol C}_6\text{H}_{12}\text{O}_6}{0.2500 \text{ L soln}} = \mathbf{1.02 \text{ M, answer B}}$$

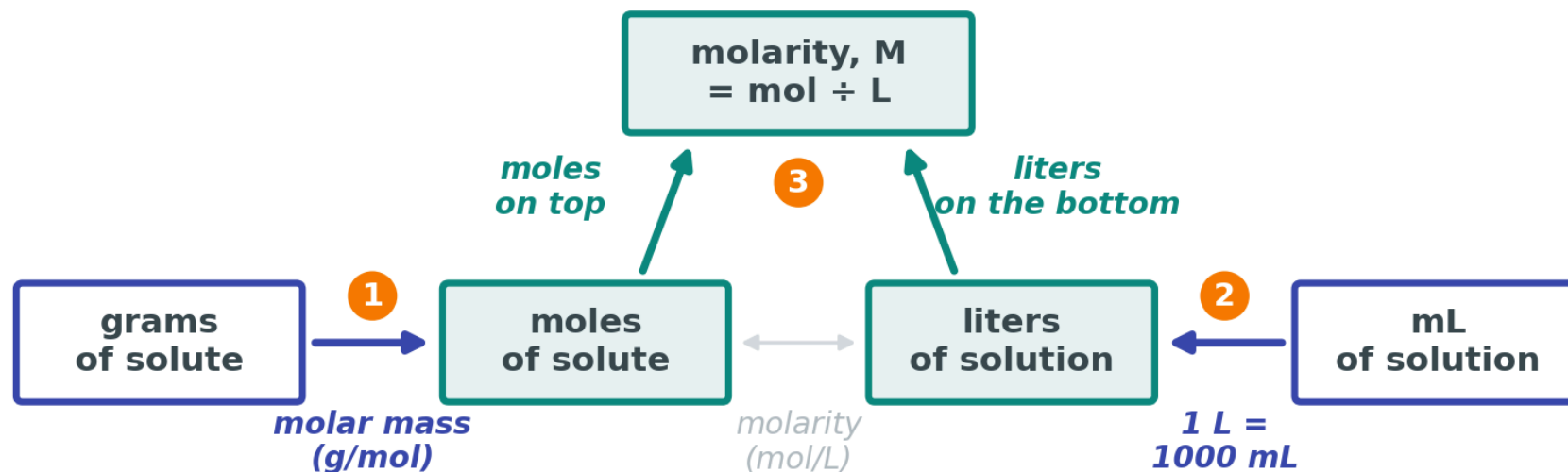
A divided by the water poured in: $0.2553 \div 0.2200 = 1.16$; the dissolved glucose takes up room too. C stopped at moles: 0.255 mol. D flipped the molar mass: $180.16 \div 46.0 \div 0.2500 = 15.7$. E divided by milliliters: $0.2553 \div 250.0 = 1.02 \times 10^{-3}$, in mol/mL.

 **Sense check:** A quarter liter carries about a quarter mole, so a full liter carries about one mole: 1.02 M ✓

✓ Practice 4: the route on the map

$$M = \text{mol solute} \div \text{L solution}$$

given: 46.0 g glucose · 250.0 mL of solution · found: 1.02 M



 **Sense check:** The same three moves as worked example 2. The whole is 250.0 mL of solution, not 220.0 mL of water. ✓

Check yourself

1. A bottle reads **12.0% (m/v) sucrose**. State the equality the label declares, then write the factor that turns milliliters of the solution into grams of sucrose.
2. **50.0 mL** of a stock is diluted with water to **200. mL**. By what factor does the concentration drop, and what stays the same?

Concentration returns with reactions in solution: molarity $\times$ liters gives moles of a reactant, and the mole ratio carries it from there.

Can you...?

- ☐ calculate molarity and percent concentration, use them as conversion factors, and dilute a stock solution with $M_1V_1 = M_2V_2$?

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