6 Solutions and Aqueous Reactions

Pure water is a poor conductor of electricity. What makes a bathtub dangerous is what is dissolved in the water: ions, which carry the current. Most of the chemistry on this exam happens the same way, between ions moving around in water, and the water itself stays out of it. Once you can see which ions are present, the reactions in this chapter become a short list of things those ions can do. The mock exam gives this chapter 9 of its 70 questions.

6.1 Molarity and Dilution

Reactions in solution run mole to mole, so you need a way to count the moles of solute without weighing them. **Molarity** does that. It is the moles of solute in each liter of the finished solution,

$$M = \frac{n_{\text{solute}}}{V_{\text{solution}}} \qquad \text{with units of mol/L, written M.}$$

Two details cause most of the misses. The volume is the volume of the whole solution, not of the water you added. And it must be in liters, so convert milliliters first. Rearranged, $n = MV$: a molarity times a volume in liters gives moles.

Solute and solvent
The solute is what dissolves. The solvent, usually water, is what it dissolves in.

Preparing a solution from a solid

Work backward from the target. Moles needed are $M \times V$, and grams are moles times molar mass. In the lab the solid goes into a volumetric flask and dissolves in part of the water. Then water is added until the bottom of the meniscus, the curved surface of the liquid, sits on the mark. That fixes the final volume exactly. Dissolving the solid in the full volume of water overshoots it.

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EXAMPLE 6.1

What mass of $CuSO_4$ ($159.61\ \mathrm{g/mol}$) is needed for $250.0\ \mathrm{mL}$ of $0.150\ \mathrm{M}$ solution?

What is asked	A mass of solid, from a molarity and a volume.
Convert	$250.0\ \mathrm{mL} = 0.2500\ \mathrm{L}$
Moles	$n = MV = (0.150\ \mathrm{mol/L})(0.2500\ \mathrm{L}) = 0.0375\ \mathrm{mol}$
Mass	$0.0375\ \mathrm{mol} \times 159.61\ \mathrm{g/mol} = 5.99\ \mathrm{g}$
Check	A liter of 1 M would need $159.6\ \mathrm{g}$. A quarter of the volume at about a seventh of the molarity gives a few grams.
Answer	$5.99\ \mathrm{g}$

Ion concentrations

An ionic compound separates into its ions when it dissolves, and the formula says how many of each ion come from one formula unit. Multiply the molarity of the compound by the number of that ion in the formula. A $0.30\ \mathrm{M}$ solution of Na_2SO_4 is $0.60\ \mathrm{M}$ in Na^+ and $0.30\ \mathrm{M}$ in SO_4^{2-}. Polyatomic ions stay together: $Ca(NO_3)_2$ releases two nitrate ions, not six atoms.

Formula unit
The smallest ratio of ions in an ionic compound, as written in its formula.

Compound, $0.10\ \mathrm{M}$	Cation	Anion
NaCl	$0.10\ \mathrm{M}$ Na^+	$0.10\ \mathrm{M}$ Cl^-
$CaCl_2$	$0.10\ \mathrm{M}$ Ca^{2+}	$0.20\ \mathrm{M}$ Cl^-
$Al_2(SO_4)_3$	$0.20\ \mathrm{M}$ Al^{3+}	$0.30\ \mathrm{M}$ SO_4^{2-}
$(NH_4)_3PO_4$	$0.30\ \mathrm{M}$ NH_4^+	$0.10\ \mathrm{M}$ PO_4^{3-}

RULE Concentration of an ion = molarity of the compound × number of that ion in the formula.

EXAMPLE 6.2

How many moles of chloride ion are in $75.0\ \mathrm{mL}$ of $0.300\ \mathrm{M}$ $AlCl_3$?

What is asked	Moles of one ion, not of the compound.
Compound	$n = (0.300\ \mathrm{mol/L})(0.0750\ \mathrm{L}) = 0.0225\ \mathrm{mol}$ $AlCl_3$
Ratio	Each $AlCl_3$ gives 3 Cl^-: $0.0225 \times 3 = 0.0675\ \mathrm{mol}$
Check	Cl^- is $0.900\ \mathrm{M}$, and $0.900 \times 0.0750 = 0.0675\ \mathrm{mol}$.
Answer	$0.0675\ \mathrm{mol}$ **Cl^-**

Dilution

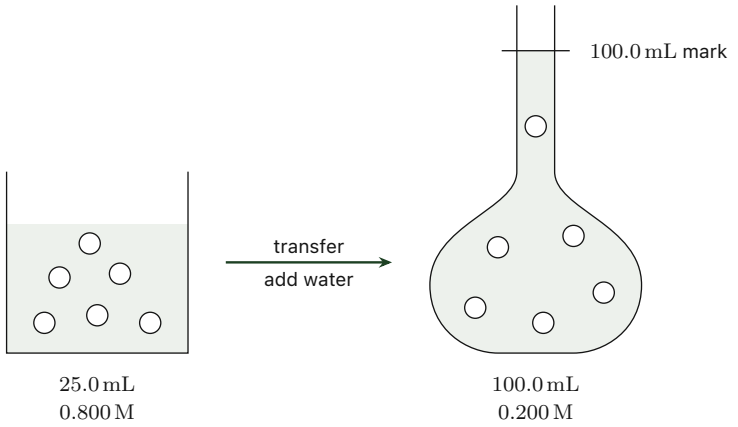
A spoonful of dye in a larger tank of water looks paler, but the amount of dye is the same. Diluting a solution does the same thing to a solute. The moles before and after are equal, so

Dilution
Adding solvent to a solution. The moles of solute do not change.

$$M_1V_1 = M_2V_2.$$

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The concentrated starting solution is the stock. The volumes can stay in milliliters as long as both use the same unit. Concentration falls by the same factor that the volume rises.



Same moles
Each vessel holds $0.0200\,\text{mol}$ of solute. Only the volume changed.

When two solutions are mixed, $M_1V_1 = M_2V_2$ does not describe the mixture. Find the moles of the ion from each solution, add them, and divide by the total volume. Assume volumes add unless told otherwise.

EXAMPLE 6.3

How many mL of $12.0\,\text{M}$ HCl are needed to make $500.0\,\text{mL}$ of $0.600\,\text{M}$ HCl?

What is asked The volume of stock, V_1.

Solve
$$V_1 = \frac{M_2V_2}{M_1} = \frac{(0.600)(500.0\ \text{mL})}{12.0} = 25.0\ \text{mL}$$

Check The stock is $12.0/0.600 = 20$ times more concentrated, so it supplies one twentieth of the final volume. Measure $25.0\,\text{mL}$, then add water to the $500.0\,\text{mL}$ mark.

Answer $25.0\,\text{mL}$ **of stock**

6.2 Electrolytes and Particulate Pictures

Water molecules are polar. They surround the ions of a soluble ionic compound and pull the solid apart. The free ions carry charge through the liquid, so the solution conducts electricity. A substance that makes a conducting solution is an **electrolyte**. How well the solution conducts depends on how many ions it contains.

- **Strong electrolyte.** Separates completely into ions. This covers soluble ionic compounds, strong acids and strong bases.
- **Weak electrolyte.** Mostly stays as molecules. A small fraction reacts with water to form ions. Weak acids and weak bases do this, and the process runs in both directions, as in $\text{HF(aq)} \rightleftharpoons \text{H}^+\text{(aq)} + \text{F}^-\text{(aq)}$.
- **Nonelectrolyte.** Dissolves as whole molecules and forms no ions. Sugar and alcohols are examples.

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PRACTICE SET 6A 12 questions · 18 minutes · calculator allowed

1. What mass of $CaCl_2$ ($110.98\,\text{g/mol}$) is needed to prepare $250.0\,\text{mL}$ of $0.400\,\text{M}$ solution?

(A) $0.100\,\text{g}$ **(B)** $44.4\,\text{g}$
(C) $11.1\,\text{g}$ **(D)** $1.11 \times 10^4\,\text{g}$

2. Which procedure correctly prepares exactly $500.0\,\text{mL}$ of $0.100\,\text{M}$ NaCl?

(A) Dissolve $0.0500\,\text{mol}$ in a $500.0\,\text{mL}$ volumetric flask, then fill to the mark
(B) Dissolve $0.0500\,\text{mol}$ in $500.0\,\text{mL}$ of water
(C) Dissolve $0.100\,\text{mol}$ in $500.0\,\text{mL}$ of water
(D) Dissolve $0.0500\,\text{mol}$ in $1.00\,\text{L}$ of water, then pour out $500.0\,\text{mL}$

3. $12.6\,\text{g}$ of Na_2SO_4 ($142.04\,\text{g/mol}$) is dissolved in water and diluted to $400.0\,\text{mL}$. What is the molarity?

(A) $0.0887\,\text{M}$ **(B)** $4.51\,\text{M}$
(C) $2.22 \times 10^{-4}\,\text{M}$ **(D)** $0.222\,\text{M}$

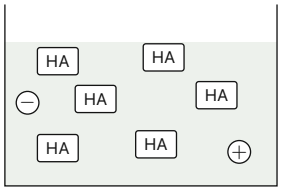
4. What is the concentration of Na^+ in $0.150\,\text{M}$ Na_3PO_4?

(A) $0.150\,\text{M}$ **(B)** $0.450\,\text{M}$
(C) $0.600\,\text{M}$ **(D)** $0.0500\,\text{M}$

5. Which $0.10\,\text{M}$ solution conducts electricity best?

(A) C_2H_5OH **(B)** HF
(C) K_2SO_4 **(D)** NH_3

6. The diagram shows a $0.1\,\text{M}$ solution of HA, with water not shown. Cations are H^+ and anions are A^-. What is HA?



(A) A strong acid
(B) A weak acid
(C) A nonelectrolyte
(D) A strong base

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