Solution Stoichiometry

Molarity and solution stoichiometry: Many reactants are solutes which dissolve in a solvent. If two solutions are mixed a chemical reaction can occur between the dissolved solutes and we need to be able to quantitatively describe these reactions.

Conventions:

M=Molarity=moles/L
n=moles
m=mass

I. Molarity and Solution Concentration: Molarity is given the symbol M and represents the moles of solute dissolved in one liter of solution (mole/L).

(In Class)

I.a) What is the molarity of Aluminum sulfate if 4.67g are diluted to 100.0 mL with water?

$$\frac{4.67gAl_2(SO_4)_3}{0.1000L}\left(\frac{molAl_2(SO_4)_3}{342.17g}\right)=0.136M$$

I.b): What is the molarity of Aluminum ion if 4.67g of aluminum sulfate are diluted to 100.0 mL with water?

$$\frac{4.67gAl_2(SO_4)_3}{0.1000L}\left(\frac{molAl_2(SO_4)_3}{342.17g}\right)\left(\frac{2molAl^{+3}}{molAl_2(SO_4)_3}\right)=0.273M$$

I.c): What mass of aluminum sulfate would you need to dilute to 50.0 mL to make a solution which is 0.700M in aluminum sulfate?

$$\frac{0.700molAl_2(SO_4)_3}{L}\left(\frac{342.17gAl_2(SO_4)_3}{mol}\right)0.0500L=12.0gAl_2(SO_4)_3$$

II. Dilution Problems: Note, in a dilution problem you are adding solvent. That is, you are not changing the moles of solute, just the volume of the solution.

Initial Moles = Final Moles

$$\mathbf{n_i = n_F}$$

$$\mathbf{M_iV_i = M_iV_i}$$

Trick: Assign your knowns, identify unknowns, and algebraically solve the equation,

II.a) What is the concentration of sodium chloride if 50.0 mL of 0.400M is diluted to 150.0 mL.

$$M_iV_i = M_fV_f$$

$$M_f = M_i\left(\frac{V_i}{V_f}\right) = 0.400M\left(\frac{50.0mL}{150.0mL}\right) = 0.133M$$

II.b) What volume do you need to dilute 50.0 mL of 0.800M Aluminum chloride to with solvent if you want a solution which is:

i. 0.400M in aluminum chloride?

$$M_iV_i = M_fV_f$$

$$V_f = V_i\left(\frac{M_i}{M_f}\right) = 50.0mL\left(\frac{0.800MAlCl_3}{0.400MAlCl_3}\right) = 100.mL$$

ii. 0.400M in aluminum ion?

$$M_iV_i = M_fV_f$$

$$V_f = V_i\left(\frac{M_i}{M_f}\right) = 50.0mL\left(\frac{0.800MAlCl_3}{0.400\,\frac{molAl^{+3}}{L}\left(\frac{molAlCl_3}{1molAl^{+3}}\right)}\right) = 100.mL$$

iii. 0.400M chloride?

$$M_iV_i = M_fV_f$$

$$V_f = V_i\left(\frac{M_i}{M_f}\right) = 50.0mL\left(\frac{0.800MAlCl_3}{0.400\,\frac{molCl^-}{L}\left(\frac{molAlCl_3}{3molCl^-}\right)}\right) = 300.mL$$

III: Solution Stoichiometry

This problems is cumulative and covers competencies from all of the competency quizzes

Consider mixing 50.0 mL of 0.700M aluminum sulfate with 50.0 mL of 0.700M lead(II)nitrate.

III.a Balancing Equations (review)

i. Write the molecular equation and include all phases.

$Al_2(SO_4)_3(aq)$ + 3 $Pb(NO_3)_2(aq)$ --> $2Al(NO_3)_3(aq)$ + $3PbSO_4(s)$

ii. Write the total ionic equation, include phases of all species except ions.

$2Al^{+3}$ + $3SO_4^{-2}$ + $3Pb^{+2}$ + $6NO_3^{-}$ --> $3PbSO_4(s)$ +$2Al^{+3}$ + $6NO_3^{-}$

iii. Write the net ionic equation, include phases of all species except ions.

SO_4^{-2} + Pb^{+2} --> $PbSO_4(s)$

iv. What is the limiting reagent?

Step 1: Calculate Moles Reactants in Net Ionic Equation.

$$0.05\text{L}\left(\frac{0.700\text{mol Pb(NO}_3)_2}{L}\right)\left(\frac{mol\ Pb^{+2}}{\text{mol Pb(NO}_3)_2}\right) = 0.035 mol\ Pb^{+2}$$

$$0.05\text{L}\left(\frac{0.700\text{mol Al}_2(\text{SO}_4)_3}{L}\right)\left(\frac{3mol\ SO_4^{-2}}{\text{mol Al}_2(\text{SO}_4)_3}\right) = 0.105 mol\ SO_4^{-2}$$

Step 2: Divide by Stoichiometric Coefficient.

$$0.035 mol\ Pb^{+2}\left(\frac{1}{1mol\ Pb^{+2}}\right) = 0.035$$

$$0.105 mol\ SO_4^{-2}\left(\frac{1}{1mol\ SO_4^{-2}}\right) = 0.105$$

So Lead is the limiting Reagent

v. What is the mass of precipitate formed?

Base Yield on Complete Consumption of Limiting Reagent.
From above

$$0.05\text{L}\left(\frac{0.700\text{mol Pb(NO}_3)_2}{L}\right)\left(\frac{mol\ Pb^{+2}}{\text{mol Pb(NO}_3)_2}\right)\left(\frac{1mol\ PbSO_4}{1mol\ Pb^{+2}}\right)\left(\frac{303.4\,g\ PbSO_4}{mol}\right)=10.6g\ PbSO_4$$

Short Cut: Use Result from Step 2 in the last step where you determined the limiting reagent and multiply by stoichiometric coefficient of desired product.

$$0.035mol\ Pb^{+2}\left(\frac{1}{1mol\ Pb^{+2}}\right)=0.035\left(\frac{1mol\ PbSO_4}{1}\right)\left(\frac{303.4\,g\ PbSO_4}{mol}\right)=10.6g\ PbSO_4$$

vi.: What are the spectator ions?
Nitrate and Aluminum

vii. What is the concentration of the spectator ions after dilution.

You have diluted the spectator ions: So you need to calculate moles present and divide by total volume
Step 1: Calculate Moles Spectator Ions.

$$0.05\text{L}\left(\frac{0.700\text{mol Pb(NO}_3)_2}{L}\right)\left(\frac{2mol\ NO_3^-}{\text{mol Pb(NO}_3)_2}\right)=0.0700mol\ NO_3^-$$

$$0.05\text{L}\left(\frac{0.700\text{mol Al}_2\text{(SO}_4)_3}{L}\right)\left(\frac{2mol\ Al^{+3}}{\text{mol Al}_2\text{(SO}_4)_3}\right)=0.0700mol\ Al^{+3}$$

Step 2: Divide by Total Volume

$$\frac{0.0700mol\ NO_3^-}{0.0500+0.0500}=0.700M\ \ NO_3^-$$

$$\frac{0.0700mol\ Al^{+3}}{0.0500+0.0500}=0.700M\ \ Al^{+3}$$

viii. What is the concentration of the excess reactant?

Step 1: Calculate Initial Moles of Excess Reagent
Step 2: Calculate Moles Excess Reactant Used Up with the Complete Consumption of the Limiting Reagent.
Step 3: Calculate Moles Excess by subtracting moles consumed (step 2) from moles initial (Step 1).
Step 4: Divide Moles Excess by Total Volume

Step 1: $0.0500\text{L}\left(\frac{0.700\text{mol Al}_2(\text{SO}_4)_3}{L}\right)\left(\frac{3mol\ SO_4^{-2}}{\text{mol Al}_2(\text{SO}_4)_3}\right) = 0.105mol\ SO_4^{-2}$

Step 2: $0.0500\text{L}\left(\frac{0.700\text{mol Pb(NO}_3)_2}{L}\right)\left(\frac{mol\ Pb^{+2}}{\text{mol Pb(NO}_3)_2}\right)\left(\frac{1mol\ SO_4^{-2}}{1mol\ Pb^{+2}}\right)$

$= 0.0350mol\ SO_4^{-2}\ consumed$

Step 3: $(0.105\text{-}0.0350)mol\ SO_4^{-2} = 0.070mol\ SO_4^{-2}\ excess$

Step 4: $\frac{0.070\text{mol}}{0.1000\text{L}} = 0.70M\ SO_4^{-2}$