Chapter 3

***Formulas, Equations, and Moles: II***

## Amounts of Reactants and Products

- In lab, we want to predict amount of product we can expect from a reaction
- Have to use ***stoichiometry***: quantitative study of reactants and products in a reaction (mole to mole ratio)
- Use the ***mole*** to relate one substance in a reaction to another (equation coefficients, see Table 3.1)
  - ♦ $2H_2$ (g) + $O_2$ (g) → $2H_2O$ (g)

## Mole Ratios

- We use coefficients in a balanced equation to determine the mole ratio in which substances need to react.
- $MgCl_{2(aq)}$ +$2AgNO_{3(aq)}$→ $2AgCl_{(s)}$ + $Mg(NO_3)_{2(aq)}$
  - ♦ 1 molecule of $MgCl_2$ reacts with 2 molecules of $AgNO_3$ to produce 2 molecules of AgCl and 1 molecule of $Mg(NO_3)_2$
  - ♦ Molecules are not practical! Scale up to moles!

## Stoichiometry Calculations

- Mole to mole conversions
- $MgCl_{2(aq)}$ +$2AgNO_{3(aq)}$→ $2AgCl_{(s)}$ + $Mg(NO_3)_{2(aq}$
  1.00 mol excess ?
- How many moles of solid product do you predict to form?

moles reactant ➡ moles product

- Cannot compare grams of one to grams of another!!

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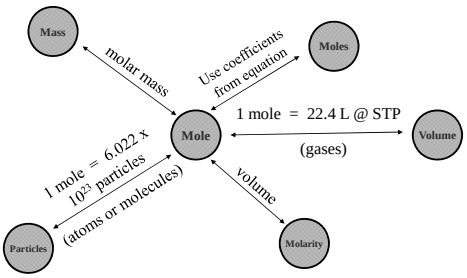
## Mole Ratios

- Calculate moles of ppt that can be made in the following reactions. Predict products and phases first.
- NaCl (aq) + $Hg(NO_3)_2$ (aq) →
  - ♦ 0.500 mol NaCl
- $FeCl_3$ (aq) + NaOH (aq) →
  - ♦ 2.35 mol NaOH
- $Li_2SO_4$ (aq) + $AgCH_3COO$ (aq) →
  - ♦ 0.1098 mol $AgCH_3COO$

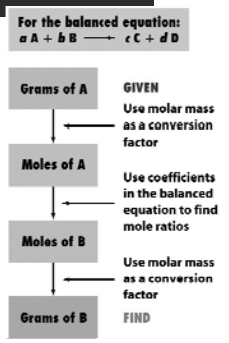
## Mole Diagram




Courtesy: *www.unit5.org/christjs/Stoichiometry/**Mole**%20Island%20**Diagram**.ppt*

## Amounts of Reactants and Products

- We can balance a chemical equation to find relative amounts of reactants and products.
- How can we predict the amount of product we should get?
- Worked Ex. 3.5 – 3.7; Problems 3.7, 3.8

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## Stoichiometry Calculations

- Mass to mass conversions
- Given mass of reactant, find mass of precipitate:
- $MgCl_2$ + 2 $AgNO_3$ → 2 AgCl + $Mg(NO_3)_2$
- 1.2482 g $MgCl_2$ and excess $AgNO_3$
  - Find number of moles of $MgCl_2$ using molar mass
  - Find number of moles of AgCl using mol:mol ratio
  - Find number of grams of AgCl using molar mass

## Mass to Mass Conversions

- How many grams of $KClO_3$ are needed to completely destroy one gummy bear? (Gummy bears have an average mass of 2.4882 g. Roughly 50% of a gummy bear's mass is sucrose - $C_{12}H_{22}O_{11}$.)
- $\_KClO_3(l) + \_C_{12}H_{22}O_{11}(s) \rightarrow \_KCl(l) + \_CO_2(g) + \_H_2O(g)$

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## Group Work

- $Al(NO_3)_3$ + NaOH → $Al(OH)_3$ + $NaNO_3$
- 10.54 g xs ?
- How many grams of aluminum hydroxide can be made by starting with 10.54 grams of aluminum nitrate? (Hint: Is the equation balanced?)

## Yields of Chemical Reactions

- If you ran that reaction in lab and only obtained 3.18 g (actual yield) of $Al(OH)_3$, what percent of the maximum did you obtain?
- Percent yield = Actual / Theoretical x 100%
- Theoretical will be calculated; actual yield will be given in a problem (or obtained in lab)
- Worked Ex. 3.8, 3.9; Problems 3.9, 3.10

## Limiting Reagents

- Analogy: making martinis
- I have 7 martini glasses, 36 olives, 12 shots of vodka, and 8 stirrers
- Each martini requires 1 glass, 2 olives, 2 shots of vodka, and 1 stirrer
- How many martinis can I make?

Limiting Reactant

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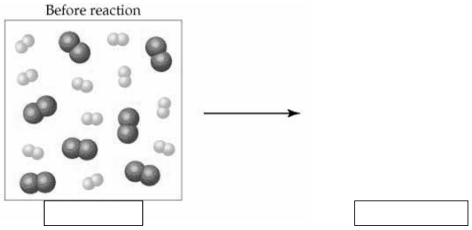
## Limiting Reagents: $2H_2 + O_2 \rightarrow 2H_2O$

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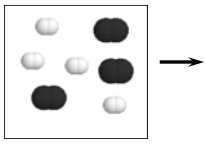
## Limiting Reagents

$2H_2 + O_2 \rightarrow 2H_2O$

What is the limiting reactant?



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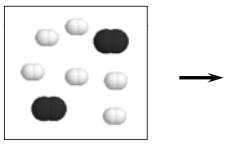
## Limiting Reagents

$2H_2 + O_2 \rightarrow 2H_2O$

What is the limiting reactant?



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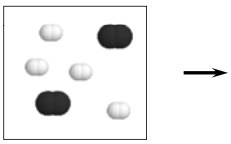
## Limiting Reagents

$2H_2 + O_2 \rightarrow 2H_2O$

What is the limiting reactant?



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## Group Work

- $Al(NO_3)_3 + 3NaOH \rightarrow Al(OH)_3 + 3NaNO_3$
- 10.54 g 10.54 g ?

- How many grams of aluminum hydroxide can be made by starting with 10.54 grams of aluminum nitrate and 10.54 grams of sodium hydroxide?

## Limiting Reagent Calculations

Mass of limiting reactant

↓

moles of limiting reactant

↓

moles of product

↓

mass of product (theoretical yield)

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## Limiting Reagent Calculations

●How do we determine, mathematically, which is the limiting reagent?

●Two ways:

- Compare moles of each reactant required to consume all of other reactant (example on next slide).
- Calculate moles of desired product from each reactant.

**Whichever REACTANT produces less product (and gets used up first) is the limiting reactant (or reagent).**

## Limiting Reagent Calculations

- $Al(s) + Cl_2(g) \rightarrow AlCl_3(s)$
- 1.67 g Al (0.06189 mol) and 1.67 g (0.02355 mol) $Cl_2$
- Moles of Al needed to use up all $Cl_2$:
  - 0.02355 mol $Cl_2$ x (2 mol Al / 3 mol $Cl_2$) = 0.0157 mol Al
  - Started with 0.06189 mol Al, but we only need 0.0157 to use up $Cl_2$; $Cl_2$ is limiting reagent
- Moles of $Cl_2$ needed to consume Al:
  - 0.06189 mol Al x (3 mol $Cl_2$ / 2 mol Al) = 0.09284 mol $Cl_2$
  - We need 0.09284 mol $Cl_2$ to use up all of the Al but we only started with 0.02355 mol; $Cl_2$ is limiting reagent.

## Group Work

- $\mathbf{2}Al(s) + \mathbf{3}Cl_2(g) \rightarrow \mathbf{2}AlCl_3(s)$
- Method 2: use each reactant to calculate mass of product that can be formed.
- 1) If we begin with 1.67 g Al (s) and 1.67 g $Cl_2$ (g), which is the limiting reactant?
- 2) How many grams of $AlCl_3(s)$ will, theoretically, be produced?
- 3) What is the percent yield if you obtained 1.76 g $AlCl_3$ in the lab?
- 4) How many grams of the excess reagent will be left over?

## Group Work

- 3.71 Hydrogen and chlorine react to yield hydrogen chloride. How many grams of HCl are formed from reaction of 3.56 g of hydrogen and 8.94 grams of chlorine?
- Worked Ex. 3.10, Problem 3.11, 3.12

## Solution Stoichiometry Example

- Consider the reaction:
  - $3CaCl_2(aq) + 2Na_3PO_4(aq) \longrightarrow Ca_3(PO_4)_2(s) + 6NaCl(aq)$
- If we mix 25.0 mL of 0.200 M $CaCl_2$ solution with 50.0 mL of 0.250 M $Na_3PO_4$ solution, what mass of precipitate is formed?

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## Concentration of Solutions: Molarity

- ***Concentration***: amount of solute present in a given amount of solution
- ***Molarity***: moles of solute in 1 L of solution
  - moles solute / liters solution; ***M = mol / L***
- Allows us to calculate 1) mass of solid needed to make a solution of a certain concentration or 2) concentration of solution if mass and volume are known.
- 1.00 M NaCl = 1.00 mol NaCl in 1 L solution

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## Concentration of Solutions: Molarity

- 1.00 M NaCl = 1.00 mol NaCl in 1 L solution
- 0.500 M NaCl = 0.500 mol NaCl in 1 L sol'n.
- To find moles of solute, **M * V = mol**
- **How many moles in 5.67 mL of 0.500 M NaCl?**
- Worked Ex. 3.11, 3.12, Problems 3.14 – 3.17

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## Concentration of ions

- What is the concentration of $Cl^-$ ions in a 0.150 M $FeCl_3$ solution?
- 1 mol $FeCl_3$ → 1 mol $Fe^{3+}$ + 3 mol $Cl^-$
- 0.150 M $FeCl_3$ x (3 mol $Cl^-$ / 1 mol $FeCl_3$) = 0.450 M $Cl^-$

## Concentration of Solutions

- We can calculate concentration (molarity) if we know mass and volume.
  - ♦ Mass solute ÷ molar mass = moles solute
  - ♦ Moles solute ÷ volume solution = Molarity
- Or we can calculate the mass of solute needed to make a solution of certain concentration (molarity).
  - ♦ Molarity * volume solution = moles solute
  - ♦ Moles solute * molar mass = mass solute needed

## Concentration Calculations

- What is the concentration of a 1.00 L solution made by dissolving 5.00 g NaCl in water?
- 5.00 grams NaCl in a 500.0 mL solution?
- What mass of NaCl do we need to make 1.00 L of a 0.500 M solution?

A measured number of moles of solute is placed in a volumetric flask. | Enough solvent is added to dissolve the solute by swirling. | Further solvent is added to reach the calibration mark on the neck of the flask, and the solution is shaken until uniform.

## Concentration of Solutions – Mad Libs

- 1) Water-soluble ionic compound
- 2) Number greater than 500
- 3) Number between 0 and 1
- 4) Number between 1 and 5
- 5) Any water-soluble compound
- 6) Number between 500 and 1000

## Concentration of Solutions - Mad Libs

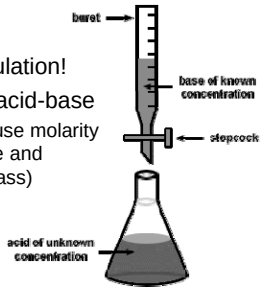
- How many grams of (1) _____ are required to prepare a (2) _____ mL solution whose concentration is (3) _____?
- What is the concentration of a solution made by adding (4) _____ grams of (5) _____ to _____ mL of water?

## Titrations

- ***Titration***: method of determining the concentration (or volume) of an unknown solution by using a solution with a known concentration (standard)
  - ♦ moles = M * V
- Equivalence point: point at which acid has completely reacted with and been neutralized by base (moles acid = moles base)
- End point: point at which the indicator changes color (slight change in solution's pH)

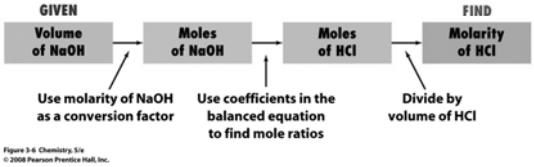
## Titration set-up

- Titrant in buret
- Unknown in flask
- Can't use dilution calculation!
- Need mol-mol ratio of acid-base
- **Solution stoichiometry**: use molarity to convert between volume and moles (instead of molar mass)
  - ♦ M = mol / L
  - ♦ mol = M * L
  - ♦ L = mol / M




## Titrations

- 23.78 mL of 0.2500 M NaOH neutralized 20.00 mL of HCl. What is the concentration of HCl? Start with a balanced equation.




- Worked Ex. 3.14, Problems 3.20, 3.21, 3.22

## Dilution

- ***Dilution***: lowering the concentration of solution (by adding water)
  - ♦ number of moles of solute stays the same, amount of solvent increases
- The number of moles of **solute** stays the same; volume increases (lower molarity)
  - ♦ moles = M * V
  - ♦ $M_{conc} * V_{conc} = M_{dil} * V_{dil}$ or $\mathbf{M_1V_1 = M_2V_2}$
- Example: What is the **final** concentration of solution made by adding 100.0 mL of 3.00 M HCl to 300.0 mL of DI water?

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## Dilution

- How would you prepare 500.0 mL of 0.500 M $H_2SO_4$ starting with concentrated (18.0 M) solution? (Hint: What variable are you solving for?)
  - ♦ Remember to add acid to water.
- How much **water** do you need to add to 25.0 mL of a 4.50 M NaOH solution to make a 1.00 M NaOH solution?
- Worked Ex. 3.13; Problems 3.18, 3.19
- 1) 87.5 mL of water added to 25.0 mL of 4.50 M NaOH; 2) 13.9 mL of 18.0 M $H_2SO_4$

## Group Work

- How many mL of 1.018 M $H_2SO_4$ are needed to neutralize 20.00 mL of 0.9989 M NaOH?
  - ♦ Write balanced equation
  - ♦ Determine number of moles of known
  - ♦ Calculate mole ratio to determine moles of unknown
  - ♦ Divide by concentration to find volume

## Percent Composition of Compounds

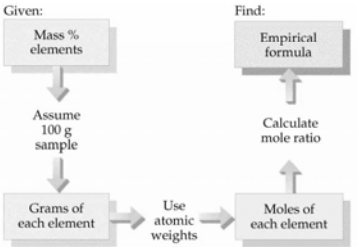
- Percent by mass: percent by mass of each element in a compound
- $H_2O_2$
  - 2 moles H, 2 moles O
  - H = 2 mol x 1.008 g/mol H = 2.016 g H
  - O = 2 mol x 16.00 g/mol O = 32.00 g O
  - $H_2O_2$ = 2.016 g H + 32.00 g O = 34.02 g
  - %H = 2.016 g H / 34.02 g $H_2O_2$ x 100% = 5.926%
- What is %O? Solve 2 ways…..

## Percent Composition of Compounds

- What is the percent by mass of Cr, S, and O in $Cr_2(SO_4)_3$?

## Percent Composition of Compounds

- We can reverse this calculation.
- Know percentages, need to calculate empirical formulas.




## Empirical Formulas

- Calculate the empirical formulas:
  - 50% S, 50% O
  - 43.64% P, 56.36% O
- Assume 100 g of the material:
  - 50 g O x 1 mol / 16.0 g = 3.125 mol O
  - 50 g S x 1 mol / 32.066 g = 1.559 mol S
  - mol O / mol S = 3.125 / 1.559 = 2.004 or 2
  - $SO_2$
- Assume 100 g of material:
  - 43.64 g P → mol P (1.4089 mol P)
  - 56.36 g O → mol O (3.5225 mol O)
  - Ratio of two moles (2.5 O / 1 P); need whole numbers

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## Molecular Formulas

- We just found the empirical formula to be $P_2O_5$. This compound has a molecular mass of 141.9 g/mol.
- We know the molecular formula has a molar mass of 283.8 g/mol. How many multiples of $P_2O_5$ do we need to reach a mass of 283.8?
- Worked Ex. 3.15 – 3.17; Problems 3.24 – 3.29

## Practice Problem

- A compound contains 30.4 % nitrogen and 69.6 % oxygen. The molecular mass of the compound is 92 g/mol.
  - What is the empirical formula of the compound?
  - What is the molecular formula of the compound?

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## Group Work

- A compound contains 40.00% C, 6.71% H, and the rest is O. Determine the empirical formula of this compound.
- If the molar mass of the substance is 180.16 g/mol, determine the molecular formula of this substance.