Nuggets: Molarity, Dilutions, Stoichiometry with M (Titrations)

MOLARITY – concentration of solutions

abbreviated as M (pronounced “molar”); square brackets, [X⁺], means the concentration of X⁺ in molarity

\[ M = \frac{\text{moles solute}}{\text{L solution}} \]

\textbf{Solute:} The chemical that is dissolved into the solvent
\textbf{Solvent:} The liquid that the solute is dissolved into
\textbf{Solution:} Solvent + Solute

Typical types of Problems:

1. “Simple” Molarity Problems: \( \text{Use: } M = \frac{\text{mol solute}}{\text{L solution}} \) (How to ID problem: Contains 1 chemical and 1 concentration)

\textbf{Example 1:} How many grams NaCl are needed to prepare 450ml of a 0.15M NaCl solution?

\textbf{Answer 1:} 3.9g NaCl \{1 chemical and 1 concentration \rightarrow need to use \( M = \text{mol/L} \)

\( M = 0.15\text{mol/L}; \ L = 450\text{ml} \times (1\text{L} \div 1000\text{ml}) = 0.450\text{L}; \ \text{mol} = x; \)

\( 0.15\text{mol/L} = x/0.450\text{L}; \ x = 0.0675\text{mol NaCl}; \ (0.0675\text{mol NaCl}) \times \left( \frac{58.45\text{g NaCl}}{1\text{mol NaCl}} \right) = 3.945\text{g NaCl} \)

\textbf{Example 2:} What is the concentration of NH₄⁺ when 3.50grams (NH₄)₂S are added to 750. ml of water?

\textbf{Answer 2:} 0.136M NH₄⁺ \{1 chemical and 1 concentration \rightarrow need to use \( M = \text{mol/L} \) but there will be an extra step for this problem;

To solve need to do this calculation: \([\text{NH}_4^+] = \text{mol NH}_4^+/\text{L solution} \)

\( \text{mol NH}_4^+ = (3.50\text{g (NH}_4)_2\text{S}) \times \left( \frac{1\text{mol (NH}_4)_2\text{S}}{68.73\text{g (NH}_4)_2\text{S}} \right) \times \left( \frac{2\text{mol NH}_4^+}{1\text{mol (NH}_4)_2\text{S}} \right) = 0.1018\text{mol NH}_4^+ \)

\( L_{\text{solution}} = 750\text{ml} \times (1\text{L} \div 1000\text{ml}) = 0.750\text{L} \)

\( [\text{NH}_4^+] = \frac{0.1018\text{mol NH}_4^+}{0.750\text{L solution}} = 0.1358\text{M NH}_4^+ = \text{0.136M NH}_4^+ \}

2. Dilution Problems \hspace{1em} (How to ID problem: Contains 1 chemical with 2 concentrations)

\textbf{Use: } \text{M}_1 \times \text{V}_1 = \text{M}_2 \times \text{V}_2 \hspace{1em} \text{(this is for dilutions; not reactions)}

\text{where } \text{M}_1 \text{ and } \text{M}_2 \text{ are the molarities of the initial and final solutions, respectively;}
\text{V}_1 \text{ and } \text{V}_2 \text{ are the volumes of the initial and final solutions, respectively; } \text{V}_2 = \text{V}_1 + \text{water added}

\textbf{Example 3:} How many milliliters of 12.0M HCl stock solution is needed to prepare 1250mL of a 0.150M HCl solution?

\textbf{Answer 3:} 15.6ml \{1 chemical and 2 concentrations \rightarrow a dilution; need to use \text{M}_1 \times \text{V}_1 = \text{M}_2 \times \text{V}_2; \)

\text{a “stock solution” is a concentrated solution that is kept in the stockroom and is used to prepare dilute solutions}
\text{M}_1 = 0.150\text{M}; \ V_1 = 1.25\text{L}; \ M_2 = 12.0\text{M}; \ V_2 = x \)

\( (0.150\text{mol/L})(1250\text{ml}) = (12.0\text{mol/L})(x \text{ ml}) \) \hspace{1em} \text{(V}_1 \text{ and V}_2 \text{ can be in L or in ml; they must simply be in the same units) \}

\( x = 15.63\text{ml} = 15.6\text{ ml} \}

3. Stoichiometric Molarity Problems \textit{(use flowchart)} \hspace{1em} (How to ID problem: Contains 2 chemicals reacting; these problems are sometimes called titrations, neutralizations, and may also have the term “equivalence point” in them)
Example 4: If it required 27.5ml of a 0.150M HCl solution to neutralize 15.5ml of Ba(OH)$_2$, what was the original concentration of the Ba(OH)$_2$?

Answer 4: 0.133M Ba(OH)$_2$  (2 chemicals → stoichiometric problem → $M_A$ → $M_B$ question (3 steps from the above flow chart)

Step 1: convert $M_A$ to mol A: $M_{HCl} = \text{mol}_{HCl} / L_{HCl}$; $\text{mol}_{HCl} = M \times L = \frac{0.150M}{(27.5ml)(L/1000ml)} = 0.004125$mol HCl

Step 2: convert mol HCl to mol Ba(OH)$_2$ using a balanced rxn;

$0.004125 \text{mol HCl} \left( \frac{1 \text{mol Ba(OH)}_2}{2 \text{mol HCl}} \right) = 0.0020625 \text{mol Ba(OH)}_2$

[hint: the stoichiometric ratio between an acid and base can be determined by *inspection without* writing the reaction; the ratio must be: 1 H$^+$ to 1 OH$^-$ or in other words, the same number of H$^+$ and OH$^-$; since HCl has 1 H$^+$ and Ba(OH)$_2$ has 2 OH$^-$, the common factor for these two numbers is 2; so there needs to be 2 HCl (2 H$^+$) and 1 Ba(OH)$_2$ (2 OH$^-$): 2HCl(aq) + Ba(OH)$_2$ → 2H$_2$O(l) + BaCl$_2$(aq)]

Step 3: calculate the concentration using $M_{Ba(OH)}_2 = \frac{\text{mol}_{Ba(OH)}_2}{L_{Ba(OH)}_2}$;

$[\text{Ba(OH)}_2] = \frac{0.0020625 \text{mol Ba(OH)}_2}{(15.5ml)(L/1000ml)} = 0.1331 \text{M Ba(OH)}_2 = 0.133 \text{M Ba(OH)}_2$

1. I. What is the concentration of HCl when 1.75g HCl is dissolved in water to a total volume of 250ml?
   II. a. What is the concentration of Na$_3$PO$_4$ when 1.50g of Na$_3$PO$_4$ is dissolved into a total volume of 725ml?
      b. What is the Na$^+$ concentration?  c. What is the PO$_4^{3-}$ concentration?

2. If the concentration of (NH$_4$)$_3$AsO$_4$ is 0.50M, what is the concentration of AsO$_4^{3-}$? What is the concentration of NH$_4^+$?

3. I. How many grams of NaOH are there in 55ml of a 0.15M NaOH solution?
   II. How many milliliters of 0.515M Ba(NO$_3$)$_2$ solution will provide 1.25grams of Ba(NO$_3$)$_2$?

4. I. You are asked to produce 250ml of 0.450M Na$_2$S. How many milliliters of 1.25M Na$_2$S are required?
   II. How much water must be added to a 2.15M HNO$_3$ solution to obtain 1.50L of a 0.750M HNO$_3$ solution?

5. I. How many milliliters of 0.10M NaOH solution is required to neutralized 50. ml of a 0.20M HCl solution?
   II. How many milliliters of 0.75M H$_3$C$_6$H$_5$O$_7$, citric acid, solution is required to neutralized 50. ml of a 0.50M Ba(OH)$_2$ solution? (Note: citric acid is a tripotetic acid; i.e., having 3 H$^+$’s)

6. I. If 26.3ml of 0.100M H$_2$SO$_4$ is titrated with 34.6ml of NaOH solution, what was the concentration of the NaOH solution.
   II. If it takes 20.0ml of a 0.100M tripotetic acid solution, H$_3$A, to neutralize 50.0ml of a Ba(OH)$_2$ solution in a titration, what was the concentration of the Ba(OH)$_2$ solution?

7. I. How many grams of Na$_2$S are needed to completely precipitate 355ml of a 0.275M solution of Al(NO$_3$)$_3$?
   II. What volume of 0.100M HCl solution is required to react with 5.00g of NaHCO$_3$ in the following reaction?
      HCl + NaHCO$_3$ → H$_2$O + CO$_2$ + NaCl

8. It is found that 56.9ml of a 0.250M LiOH solution was needed to complete react with 1.15 grams of a monoprotic acid, HA. What is the molar mass of this unknown acid?
9. (This is a longer and more challenging question.) 450.0 ml of 1.25M Pb(NO₃)₂(aq) solution was mixed with 250.0 ml of 2.50M KI(aq) solution and yields a solid.
   a. What is the balanced molecular reaction?
   b. How many moles of the solid product was formed?
   c. Which reactant was the limiting reactant?
   d. How many moles of the excess reactant is left over?
   e. What is the concentration of the excess reactant?
   f. What ions are present at the end of the reaction?

ANSWERS

1. I. [HCl] = 0.192M \{1.75g HCl \left( \frac{1mol HCl}{36.45g HCl} \right) = 0.04801mol HCl \}; [HCl] = \frac{0.04801mol HCl}{0.250L solution} = 0.1920M HCl \}

II. a. [Na₃PO₄] = 1.26 \times 10^{-2}M \{1.50g Na₃PO₄ \left( \frac{1mol Na₃PO₄}{163.94g Na₃PO₄} \right) = 0.009150mol Na₃PO₄ \};
   \[Na₃PO₄\] = \frac{0.009150mol Na₃PO₄}{0.725L solution} = 0.01262M Na₃PO₄ \}

b. [Na⁺] = 3.79 \times 10^{-2}M \{0.009150mol Na₃PO₄ \left( \frac{3mol Na⁺}{1mol Na₃PO₄} \right) = 0.02745mol Na⁺ \};
   \[Na⁺\] = \frac{0.02745mol Na⁺}{0.725L solution} = 0.03786M Na⁺ \}

c. [PO₄³⁻] = 1.26 \times 10^{-2}M \{0.009150mol Na₃PO₄ \left( \frac{1mol PO₄³⁻}{1mol Na₃PO₄} \right) = 0.009150mol PO₄⁻³ \};
   \[PO₄⁻³\] = \frac{0.009150mol PO₄⁻³}{0.725L solution} = 0.01262M PO₄⁻³ \}

2. [AsO₄³⁻] = 0.50M \{0.50M (NH₄)₃AsO₄ \left( \frac{1mol AsO₄³⁻}{1mol (NH₄)₃AsO₄} \right) = 0.50M AsO₄³⁻ \}
   \[NH₄⁺\] = 1.5M \{0.50M (NH₄)₃AsO₄ \left( \frac{3mol NH₄⁺}{1mol (NH₄)₃AsO₄} \right) = 1.50M NH₄⁺ \}

3. I. 0.33g NaOH \{M = mol/L; mol = M x L = (0.15)(0.055) = 0.00825mol NaOH; \}
   0.00825mol NaOH \left( \frac{40.00g NaOH}{1mol NaOH} \right) = 0.330g NaOH \}

II. 9.29ml \{M = mol/L; L = mol/M; find mol Ba(NO₃)₂ \cdot 1.25g Ba(OH)₂ \left( \frac{1mol Ba(OH)₂}{261.32g Ba(OH)₂} \right) = 0.004783mol Ba(OH)₂ \};
   L = \frac{mol}{M} = \frac{0.004783mol Ba(OH)₂}{0.515M Ba(OH)₂} = 0.009287L = 9.287ml \}

4. I. 90.0ml of 1.25M Na₂S \{dilution: M₁V₁ = M₂V₂; (1.25M)(x ml) = (0.450M)(250ml); x = 90.0ml\}
   II. 0.977L water \{dilution: M₁V₁ = M₂V₂; (2.15M)(x L) = (0.750M)(1.5L); x = 0.523L; \}
   x = amount of 2.15M used \neq amount of water; V₂ = total volume = V₁ + H₂O added; 1.50L = 0.523L + H₂O; H₂O = 0.977L\}
Step 1: mol\textsubscript{HCl} = M\textsubscript{HCl} x L\textsubscript{HCl} = (0.20M)(0.050L) = 0.010mol HCl;

Step 2: 0.010mol HCl \left( \frac{1mol NaOH}{1mol HCl} \right) = 0.010mol NaOH;

Step 3: L = \frac{mol}{M} = \frac{0.010mol NaOH}{0.10M NaOH} = 0.10L = 100ml; the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1 H\textsuperscript{+} to 1 OH\textsuperscript{-} or in other words, the same number of H\textsuperscript{+} and OH\textsuperscript{-}; since both HCl and NaOH have 1 H\textsuperscript{+} and 1 OH\textsuperscript{-}, respectively, the ratio between HCl and NaOH must be 1:1

II. 22ml {from the flow chart: this is a A \rightarrow B calculation;

Step 1: mol\textsubscript{Ba(OH)\textsubscript{2}} = M\textsubscript{Ba(OH)\textsubscript{2}} x L\textsubscript{Ba(OH)\textsubscript{2}} = (0.50M)(0.050L) = 0.025mol Ba(OH)\textsubscript{2};

Step 2: 0.025mol Ba(OH)\textsubscript{2} \left( \frac{2mol H_3C_6H_5O_7}{3mol Ba(OH)\textsubscript{2}} \right) = 0.0167mol H_3C_6H_5O_7;

Step 3: L = \frac{mol}{M} = \frac{0.0167mol H_3C_6H_5O_7}{0.75M H_3C_6H_5O_7} = 0.0222L = 22.2ml H_3C_6H_5O_7; the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1H\textsuperscript{+} to 1OH\textsuperscript{-} or in other words, the same number of H\textsuperscript{+} and OH\textsuperscript{-}; since Ba(OH)\textsubscript{2} has 2 OH\textsuperscript{-} and H_3C_6H_5O_7 has 3 H\textsuperscript{+} (triprotic = 3 H\textsuperscript{+}), the common factor for these 2 numbers is 6; so there needs to be 3 Ba(OH)\textsubscript{2} (contains 6 OH\textsuperscript{-}) and 2 H_3C_6H_5O_7 (contains 6 H\textsuperscript{+});

II. 0.152M {from the flow chart: this is a A \rightarrow B calculation;

Step 1: mol\textsubscript{H_2SO_4} = M\textsubscript{H_2SO_4} x L\textsubscript{H_2SO_4} = (0.100M)(0.0263L) = 0.00263mol H_2SO_4;

Step 2: 0.00263mol H_2SO_4 \left( \frac{2mol NaOH}{1mol H_2SO_4} \right) = 0.00526mol NaOH;

Step 3: M\textsubscript{NaOH} = \frac{mol\textsubscript{NaOH}}{L\textsubscript{NaOH}} = \frac{0.00526mol NaOH}{0.0346L} = 0.1520M NaOH;

the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1H\textsuperscript{+} to 1OH\textsuperscript{-} or in other words, the same number of H\textsuperscript{+} and OH\textsuperscript{-}; since H_2SO_4 has 2 H\textsuperscript{+} and NaOH has 1 OH\textsuperscript{-}, the common factor for these 2 numbers is 2; so there needs to be 1 H_2SO_4 (contains 2 H\textsuperscript{+}) and 2 NaOH (contains 2 OH\textsuperscript{-});

II. 0.0600M {from the flow chart: this is a A \rightarrow B calc; let H_3A be a tripotric acid;

Step 1: mol\textsubscript{H_3A} = M\textsubscript{H_3A} x L\textsubscript{H_3A} = (0.100M)(0.0200L) = 0.00200mol H_3A;

Step 2: 0.00200mol H_3A \left( \frac{3mol Ba(OH)\textsubscript{2}}{2mol H_3A} \right) = 0.00300mol Ba(OH)\textsubscript{2};

Step 3: M\textsubscript{Ba(OH)\textsubscript{2}} = \frac{mol\textsubscript{Ba(OH)\textsubscript{2}}}{L\textsubscript{Ba(OH)\textsubscript{2}}} = \frac{0.00300mol}{0.0500L} = 0.0600M Ba(OH)\textsubscript{2}; the stoichiometric ratio between an acid and base can be determined by inspection without writing the reaction; the ratio must be: 1H\textsuperscript{+} to 1OH\textsuperscript{-} or in other words, the same number of H\textsuperscript{+} and OH\textsuperscript{-}; since H_3A has 3 H\textsuperscript{+} and Ba(OH)\textsubscript{2} has 2 OH\textsuperscript{-}, the common factor for these two numbers is 6; so there needs to be 2 H_3A (contains 6 H\textsuperscript{+}) and 3 Ba(OH)\textsubscript{2} (contains 6 OH\textsuperscript{-});

7. I. 11.4g Na_2S {this is a A \rightarrow B calc; mol\textsubscript{Al(NO_3)\textsubscript{3}} = M\textsubscript{Al(NO_3)\textsubscript{3}} x L\textsubscript{Al(NO_3)\textsubscript{3}} = (0.275M)(0.355L) = 0.09763mol Al(NO_3)\textsubscript{3}; \left( \frac{3mol Na_2S}{2mol Al(NO_3)\textsubscript{3}} \right) \left( \frac{78.04g Na_2S}{1mol Na_2S} \right) = 11.425g Na_2S;

II. 0.595L {this is a g\textsubscript{A} \rightarrow M\textsubscript{B} calculation; \left( \frac{5.00g NaHCO_3}{84.01g NaHCO_3} \right) \left( \frac{1mol NaHCO_3}{1mol HCl} \right) \left( \frac{1mol HCl}{1mol NaHCO_3} \right) = 0.05952mol HCl

L\textsubscript{HCl} = \frac{mol\textsubscript{HCl}}{M\textsubscript{HCl}} = \frac{0.05952mol}{0.100M} = 0.5952L HCl}
8. 80.8 g/mol \{this is a M_A \rightarrow mol_B; molar mass = grams HA/mol HA; find mol LiOH from titration data:
0.0569 L x 0.25 M = 0.01423 mol LiOH; reaction: LiOH + HA \rightarrow H_2O + LiA;
0.01423 mol LiOH \left( \frac{1 \text{ mol HA}}{1 \text{ mol LiOH}} \right) = 0.01423 \text{ mol HA}; molar mass = \frac{\text{grams HA}}{\text{mol HA}} = \frac{1.15 \text{ g HA}}{0.01423 \text{ mol HA}} = 80.84 \text{ g }/ \text{ mol } \}

9. a. Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)
    b. 0.313 mol PbI_2 \{this is a limiting reagent question since 2 reactant quantities were given;
the calculation is: M_A \rightarrow mol_B done twice;
Pb(NO_3)_2: \text{ mol Pb(NO}_3)_2 = M \times L = (1.25 M)(0.450 L) = 0.5625 \text{ mol Pb(NO}_3)_2;
\left( 0.5625 \text{ mol Pb(NO}_3)_2 \right) \left( \frac{1 \text{ mol PbI}_2}{1 \text{ mol Pb(NO}_3)_2} \right) = 0.5625 \text{ mol PbI}_2 ;
KI: \text{ mol KI} = M \times L = (2.50 M)(0.250 L) = 0.625 \text{ mol KI}; \left( 0.625 \text{ mol KI} \right) \left( \frac{1 \text{ mol PbI}_2}{2 \text{ mol KI}} \right) = 0.3125 \text{ mol PbI}_2 \}
    c. KI \{KI produced the smaller amount of product so it is the limiting reagent\}
    d. 0.250 mol Pb(NO_3)_2 \{left overs = starting amount – amount used; for amount used the calculation is: LR \rightarrow EX;
\left( 0.625 \text{ mol KI} \right) \left( \frac{1 \text{ mol Pb(NO}_3)_2}{2 \text{ mol KI}} \right) = 0.3125 \text{ mol Pb(NO}_3)_2 \text{ used}; \text{ left overs} = 0.5625 \text{ mol} – 0.3125 \text{ mol} = 0.250 \text{ mol Pb(NO}_3)_2 \}
    e. 0.357 M \{ [Pb(NO_3)_2] = \frac{\text{mol Pb(NO}_3)_2}{L_{\text{total}}} = \frac{0.250 \text{ mol Pb(NO}_3)_2}{(450 \text{ ml} + 250 \text{ ml})/1000} = 0.357 \text{ M } \}
    f. Pb^{2+}, NO_3^-, and K^+ \{Pb(NO_3)_2(aq), PbI_2(s), and 2KNO_3(aq) exist at the end of the reaction; ignore PbI_2(s) since it is a solid; the other two chemicals dissolve yielding: Pb^{2+}, NO_3^-, and K^+ \}